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# DEMSEE 2007
# Deregulated Electricity Market Issues in South-Eastern Europe

September 2007

Edited by Levent Sevgi

**DOGUS UNIVERSITY PUBLICATONS**
**Publication Number, 2**

# DEMSEE 2007

## Deregulated Electricity Market Issues in South-Eastern Europe

**Edited by**

**Levent SEVGİ**

**Dogus University**

**September 2007, Istanbul**

Dogus University Publications, 2

1st ed., September 2007

ISBN 978-9944-5789-1-2



**Cover Design**
By Ardan ERGÜVEN

**Page Design**
By Sönmez ÇELİK

**CIP - Dogus University Library**

DEMSEE (2007 : Istanbul)

Deregulated Electricity Market Issues in South-Eastern Europe, September 2007 / Edited by Levent Sevgi. -- 1st ed. -- Istanbul : Doğuş University, 2007.

iv, 222 p. : ill. ; 24 cm. -- (Dogus University publications ; 2).

ISBN 978-9944-789-1-2

1. Electricity. 2. Electric utilities -- Deregulation -- Europe, South-Eastern., I. Sevgi, Levent. II. Title

537 -- dc22 / 333.79 -- dc22

**Distribution**
Dogus University
34722 – Acibadem, Kadikoy, Istanbul, TURKEY
Tel. : +90 0212 544 55 55
Fax : +90 0212 544 55 14
e-mail : info@dogus.edu.tr
URL : http://www.dogus.edu.tr

**Print** : Atak Matbaacılık
Tel./Fax : +90 0212 483 42 51

## Introducing DEMSEE 2007

It is true that *Electricity* is a pillar for our present *Civilization* and *Culture*. One should also recognize that *Electricity* is the *finest* useable form of *Energy* and therefore the most *precious*. *Deregulation* of *Electricity Markets* aims ultimately to make almost everyone responsible for the way electricity is generated, distributed and used. It aims to let fair market rules result in a *Market Operation* that will advance this sense of responsibility for everybody. This is particularly important in view of the present delicate state of the *Environment* which should for *Humanity's* sake be preserved, at all costs. And indeed, we are lucky in the sense that the current *Information Technologies* and *Information and Communication Technology* will allow us to live up to our responsibilities concerning rational electricity usage as well as the preservation of the environment. However, a strong, wide and lasting commitment is necessary, i.e. political will by every nation, to achieve progress with respect of the environment.

The annual *International Workshop* on *Deregulated Electricity Market issues in South-Eastern Europe* focuses on critical present-day problems such as Regulation issues, TSO issues, DSO issues, Security of Supply, Economics – Management, Environmental issues, Law and Codes, Market Integration, Dispersed Generation and Renewables issues, and Deregulation in Island Systems. It usually brings people from around ten Countries disseminating experience from a wide area and technology spectrum. It brings together people from *Academia* and *Industry* both having vital roles in the solution of large-scale problems.

*DEMSEE 2007* in Istanbul comes at an opportune time at the completion of the High Voltage OHL between *Nea Santa* and *Babaeski*, bridging the transmission grids of *Greece* and *Turkey* at the 400 kV-level, which is expected to go into full operation beginning 2008. It may, therefore, carry a *symbolism*, too, that the *European Grid* is strengthening its own interconnections pointing to the way-to-go for the future.

Istanbul is a City with wonderful natural and historical surroundings, a city not only interconnecting Asia and Europe but also Eastern and Western Cultures. Therefore, DEMSEE'07 is a wonderful event and opportunity to visit Istanbul and spend sometime for all participants.

We are indebted to various individuals and organizations for their support of DEMSEE'07. Acknowledgement in particular goes to Doğuş University, IEEE Turkey Section and CIGRE. We express our appreciation to Prof. Dr. Talha Dinibütün, the President and Honorary Chair. We thank to all authors who contributed to this event. Special acknowledgement goes to the local committee members and editorial assistants Gonca Çakır, Çağatay Uluışık, and Merih Yıldız for their valuable efforts and collaboration. Finally, many thanks to Sönmez Çelik, Manager of Doğuş Library, who made this book reality.

*Welcome* everyone to *DEMSEE 2007* in *Istanbul*!
*The DEMSEE'07 Chairs,*

Levent SEVGI
DOĞUŞ University
Istanbul – TURKEY

Thales M. PAPAZOGLOU
EPSL – TEIC
Crete - GREECE

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# ELECTRIC POWER SUPPLY: THE ENGINEERING CHALLENGES AND THE CONTRIBUTION OF CIGRE

**Jean KOWAL**
*Secretary General of CIGRE, France*

## Abstract

The paper presents the global challenges faced by the Electric Power Supply Industry in the near future: supplying electricity for all, where ever they are, answering the expectations of a digital society which needs higher quality electricity and contributing to sustainability.

Starting from these considerations it focuses more in detail on the technical issues related to these challenges: wheeling huge quantity of power over long distance; accommodate renewables and dispersed generation; serve isolated areas or crowded megacities.

It concludes saying that cooperation is a must if Electricians want to bring a contribution to the welfare of mankind; technical Associations and CIGRE are from this point of view a model.

## 1. Introduction

At the beginning of the new century the Electric Power Industry faces much important challenges:

- The consumption of energy has never been so high and still will grow dramatically in the future,
- Still, we are in a world were 20% of the population have no access to electricity, which is a prerequisite for access to education, to health and to economic development,
- Global warming is recognized as the threat for our world. Electricity is the energy vector which will more contribute to answer the problem,

The challenge is basically: how to meet the needs for a reliable, environmentally friendly electricity, which achieves the three **A** : **A**vailable, **A**cceptable and **A**ffordable?

The answers are political, economical and technical, but I have the weakness to think that answering the technical challenges must be the first.

## 2. What is the present picture?

### 2.1 The Poorest Countries

The International Energy Agency (IEA) writes: "**some 1.6 billion people have no access to electricity** today…. The transition from energy poverty to relative affluence is a complex and irregular process.....In a general way it is a journey from nearly exclusive reliance on traditional biomass to the access and use of electricity with a range of other modern fuel. By 2030 about 2 billion people will have completed the trip to electricity, but more than a billion will still be stranded in primitive energy poverty".

Access to electricity - and other energy as well – governs economic and social development. Obviously access to water, health care and education, widely governed by access to electricity, are also vital.

At stake is also the control of demography, which calls for education and minimal welfare, and the future of our world:

- because of the environmental impact of the primitive use of biomass energy - deforestation, pollution..
- because of the instability of overpopulated and extremely poor world.

**2.2 The Complex Situation of The Developed Countries**

After a tremendous development of their electrical infrastructures, they have experienced a long period of under investment, mostly related to the evolution of their model, from monopoly to market.

Now they have to live with a power system, ageing, under-maintained which is used in a way it has not been designed for, as electricity markets have been organized without taking into account properly the existing infrastructures. This has resulted in increased constraints due both to the lack of equipment and to its inappropriate use.

At the same time the so-called affluent society needs for energy grow as well in term of quantity as of quality, mostly as a consequence of its development towards the digital society.

More disturbing even, there appears a growing divorce between the needs of the consumers and their environmental aspirations, which makes more and more difficult the development of new infrastructures.

Replacement or refurbishment of the existing assets and creation of new capacities are unavoidable and represent financial, environmental and technical challenges: for western Europe investment in generation until 2030 is 600 GW, half for replacement of obsolete equipment, half for increase of demand; transmission infrastructures will have to follow also.

**2.3 The Developing Countries**

These countries experience economic development and access directly to modern technologies. This means high rate of growth, high level of investment in infrastructures, usually most modern ones.

They have to master the new techniques, train staff. As the control of energy is vital, they have to develop a national industry, to be partly self sufficient.

Technical problems are often novel, as geographical or demographic configuration can be configuration are special: long transmission distances, specific climatic conditions.

The financial burden often leads to questions about the best model of the industry, public and monopolistic, or private.

Today with the emphasis on sustainable development the developing countries cannot escape the problem of environment, even if their relative contribution to global warming is small.

**2.4 Electric Power Engineering is a Key Answer to These Challenges**

Technology development has been in the past and will in the future a main of the answer to the various challenges.. Recent technical breakthroughs in the different fields of electricity proved that a mature technique can still be imaginative:

- Big evolutions in the field of generation in the immediate past, with combined-cycles turbines, wind-power, dispersed generation and other renewables; for tomorrow the issues are for nuclear power – can we do without, with which technology? –, about fuel cells, hydrogen…
- Transmission infrastructures have seen new technologies: gas insulated Lines (GIL); High Temperature Superconductor Cables, but also new conductors for overhead lines...; Power Electronics and derived devices with already many applications...
- Control capabilities, with digitalisation of vital control functions in the system; combination with telecommunication techniques
- At load levels, efficiency of use has increased and represents in the short term the main source of energy, where loads exist of course.

## 3. The Step Upward to Ultra High Voltage

Growing electricity demand is a general pattern. The case of populated countries with huge concentration of populations quite far of the possible generation sites is a situation which proves that looking at the interest of higher voltages is relevant. It is not a new subject: Russia, Japan have built 1000 kV lines, not used at this voltage today; Italy also developed a 1000kV test system to assess the feasibility. The new actuality is the emergence of the 1000kV AC and 800kV DC projects in China. Other countries are contemplating similar developments: Brazil, with projects to bring energy from the Amazone region, India and even South-Africa, which wants to take advantage of the hydro power of Central Africa, to be transmitted by a 800kV system.

Reasons for going to higher voltages are well known when you address the problem of moving huge quantities of power over very long distances. Today feasibility of a 1000kV AC system is almost certain; feasibility of most of the equipment has been proved; as for 800 kV DC the answer is much less clear and there are still huge doubts. But feasible does not mean suitable for industrial operation, at acceptable conditions, with manufacturers ready to produce them. There are many questions to be answered :

- which nominal voltage: 1000, 1100 or even 1200 kV?
- temporary overvoltage definition and control
- fast reclosing after single pole operation, with induced currents
- insulation problems, behaviour of air gaps, impact of altitude, pollution
- conductors bundle, Corona effect, noise, mechanical problems
- electric and magnetic fields, switching equipment design; surge arresters..
- measuring and testing conditions
- insulation behaviour at UHV DC.

All these questions will de addressed during a Symposium on UHV International standards, in Bejing, July 2007. This event organized jointly by CIGRE and IEC aims at assessing the real status of the Industry technical knowledge on these voltages, and to decide on a work programme to be carried out before International Standards could be produced for these voltage levels.

## 4. Dispersed Generation

At the other end of the picture is the subject of Dispersed generation. The subject was an topic in the 80's, when the microturbines were supposed to be the answer to the supply, with a very cheap fuel. Today dispersed generation has become a reality, with the emergence of wind power; at the same time we can question the word dispersed as large wind farms are quite similar, in size, to the big units. In Europe countries like Germany (some 20 GW installed), Denmark and Spain have developed. Furthermore new concepts are coming up, which could soon be reality, as active Distribution Systems and micro-grids, not to mention the close connection between Dispersed generation and renewables.

The extensive development of Dispersed Generation has quickly highlighted the challenges related to its integration in power systems:

- impact of connection : use of the capacity of the existing network, at transmission and distribution levels; network development planning;
- financial problem attached: cost of connection and cost reflectivity
- behaviour of the generators under fault conditions on the network: influence of the DC connection to the grid resulting in very low Isc, need of "fault through ride capability";
- how to solve the question of intermittence? Prediction tools, impact on spinning reserves; impact of large wind farms
- dispatchability, remote control of DG and use of ICT
- levelling of loads and storage issues,
- active distribution systems and microgrids.

## 5. Rural Electrification

Keeping in mind the objective of supplying electricity we must consider the problem of sparsely inhabited spaces: countryside, remote villages, islands.., what we usually call "Rural electrification". It is a real concern many parts of the world, a world where population is distributed between heavy populate megacities or these "rural" zones.

The challenge is to develop power systems which answer this objective of supplying basic needs of electricity over a limited space. Different directions are explored:

- zones off grid:
  - solar home systems with PV generators and batteries, for very low loads only,
  - wind mills and batteries
  - more complicated systems combining small hydro, diesel generators and storage
- suburban zones (townships)
  - low costs distribution systems, one wire distribution
  - low cost metering
- Shield wire systems, where energy is collected by induction from transmission lines. There are examples of 20kV network fed from a 220kv line (with even three phases distribution)

There is wide consensus about the reality of the need, but industrial answers are not available for the time being, as the answers must be with cheap technologies, which must be standardized to some extent: often the poorest countries are given equipment from various origins, for which they cannot get spares, or cannot expand the system by lack of compatible equipment.

## 6. Supplying Large Cities

Supplying large cities is another of the present challenges: loads are growing, cities are getting larger and larger, space is rare. There is a need to transmit large quantity of power, without using much space while being acceptable from the environment point of view, right to the heart of the cities.
Various techniques are now developed.

- Solid state insulated, high capacity cables: today such cables exist for voltage up to 500kV and 2500A. Being without oil, pollution related to leakage and fire hazards are reduced. Installation conditions have improved as prefabricated joints have been developed, as well as “transition” joints which allow the connection of cables of different technologies. Cost is still the main hurdle to a wider use of the technique.
- Gas insulated lines (GIL) is not really a new technology. A kind of long gas insulated busbar, they have been installed in the past, but were mainly used inside private premises, for instance to connect a substation to a generator. Opposition to the construction of overhead lines resulted by the end of the 90ies to the development of a second generation of GILs, which were planned to replace overhead lines, which a transmission capacity of 3000MVa or more. The main changes have been the use of a mixture Nitrogen-SF6 (20 - 80 %) instead of SF6, to answer the fears of gas leakage (SF6 is a very powerful GHG) without increase the size of the envelop. The new GIL is designed to be buried directly in the soil, for 50 years, and the envelop is made of an aluminium alloy. Erection on site is feasible with this new design, as is possible the reparation.
  Cost of this second generation GIL is some 50% less than the previous. When comparing to cables, GIL are more expensive for small capacities(around 2000 MVA), but are competitive for higher values, when 2 cables system must be used.
- Superconducting cables
  This technique has been contemplated for a long time already, but the breakthrough has been the discovery of High temperature superconductor, i.e. superconductor working at liquid nitrogen temperature. Prototypes have been developed and installed , at distribution level. Not an industrial technology to day it offers important advantages as it allows using existing cable duct to transmit much larger quantities of power.
- It should be added that the same kind of concern about environment and fire prevention applies also to substations inside cities. There is a need to site them nearer to the load in city centres: underground substations are the normal continuation of cables systems. They have seen numerous technical evolutions and one of the most noticeable is the use of gas insulated transformers.

## 7. The ICT World

It is today impossible not to say a few words about the implications of the techniques covered by “Information and Communication technologies” - ICT –

- Access to huge computation power has resulted in development of numerous applications in the field of system operation and new developments are still in progress. The increased complexity of the power systems calls for more and more sophisticated tools: highly meshed systems, as for instance in Europe, imply more complex power flow computations; real time assessment of systems security is still awaited, at a time when power flows are decided by markets and when TSOs must accept them..
- Digital protection and integrated protection, monitoring and control systems are now a standard technology, and further to their basic function provide valuable information about the condition of the assets, at a time when asset management is a priority of the operators and owners.
- A step farther has been reached now with what is known as “Wide area monitoring systems” – WAMS - which combine sophisticated sensors, synchronized transmission via satellites and can give a real time photo of a large system. Detection of potential instability is then possible: for instance such a system can detect in Europe inter-area low frequency oscillations between two zones which are 3000 km apart.

Potential of this family of ICT tools is almost unlimited, but access to this potential is not without highly difficult challenges: costs of development , capability of maintaining the equipment when software evolves very quickly, risks of all sorts (cyber-security concerns).. not to mention the impact of the deregulation, which reduce the exchange of information.

## 8. Exchange and Cooperation

Development of technology is obviously the result of the work of researchers, manufacturers and likes. We can be confident in their capability to provide answers.
But I would like to insist on the importance of cooperation in the field of Power Engineering: the stakes are too high to keep the knowledge; exchanging technical knowledge must be the rule, as it has been for along time.

Technical and Scientific Associations, events like this one, play a part in the dissemination of information, and CIGRE is probably the best example of the contribution of such Associations.

CIGRE - “Conseil international des Grands Réseaux Electriques” is an international, non-profit, technical Association.. It covers all the aspects of the design, operation, regulation, environmental impacts, of the high voltage power systems and their individual components and brings together all the profiles of expertise involved in the Industry, manufacturers, utilities, educational bodies, laboratories, government representatives…

CIGRE works two ways: it organizes conferences where papers are discussed and it maintains permanent working structures - 16 Study Committees today - which carry out studies on topical issues and publish reports. Papers from the conferences and technical reports are made available to members and, partly, for non members, in its technical Library, which now on-line.

In the recent years CIGRE also got involved in Electric Power Engineering Education and Training:

- bringing together representatives of the Industry and University, for exchanges about the needs for the future, the role of University and questions like training throughout professional life.
- developing tutorials, derived from the work of the Study Committees.

www.cigre.org and www.e-cigre.org

## 9. Conclusion

Access to electricity is vital for mankind. Your part as specialists is central in answering the numerous challenges to be faced in the coming years and we can be sure that they will see the advantages of a wide cooperation.

It is a daunting perspective, perhaps, but for sure a quite stimulating one also, at a time when electricity is regarded as a mature technology, not to say “has been”.

# SUBSIDIES IN WHOLESALE ELECTRICITY MARKET

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## Abstract
In this paper subsidies based on social and political concerns in the wholesale electricity markets are discussed and special attention is given to the negative effects of these subsidies on deregulation.

The paper first serches for the objectives of deregulation and comes out to a conclusion that the main objective of deregulation is the fact that the energy projects are huge investments requiring large amount of financial resources, hence public resources comes out be scarce in and difficult to allocate in meeting these financial requirements. The paper then searches for the meaning of the term: "public service", and comes out to a conclusion that electricity must be regarded as a public service since it satisfies the given definition.

The paper then examines the possibility of transferring the ownership of natural wealth and resources in terms of the principles introduced by the Article 168 in the Turkish Constitutional Law and arrives at the conclusion that the only valid and applicable deregulation model for the generation sector in Turkey is the one known as; TOR (Transfer of Right) due to the constraints introduced in the Article 168 in the Turkish Constitutional Law.

The paper then presents descriptive diagrams for the most widely implemented subsidy models for wholesale electricity markets and the conditions of entering a subsidized wholesale markets with TOP (take or Pay) agreements or fully deregulated wholesale electricity markets (Cost Based Tariff Model). The paper finally presents an evaluation about the viability of the subsidy models described in the paper.

## 1. The Main Driving Force behind Deregulation
It has widely been accepted that the main driving force behind deregulation in the electricity markets arises from the challenging financial problems in the investment of energy projects.

These problems may shortly be described as the facts that, Energy projects require huge investments with a large amount of financial resources, and public resources on the other hand are getting more and more difficult to achieve, due to severely demanding social conditions and constraints.

## 2. Electricity as a Public Service
In many developing countries, including Turkey, electricity was regarded as a public service mainly due to social concerns during the last decades for the sake of realizing energy projects with mostly non-profiting characteristics, by using public

resources and making subsidy to the energy tariffs of those parts of the society with low level of income.

The main objectives of this type of political attitude are to compensate the deficiency in the investment needed for the energy sector by using public resources, *-that must otherwise be realized by the private investors-* at the expense of neglecting other vital public services, such as defense, security, justice and partially public health, and to be politically popular and successful in the next election.

## 3. Definition of Public Service

According to the decision of the Turkish Constitutional Court public services are regarded to be regular and continuous activities carried out either by public authorities or under the supervision of public authorities in order to meet the general mutual needs of the society within the direction of the public interests and benefits (Decision of The Constitutional Court, 28.02.1996, 1994/71 (K), 1995/23 (E)).

Public services that are never to be deregulated are; national defense (army), metropolitan security (police) and justice.

Present point of view in terms of the general principles deregulation is such that all other public services can partially or fully be deregulated, including education, public health and municipality services.

Legal Framework for deregulation of electricity services is based on the Article 168 in the Turkish Constitutional Law, named "Exploration and Operation of Natural Resources". The article states that the natural wealth and resources are under the control and at the disposal of the Government. The right to explore and operation of natural wealth and resources belongs to the Government. The Government may delegate this right to private enterprises (only) for certain periods of time.

Of the natural wealth and resources, those to be explored and managed by the Government in partnership with/or private enterprises are subject to the explicit permission of the law.
The conditions to be fulfilled in exploring and managing the natural wealth and resources by private enterprises and the procedure, principles governing supervision and control by the Government and the sanctions to be implemented are prescribed by the law.

## 4. Legal Framework for Delegating Public Services to Private Enterprises

According to the Article 168 in the Turkish Constitutional law, public services may be delegated to private enterprises;

- (Only) for a certain period of time,
- Through a Concession Agreement

Hence, transfer of ownership of the property for exploration and/or operation of the public natural wealth and resources is legally impossible.

In terms of directions of the above views, possible deregulation models for the Turkish Energy Market may be outlined as follows;

- TOR Model (Transfer of the Operation Right) is implemented for distribution networks, generating plants with Vesting Contracts,

- BOT Model (Build Operate and Transfer) is implemented for generating plants until 2001,

- BO Model (Build and Operate) is implemented for generating plants with imported fuel until 2001,

- Licensed Generation Model is implemented for generating plants after 2001 with respect to the Law 4628.

It must be noted that the BO and BOT Models are no longer valid, since the enactment of the Law 4628 in 2001.

## 5. Consumer Conditions

Customer conditions are the main governing factors influencing investment and prices. These conditions can simply be stated as follows;

- **Constant Voltage**: Voltages at all nodes of the customers must be held constant within certain tolerable limits, such as ±10 %. This condition has a direct influence on the transmission and distribution infrastructure, since all investments are planned and realized with respect to this condition.
- **Constant Frequency**: Frequency of the overall system must be maintained within a very narrow operation limits, such as within ±1 % variation around the nominal frequency, 50 Hz. This condition dictates that a certain percentage of the generating reserves must always be kept and maintained as hot and/or cold reserve in order to be able to meet the demand in case of a sudden unexpected contingency.
- **Reasonable Price**: Domestic natural resources must be preferred in generating electrical energy in order to reduce the dependency to foreign resources and politics.
- **Availability of Supply**: Electricity must be held always in available condition, under all system operating conditions, regardless of the price. It is a common opinion that the cost of lack of energy to industry is always multiples of the prices of the energy to be obtained from the most expensive fuel.

Fulfillment of the above customer conditions is of a social and hence a political concern. Hence, politicians are highly sensitive to fulfill the customer conditions for the sake of their political career.

## 6. Conditions for Entering Market

In Figure 1, a diagram describing the conditions for entering a subsidized wholesale electricity market is shown. Due to mostly for social and political concerns, the Government implements a subsidy on the prices of the energy generated by the Government owned portfolio, thus offering electricity at a price lower than those offered by the private owned portfolio companies, which act simply on the principle of cost based tariff. In this type of market operation, electricity generated by the private owned portfolio companies can not enter market, unless a similar subsidy is implemented on their tariffs, thus eventually resulting in supply-demand gap and rise in prices.

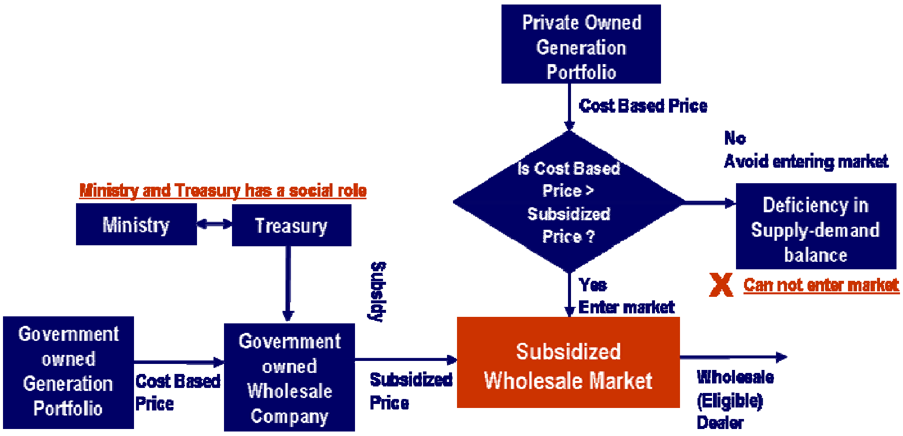


**Figure 1.** Diagram for entering a subsidized wholesale electricity market.

In Figure 2, a remedy to the problem described in the market model in Figure 1 is shown. As a solution to the supply-demand problem described in Figure 1, Government finds itself in a situation that it has to make TOP (Take or Pay) Agreements with the some private owned portfolio companies satisfying some conditions to be imposed by the Government. These conditions may be designed as using domestic fuel, i.e. domestic coal reserves, the power rating of the plant being above a certain level, etc. In this model, the Government agrees to purchase the energy produced by these companies at a tariff specified in the TOP (Take or Pay) Agreement for a certain time duration, such as 15 years. In order to be able to hold the prices below a certain level, the Government owned wholesale company is then subsidized, if deemed necessary.

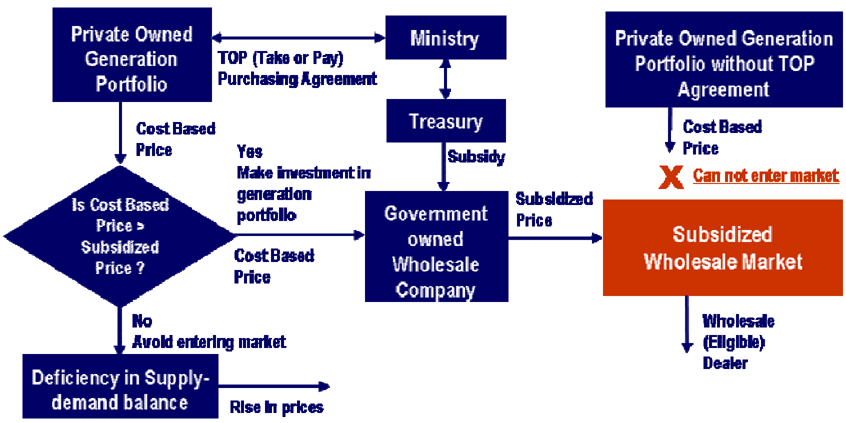


**Figure 2.** Diagram for a wholesale electricity market with TOP (Take or Pay) Agreements

Private owned portfolio companies who fail to satisfy the conditions imposed by the Government for TOP Agreement will fail to enter market, since their cost-based prices will exceed the market price.

In Figure 3, a fully deregulated market model is shown. In this model the Government does not intervene the market, except the direct subsidy to be made those customers with low level of income.

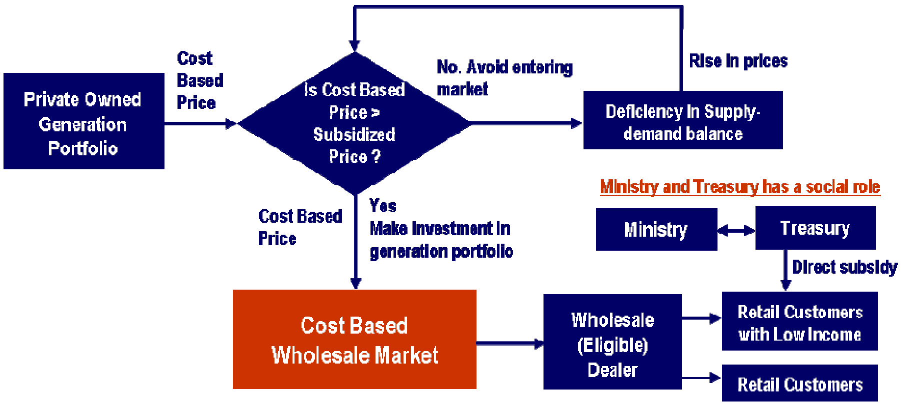


**Figure 3.** Diagram for a fully deregulated wholesale electricity market

Within the directives of EU Energy Directives, only the model described in Figure 3 is deemed to be viable and sustainable, since it does not involve the organic complications and high subsidies implemented in models described in Figures 1 and 2.

## 7. Future Prospectives of the Turkish Electricity Market

Future prospectives of the Turkish Electricity Market within the direction of deregulation may shortly be outlined as follows;

- Operation Rights of the government owned generation and distribution assets shall be transferred to private enterprises and wholesale trading activity shall fully be deregulated,
- Retail trading activity shall partially be deregulated,
- Distribution, transmission activities shall be regulated by an independent regulatory authority, EMRA,
- A competitive wholesale electricity market based on Cost Based Tariff shall be established.

# GASEOUS DIELECTRICS IN POWER TRANSMISSION AND DISTRIBUTION

**Loucas G. CHRISTOPHOROU**
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## 1. Introduction

As we all know, energy has shaped man's past and, undoubtedly, it will shape man's future; all industries are, in effect, devices for turning materials of one kind into another and they all require energy to be effective. Today's society has a growing need of a particular form of energy: ***electricity.*** Power consumption is rising across the world and the power industry needs novel ways to transmit and distribute electrical energy in efficient, safe, and environmentally acceptable ways.

Gaseous Dielectrics is a multidisciplinary field of science and technology which aims at the understanding and the development of gaseous media for use as high voltage insulation; the field surged in the 1970s and blossomed since, but subsided somewhat of late. Basic and applied research in gaseous dielectrics and engineering tests on prototypical gas-insulated equipment, over the past four decades (e.g., see Refs. [1-9] and sources cited therein) have generated fundamental knowledge which allowed systematic identification and tailoring of gaseous insulators for use by the electric power industry in the transmission and distribution of electric energy. (Other technologies make use of gaseous dielectrics in, for instance, pulse power generation, gas lasers, and particle accelerators.) In these uses, the insulating gas must be environmentally acceptable at all times.

In this lecture I shall focus on the following topics: basic physics and properties of gaseous dielectrics, the concept of the multicomponent gaseous insulator, gas-insulated equipment, $SF_6$ and environmental concerns related to its use, $SF_6$ substitutes, and future needs. This paper is an abbreviation of the lecture material.

## 2. Basic Properties of Gaseous Dielectrics and the Concept of the Multicomponent Gaseous Insulator

### 2.1 Electrical properties

The basic physics of gaseous dielectrics have shown that of the multitude of processes that take place in an electrically stressed gas, the most significant are those that involve free slow electrons and their interactions with the molecules of the insulating gas [1-5]. Foremost among these interactions are the processes which control the number densities and electron energies in the electrically stressed dielectric: those which generate electrons via ionization, those which deplete electrons via electron attachment, and those which control the electron energies via electron scattering from molecules. Actually, so important is the ability of a gas dielectric to remove electrons via electron attachment in determining its dielectric strength that gaseous dielectric media have been separated into those which attach electrons, called electronegative, and those which do not attach electrons, called non-electronegative. The dielectric strength of the former is high and that of the latter is low [1-5].

If ***α/N***(*E/N*)***, η/N(E/N),*** and ***f***(ε,*E/N*) are, respectively, the electron-impact ionization coefficient, the electron attachment coefficient and the electron energy distribution function, the limiting value, $(E/N)_{lim}$, of the density-reduced electric field *E/N*, is determined as shown in Table 1.

**Table 1. Basic Physics of Gaseous Dielectrics**

- For a non-electronegative (non-electron attaching) gas such as $N_2$

  ***$(E/N)_{lim}$ is small, determined by $\alpha/N \rightarrow 0$***

- For an electronegative (strongly electron attaching) gas such as $SF_6$

  ***$(E/N)_{lim}$ is large, determined by $\alpha/N = \eta/N$***

- The dielectric strength of a gaseous insulator can be optimized by using basic knowledge on electron-gas molecule collisions.

  - Ionization coefficient ***α/N*** (*E/N*) must be **small**
  - Electron attachment coefficient ***η/N(E/N)*** must be **large**
  - Electron energy distribution ***f***(ε, *E/N*) must be **shifted to lower energies** to minimize electron production and maximize electron removal by attachment.

The basic knowledge on electron-impact ionization, electron attachment and electron slowing down via scattering, led to the concept of the multicomponent gaseous insulator [1-2], where electron scattering and electron attaching gases are combined so that they act synergistically to optimize the dielectric gas properties (see Table 2).

**Table 2. Concept of the Multicomponent Gaseous Dielectric**

- Two or more gases are combined on the basis of knowledge of their electron-molecule interaction properties to act synergistically to optimize insulation properties.

- High dielectric strength, $V_s$, can be effected by combining electron scattering and electron attaching gases, so that one scatters electrons into the energy region where the other picks them up efficiently (classic example, $SF_6/N_2$ mixtures).

### 2.2. Chemical and other properties

Besides good electrical properties, a dielectric gas must have good chemical properties such as stability, good thermal conductivity, high vapor pressure, and inertness. It must also be non-toxic, non-flammable, easy to handle and transport, available and affordable, and compatible with gas equipment materials (see, for example, Refs. 3-10; see also following Tables as to the desirable properties depending on application). The gas must also be environmentally friendly and recyclable after use.

## 3. Why Gas-insulated systems?

Some of the reasons are listed in Table 3.

**Table 3. Why Gas-Insulated Systems?**

- Conserve energy
- Work better, are more compact and reliable, have low maintenance costs
- Protect the environment (reduced land use, reduced noise, aesthetics)
- Avoid possible health effects (magnetic field effects?)
- Politics and land requirements may impose their use.

## 4. Principal Uses of Gaseous Dielectrics by Electric Power Industry

The principal uses of gaseous dielectrics by the electric power industry are listed in Table 4. In these uses, but especially in circuit breakers, the most common gaseous dielectric used today is sulfur hexafluoride, $SF_6$.

**Table 4. Principal Uses of Gaseous Dielectrics by Electric Power Industry**

- Gas-circuit breakers (GCB)
- Gas-insulated substations (GIS)
- Gas insulated transformers (GIT)
- Gas-insulated transmission lines (GIL).

***Table 4.1. Gas-insulated Circuit Breakers***

- $SF_6$-insualted circuit breakers (4-5 atm) have superior performance (better interrupting capacity) compared to commercial circuit breakers utilizing air, oil, solid state or vacuum interrupting media.
- They:
  - are reliable and unaffected by environmental conditions.
  - have reduced maintenance, minimum operating noise, and low risk of explosion.
- $SF_6$ is used because it has high dielectric strength, $V_s$, high thermal conductivity, and fast dielectric recovery (the gas is self-healing).

***Table 4.2. Gas-insulated Substations (GIS)***

- Integrated construction systems in which all apparatus (combination of transformers and switchgear) is isolated from air in compact metal enclosures filled with $SF_6$ (2-6 atm).
- Advantages:
  - Compactness (GIS 1/00 to 1/20 the area of conventional substations)
  - Feasible to build in cities (small size, flexible design, low noise)
  - Higher reliability and safety
  - Quick installation/Reduced maintenance
  - Excellent seismic withstand characteristics
  - Protection against pollution.

***Table 4.3. Gas-insulated Transformers***

- $SF_6$ is used as insulation and cooling medium.
- Superior system properties:
  - Compact
  - Highly reliable
  - Low noise
  - Non-flammable
  - Non-explosive
  - Compatible with gas insulated switchgear
  - Easy to install, inspect and maintain.
- Desirable gas properties
  - High dielectric strength, high thermal conductivity, high thermal stability
  - Non-flammable, non-explosive, long-range stability
  - High specific heat for cooling
  - Low corona.

***Table 4.4. Gas-insulated Transmission Lines (GIL)***

- GIL are composed of pipes that house conductors in $SF_6$; are suitable for burying, installation in tunnels, or running above ground
- Are installed for 40-50 years and are maintenance free for decades
- Offer an economic, environment friendly and maintenance fee alternative to overhead transmission lines
- Are suitable for metropolitan areas where space is a premium
- Their most outstanding feature is their lower operating losses (lower heat dissipation to the environment)
- Ideal for environments sensitive to electromagnetic fields
- Can transmit high power ratings without forced cooling
- Generally so far employed as short transmission lines, many kilometers long.

*Most desirable gas property: High dielectric strength.*

## 5. Why does Industry insist on using $SF_6$?

Because:

- $SF_6$ is an extremely stable molecule.
- In its normal state it is chemically inert, non-toxic, non-flammable and non-explosive.
- It is an electronegative gas and has a high dielectric strength (~3 times higher than air at 1 atm).
- It has good heat transfer characteristics.
- It has good arc-interruption properties.
- It is “self healing” and rapidly recovers its dielectric strength in arc.
- Most of its stable decomposition products do not significantly degrade its dielectric strength and are removable by filtration.
- Although when $SF_6$ is subjected to electrical discharges forms toxic (e.g., $SO_2F_2$, HF, $S_2F_{10}$) by-products, on the whole, these can be removed by filtration.
- It is compatible with most solid insulating and conducting materials in electrical equipment up to 200C.
- It has sufficient pressure, is available, and is easy to handle and transport.
- Its physical and chemical properties, behavior in various types of gas discharges, and industrial equipment have been broadly investigated.
- The electric power industry is familiar and experienced with its use.
- Alternative systems are inferior and new technology (e.g., superconductors) is not presently available.
- $SF_6$ gas-insulated equipment is indispensable due to the steady expansion of electricity demand.

***So, what’s the problem?*** The problem basically is that the properties that make $SF_6$ gas a good insulting and switching medium make it environmentally unacceptable: *$SF_6$ is a potent greenhouse gas.* It is an efficient absorber of infrared radiation, particularly near 10.5 μm.
Because the $SF_6$ molecule is very stable, it is largely immune to chemical and photolytic decomposition. Hence, the lifetime of $SF_6$ in the environment is very long (half time ~ 3,200 years) and its global warming potential extremely high (~ 25,000 times higher than that of $CO_2$).
Thus, while the concentration of $SF_6$ in the environment is presently low (see Table 5), its contribution to global warming is expected to be cumulative and virtually permanent.
$SF_6$ is one of the six greenhouse gases on the Kyoto Protocol List (drafted ~20 years ago).

**Table 5. $SF_6$ in the Atmosphere**

- The amount of $SF_6$ in the atmosphere in the near term should be too small to have significant environmental consequences.
- Estimates of the relative contribution of $SF_6$ to non-natural global warming using 1993 estimated $SF_6$ concentration levels range from 0.01 % to 0.07%.

- Estimated world production steadily increased since the 1970's to ~ 7,000 metric tons per year in 1993. This has resulted in increased concentration of $SF_6$ in the atmosphere (~ 8.7%/yr) [8, 9].
- The electric power industry uses 80% of world production of $SF_6$ (80% of this is used in circuit breakers).

## 6. Solution

The societal benefit of using $SF_6$ must be weighed against its detrimental effects on the environment. Clearly, every effort should be made to prevent the release of $SF_6$ into the environment. Two ways to accomplish this goal have been followed.

– Reduce $SF_6$ releases and use, and
– Use $SF_6$ substitutes – environmentally more acceptable gaseous dielectrics.

### 6.1. Reduce $SF_6$ Releases

Since the mid 1990s the electric power industry instigated procedures and used new equipment to reduce $SF_6$ releases and use. Two aspects of this effort are worth noting:

– $SF_6$ recycling and reuse (for standards and protocols, see, for example, Refs. 10 and 11). The development of efficient gas handling procedures and new equipment (better compact designs and sealings) over the last 20 years have reduced leakage rates from > 3% p.a. to <0.5% p.a. (for seal-for-life equipment leakage rates are <0.1 %).
– Replacement of obsolete highly leaking equipment. While much has been accomplished in this area, there still remains in use highly polluting equipment which needs to be replaced.

### 6.2. $SF_6$ Substitutes – Environmentally Acceptable Gaseous Dielectrics

$SF_6$ substitute gases are difficult to find because of the many basic and applied requirements that a gas must satisfy and the many studies and tests that must be performed (e.g., see Refs. 3, 5, 6 and 9). Systematic studies have indicated the following gases as promising.

**• Single gases (high-pressure gaseous dielectrics)**

Non-electron attaching gases at high pressures

$N_2$
$CO_2$

**• Gas mixtures**

$SF_6/N_2$ (at somewhat higher total pressure than pure $SF_6$): These mixtures constitute the most promising $SF_6$ substitute; they are used in GIL and other types of electrical equipment (e.g., see Refs. 9 and 12). They reduce the amount of $SF_6$ used, they reduce cost and they have a lower liquefaction point than pure $SF_6$. Their development resulted from basic studies which indicated a remarkable synergism between $N_2$ and $SF_6$ and constitute a classic example of a multicomponent gaseous insulator [e.g, Refs. 2, 3, 7, and 9].

Christophorou et al. [7, 9] suggested that high pressure (~10 atm) $N_2$ and mixtures of low concentrations (<20%) of $SF_6$ with $N_2$ can be used for insulation (GIL), and higher $SF_6$ concentrations (40% to 50%) in $N_2$ can be used for arc quenching and current interruption.

There is, however, a need for an in-depth investigation of high-pressure (6-12 atm) gaseous dielectrics [13].

## 7. Concluding Remarks

I wish to conclude this lecture with the following remarks:

- The development of Gaseous Dielectrics for the needs of the Electric Power Industry is an example of how basic and applied scientific research and engineering leads to new technologies.
- There is a need to develop new environmentally acceptable gaseous dielectrics, especially if GIL is used widely and GIT scale up in numbers.
- Any serious effort to find viable $SF_6$ substitutes must pay attention to
- full characterization of $N_2$ and $SF_6/N_2$ gas mixtures;
- new gases for insulation (limiting the use of pure $SF_6$ to arc and current interruption equipment).
- Research in Gaseous Dielectrics should be rekindled in view of future energy needs and new energy sources.

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# INFRASTRUCTURE DEVELOPMENT AND POWER SYSTEM SECURITY ISSUES IN A LIBERALIZED ENVIRONMENT IN SOUTH-EASTERN EUROPE (SEE)

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## 1. General Overview

At present, the power systems of South East European (SEE) countries operate on parallel and synchronous mode with the UCTE network. The power systems of Armenia, Azerbaijan, Georgia, Moldova, Russia and Ukraine belong to the IPS/UPS group of power systems that operate with different standards and independently from UCTE. The IPS/UPS group includes also many more countries such as the Baltic States (Latvia, Lithuania, and Estonia), Belarus, Kazakhstan, Kyrgyzstan, Tajikistan, and Uzbekistan. The Turkish system operates independently from both UCTE and IPS/UPS systems. Turkey has applied to become a member of UCTE and a study has been carried out investigating this possibility.

The synchronous interconnection of the IPS/UPS with the UCTE system is a difficult task that is under consideration by a group of 80 experts from 17 countries from both sides. The connection of two huge power systems, with different generation and network structures, norms and standards, and rules of operation, needs the establishment of a minimum set of technical requirements, organizational structures and procedures, as well as legal agreements.

Because of this, many studies and multilateral negotiation procedures are required before any sound and concrete decisions become mature enough, in order to be accepted by all involved parties and be eventually implemented. Thus the dream of an **"Electricity market from Lisbon to Vladivostok"** may need time, and maturity to be realized. Therefore it seems reasonable that a **staged approach** is necessary to be developed in order to strengthen cooperation in the electricity sector of the broader SEE region.

## 2. A Staged Approach

The development of a regional electricity market is a project far more complicated than the liberalization of a national electricity market. We must not forget that in EU, e.g., it took more than 10 years of hard negotiations between the Member States in order to adopt the initial Directive 96/92 for the establishment of the Internal Electricity Market in Europe. The project is even more difficult and challenging in the region of the SEE countries, for, in this case, one must take into account the following important issues:

- The SEE region consists of countries with various national, religious and cultural origins.
- Most countries of the region are going through a transition period that involves structural, political, and economic changes.
- The state owned, vertically integrated utilities covering all stages of power generation and supply has led to the development of national electrical systems

with a number of shortcomings, especially with respect to the proper utilization of the investments.

- There are wide variations between the countries in terms of their existing and future internal electricity market structures, the pace at which reform may take place, the changing demand patterns and the fuel supply situation. As a starting point, it can not be assumed that all countries will have the same need or desire to trade in a similar manner at the time when a regional market is initiated. It may therefore be desirable to establish a market structure that has the flexibility to cope with the differing possibilities to trade.

The establishment of a regional market in SEE is expected to have immediate positive effects in system reliability, economies of scale in planning, constructing and operating generation and transmission systems. In addition to these immediate benefits the generation of a regional market will exercise competitive pressures on existing systems, increase their efficiency and encourage inflow of private capital.

An essential feature of the regional market design should be to acknowledge that flexibility might be required to accommodate the approaches taken in each country in restructuring their electric systems and in the design of their own markets. An efficient market design should allow market participants a maximum choice in trading opportunities.

The region of SEE countries is characterized by a number of different, frequently separated, electricity "markets" in various stages of early development. In some cases the pricing mechanisms adopted are inadequate to encourage long-term investment in new electricity generation capacity. In most cases this is due to the fact that retail prices, as set by governments, are far below the cost of new entry. It will be a great challenge for the politicians to provide the conditions for consumers to choose their suppliers, and, at the same time to convince them of the need to raise prices up to the level of costs. The situation is even more difficult in those countries with economies in transition in which the rates of collecting electricity bills are still very low. It is obvious that such obstacles can only be overcome when the economies of the countries converge. And this needs time.

For the successful integration of the electricity systems of the SEE Region the development of national system operators, independent of commercial interests is needed. Collaboration and co-ordination between the system operators is a prerequisite for the development of interconnected systems. Infrastructure across the borders is another important prerequisite for an integration of the electricity markets of SEE countries. For these reasons supporting of investments in infrastructure is sine qua non.

The existing transmission lines and interconnections among the national power systems of the SEE region permit transactions ranging from 250 MW to 1600 MW, depending on the origin, destination, path, and time period. However, they are not always sufficient to cover the respective power transfer needs. We emphasize here the importance of the Adriatic interconnection line, the interconnection line Elbasan-Tirana-Podgorica, the interconnections of the Former Yugoslav Republic of Macedonia with Serbia (Nis), with Albania and with Bulgaria (Cervena Mogilla), as well as the interconnection between Greece and Turkey. These are some examples of important interconnections within SEE that have to be implemented or restored in order to enhance trade in the region.

## 3. Market Liberalization versus Power System's Security

Traditionally Public utilities were granted areas where they had the exclusive right to provide their services. Thus within these service areas, public utilities were protected from competition from enterprises offering the same services. In the past 15 years, the energy market has been one of the main sectors in the global liberalisation trend that aims to improve the efficiency of the previously monopolistically run activities, enhance competition and bring to consumers new choices and economic benefits.

The economical, environmental and social role and the investment intensive nature of the energy sector has attracted the interest of different groups from politicians and authorities to investors, environmental activists, energy intensive industries and even household customers.

The difficulty to predict and model actual system operating conditions determined largely by economic drivers, such as fuel cost and market forces, introduces a significant degree of uncertainty both in short term operation and long term planning The great importance of economic factors, being the main operational drivers, implies that there is more incentive for maximum utilization of existing facilities. This inevitably leads to more risk-taking, to the detriment of security and reliability operation levels of the power systems, unless new highly sophisticated electronic surveillance, control and protection schemes and models are applied.

## 4. Liberalisation, Uncertainty and Complexity

Liberalisation, obviously, necessitates reformulation of established models of power systems operation and control activities. Similarly, issues such as systems reliability, control, security and power quality in this new environment have suffered drastic changes that are still under scrutiny and debate.

The liberalised market needs new models and methods for planning because market rules increase the uncertainty and the problems in forecasting become larger. Optimisation under uncertainty is a new challenging field. It must be emphasised here that, in addition to the uncertainties introduced by market liberalization, there are two more sources of growing uncertainty we must take care of. The vast use of renewable energy sources with high level of unpredictability (e.g. wind power) and a, so far, not well defined Emissions Trading Scheme introduce growing uncertainties both in long-term planning and in short-term (daily, hourly, real time) operations.

The new liberalised market means also that there are more transactions to process and more data to manage. This is mainly due to the conflicting interests that are competing in the market. Hence, more information needs to be included in the decision making and planning processes and more attention needs to be paid on how to formulate and implement the models efficiently.

While the complexity of the problems increases, the computational power of computers keeps also increasing. This allows for more accurate and sophisticated modelling. The energy sector is one of the core application areas in operations research and decision sciences due to the fact that energy systems are large, require large investments and are technologically challenging to implement. Plenty of algorithms have been developed for and applied to problems related to energy systems. **WASP** e.g. is a good and well known source code used to solve the optimal **long-term** power generation expansion planning problem of a monopolistic energy company. However, with the uncertainties introduced by the market, **WASP** and similar algorithmic codes need to be changed or suitably adapted. On the other hand if we think of **short-term** operations, e.g. intraday, hour by hour, or even real time markets, then changes are needed of the tools used to help decisions in the short-term operational level. The conclusion is that the energy system related operations research needs to be reoriented and refocused to better match the needs of the fast evolving energy markets. New methods are needed to solve the decision making problems in the strategic as well as the operational level of energy companies. In addition, several previously non-existent tasks, such as risk analysis and optimal bidding, necessitate the implementation of new market oriented models.

It worth to mention here that all these changes pose heavy requirements on information technology and software used to cope with the higher complexity of these problems. The introduction of new powerful mathematical tools, such as **Mixed Integer Linear Programming (MILP)**, is promising.

## 5. Planning, Optimisation and Decision Support in the Liberalised Energy Market

As more utility markets are liberalised and competition is introduced, there is an increasing need to understand how the planning methods used under monopolistic regimes have to change to take the new deregulated environment into account. Although this seems rather obvious, it has been a very difficult problem for a large number of power utilities which, because of **behavioural inertia**, have continued using the same planning approaches that they used when they were monopolies.

We must understand that the environment which, under monopoly conditions, gave rise to the use of mainly operational research methods for planning is inevitably changing. Liberalisation changes the fundamental assumptions of the monopolistic environment, making the planning methods used under monopoly less useful.

After the liberalization of the power generation industry, capacity expansion decisions are made by multiple self-oriented power companies. In the liberalised environment, market participants base their decisions on price signal feedbacks and an imperfect foresight of the future market conditions that they will face. In such an environment, decision makers need to understand the dynamics of the supply and demand side of the power market. We, therefore, need models that include:

- demand (long and short term) forecasting models,
- network capacity expansion models,
- power generation models, including optimal handling of hydro reservoirs,
- congestion management, including cross border capacity allocation auction mechanisms,
- bidding mechanisms (e.g. a power pooling system),
- auxiliary services market models,
- and accounting and financial models.

By means of such decision tools, companies and regulators have a better opportunity to understand possible consequences of different decisions that they may make under different policies and market conditions.

## 6. IT and Telecommunication Requirements

Even though deregulation has faced some obstacles and delays in many countries, we have nevertheless seen a major growth in the amount of information that must be managed in daily (often in intra daily) operations. At the same time the response times in decision making processes have become much shorter than what they used to be. The planning, optimisation and decision support problems can no more be separated from the information they are based on. Many new tasks require the use of information management systems and embedded applications with very fast time and extremely large memory requirements.

The changes have also included the establishment of new service companies and outsourcing of operations like **meter reading, billing, risk management** and some maintenance and service operations of the assets. The most recent notable developments have been the introduction of **emissions trading** and **large scale automated (smart) meter reading**. To summarize the developments, we can say that the changes are revolutionary and have an impact on the whole industry. The new business principles and practices formed during the liberalisation process require clearly more communication between the various market parties and thorough changes in their information infrastructure. It is necessary to develop new information technological solutions for balance settlement, for communication between parties, for profiling of non-interval measured customers and for telemetering and billing. On the other hand, the increasing competition and diversification has dictated a need for new tools to handle new competitive pricing methods with complex product structures (market prices, cap and floor components etc.) and to manage different customer segments and portfolios. This has also impacted the procurement side where the optimal procurement has required enhancement of optimisation and forecasting tools.

In short we may conclude that the market can no more operate without strong automatic information management tools.

## 7. Power System Security in the New Market Environment

Although the industry restructuring has lead to debates on the electricity market structure and market rules, comparatively little attention has been directed towards the issue of power system security in a market environment. Regardless of the market model chosen, it is still essential to carefully balance the power requirements of the supply side and demand side in the presence of disturbances. It is well known that this balance is required to maintain system voltage, frequency and angle stability of the network.

The market expresses the will of human beings to meet at the point of equilibrium of supply with demand by maximizing the, so called, **Social Surplus**. But the will of human beings, especially when expressed in terms of conflicting economic interests, may lead the power system to risky levels of operation or even to operations that are not feasible from the physical laws point of view. Indeed, following the liberalisation over the past 2 decades, many power systems have been pushed toward their **stability limits** in order to **maximise profit** in energy trading, thus endangering the operation of the power system. It is very important to understand that power systems are large-scale systems and, as such, they are composed of large number of devices that operate within physical limits. Such individual limits pose operational constraints which typically contribute to the definition of feasibility regions. We, therefore, need new algorithms that will enable fast assessment of security regions and limits. We need to develop efficient and fast methods to evaluate the power flow and stability limits. Also, we have to develop comprehensive methods to assess most of these security characteristics and system security conditions and also provide important information for optimal, co-ordinated control actions aimed at securing overall system stability. Genetic Algorithms seem to be promising when used to locate the optimal control scheme for better security of a power system.

It must be emphasized that true optimality of the market requires complete co-optimisation of the energy dispatch and security preparation. However, for practical reasons, it is more likely that sub-optimal structures will be used. There is a lot of work to be done in order to compare several different approaches that have been already proposed to dispatch the ancillary services market for security services. In contrast to the genetic algorithm approach mentioned above an exhaustive search approach for ancillary services markets has been proposed.

Various liberalisation models will be evaluated from the viewpoints of the introduction of competition, conservation of the environment, promotion of energy conservation, and energy security. Of course, all market models and analytic techniques should be demonstrated on various test power systems before they are finally applied and checked on real power systems.

## 8. Future Initiatives

The role of electric power has grown steadily in both scope and importance and electricity is increasingly recognized as a key to societal progress throughout the world, driving economic prosperity, security and improving the quality of life. In the coming decades, electricity's share of total energy is expected to continue to grow, as more efficient and intelligent processes will be introduced. For example, controllers based on power-electronics, combined with wide-area sensing and management systems have the potential to improve situational awareness, precision, reliability and robustness of large, continental-scale, systems. It is envisioned that the electric power grid will move from an electro-mechanically controlled system into a fully electronically controlled network in the next two decades.

The construction of more interconnections in order to make increased transactions possible has lead to some global problems (such as inter-area oscillations) which require very large system models and sophisticated protection schemes to be used for security assessment. **A local disturbance anywhere can have immediate impact everywhere**. Large-scale cascading failures and failures in seemingly unrelated businesses can occur. Because these networks support critical services and supply critical goods, disturbances can have serious economic, health, and security impacts. These pose new challenges for reliable, robust and secure network measurement, control, management, and operation.

Modelling, simulation and control of energy generation and delivery systems and interdependencies with other interactive infrastructure networks and identification of their vulnerabilities become extremely important and require preventive and corrective control of cascading failures .

The introduction of new technologies, such as wind power, or hybrid generation types, for which performance assessment experience is, at present, limited may introduce additional complexity into the prediction of security (effect of wind unpredictable variation on security for example). The use of Power electronics and instruments, (e.g. Flexible AC Transmission Systems (FACTS), or Superconducting Magnetic Energy Storage (SMES) devices), which enable new capabilities for sensing and control of large-scale networks may be helpful in re-establishing an acceptable security level in such cases.

## 9. Conclusion

A lot of work has to be done for the development of new interconnections to enable trading and for the development of new tools and methods to enhance system observability (including visualization of wide-area networks), efficiency, robustness and reliability and to achieve faster than real time simulation for security assessment and dispatching.

# NATURAL HAZARDS, GLOBAL CLIMATE CHANGE AND ENERGY PRODUCTION

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With the recent release of the Intergovernmental Panel on Climate Change [1] report, put together by an international panel of experts under the auspices of the United Nations, governments and the public throughout the world are becoming acutely aware of the dangers to human societies of global warming, precipitated by the uncontrollable and continuing in an ever increasing manner release of greenhouse gases such as carbon dioxide and methane. These emissions are the result of ever increasing energy consumption via fossil fuel burning. Model predictions carried out into the future, indicate possible increases of global atmospheric temperatures by as much as 5 degrees Celsius over the next hundred years, which would have disastrous global consequences for droughts, agricultural productivity and sea level rise.

Governments in the world are increasingly under pressure from not just the scientific community but also the public to do something about curtailing the release of greenhouse gases from fossil fuels, which, most scientists believe, is the direct reason for the increase of global temperatures. It is here where global politics, development of new economic powers and associated industrial productivity, sustaining and expanding a modern way of life, and other factors, enter the picture and complicate any possible solutions: The Kyoto Protocol needs to be renewed but it is still not clear how, who will sign it and what it will mean; the refusal of U.S. governments, to acknowledge the need to curtail greenhouse releases and limit fossil fuel burning; the emergence of India and particularly China as world economic powers, with their associated increasing need of energy production and thirst to find new energy sources [2]; the lack of massive usage of alternative sources of energy production, which to compete with fossil fuels will require years of development and economic viability; and the dream of billions of people in the world to enjoy the same modern way of life that we in developed nations take for granted, all play an effect here.

It is here where DEMSEE'07 can add to the issues under question. Control of energy sources presents additional risks: It is hard to make the case that somehow governments will abandon their usual ways and not use power to prevail over others when future resources become scarce and agricultural production and feeding of their own people are threatened.

What has emerged in addition to global warming as additional major concerns is the severity and increase of natural hazards, which often become catastrophes; and the collapse of ecosystems in many parts of the world. There are often non-linear feedback mechanisms at work, which once set in motion, spread uncontrollably [3]. Although hazards are or may be tied to human activities, they present the additional challenge in that they are occurring *now* and not tens of years into the future. Let's examine them in detail.

Natural hazards include: Wildfires, sand and dust storms, tropical cyclones, known as hurricanes and typhoons, severe weather, floods, and their opposite, droughts, as well as earthquakes. It is possible that the increase of occurrence and severity of all or most of the above, with the exception of earthquakes, are somehow associated with human activities in that they may be directly tied to global climate change. The IPCC report outlines several connections. But it is fair to say that we still don't understand all the complex interactions of the Earth systems. Yet, the severity and increase of natural hazards, are sounding the alarm for us to pay attention and heed the call to mitigate the disastrous consequences.

Recent droughts and heat waves in Europe have led to massive fires in several countries, such as Portugal, Spain, France, Italy and Greece, as well as many deaths in heat-stricken countries like France during past summer seasons. Tropical forests are being burned to make way for agricultural development, grass fields, to feed cows and other livestock which then get slaughtered to feed humans, in a highly inefficient and environmentally degrading manner; or to make way for new human communities. Forest fires in one country affect not just that country but many neighboring countries through the spread of smoke aerosols, such as Indonesian fires affecting major nearby cities like Kuala Lumpur. Burning of forests in Africa leads to more desertification by Nature, which decreases available forests even more.

Desertification in Africa has exacerbated droughts, collapse of local agricultural production and resulted in unabated famines, which have killed millions of people. The other apocalyptic dread, war, has conspired with droughts to lead to untold human suffering. This may become a common occurrence in other parts of the world as warming may turn many agricultural areas dry, depleting water resources in attempts to save them. Desertification is often associated not just with outbreaks of fires but also with an increase of sand and dust storms. Desertification and droughts in Australia are now threatening the water supplies of most Australian cities. What we are witnessing now will become much worst with future climate change as all indications point to increased levels of droughts, warming of many areas of the Earth and risks to the Earth's forests. It is conceivable that the increasing scarcity of water will pitch countries against countries for control of this most important commodity, particularly in arid and semi-arid regions.

The increase of severe weather often leads to floods, which although opposite to droughts, seem to also be on the increase. Often some areas are afflicted by droughts while other areas by floods. One prediction of global climate change is the severity of such opposites. Floods in Central Europe may be associated not just with the cutting of forests but also with global warming. Severe weather causes floods in India, Pakistan, Bangladesh, the Philippines, South American countries and China, which not only affect their economies, they lead to massive deaths. Severe rains not only help to overflow large rivers, they cause sudden flash flooding in major urban centers, trapping or drowning many people. Even traditionally dry areas such as Athens, are increasingly experiencing flash floods. Such severe weather has a particularly devastating effect in major cities, like the recent example of Mumbai, India, striking without notice and killing many people. Is climate change responsible for the increase of severe weather? Models seem to indicate that this is indeed the case. But, again, this is not reserved for some time in the future, it is happening right now under our eyes.

Desertification in Asia and strong winds have led to an increase of the so-called “yellow sand” phenomenon, affecting several East Asia countries, particularly China, Korea and Japan. During the spring months, many cities in East Asia become afflicted by this phenomenon, leading to economic losses and increase or respiratory ailments. Desert dust from Africa crosses the Mediterranean causing bad weather and affecting agriculture and living conditions in many European, Turkey and Middle East countries, in addition to Northern Africa itself. Forecasting dust storms is difficult as they depend on a complex interaction of winds, and local conditions such as the nature of soil and the changing weather patterns. Once though a dust storm develops, satellites from space track it and weather and dust propagation models can be employed to provide important information to authorities downstream of the storm.

The existence of deserts from where sand and dust storms originate, predates global change. Yet, global warming will increase the strain on the Earth’s ecosystems, likely turning many past green areas into future arid areas or even deserts. It is unlikely that deserts will recede as result of our activities. Then natural hazards like sand and dust storms will continue to increase in the future. It is clear that such storms know of no political boundaries or countries. Dust storms from Asia and Africa often travel thousands of kilometers, crossing the great oceans, affecting distant regions, far away from their places of origin.

The connection of tropical cyclones to climate change is still under debate. Yet there seems to be an emerging view that the culprit, climate change, is at least to be partially blamed. The recent increase of tropical Atlantic storms or hurricanes seems to be tied to an increase of the sea surface temperature. For example, it has been convincingly shown that the abnormal higher than average temperatures in the Gulf of Mexico in the summer of 2005 led to the formation of the devastating hurricanes Katrina, Wilma and Rita. What nature failed to accomplish by direct wind devastation, human neglect did it by ignoring signs of what might happen in terms of flooding, namely in the case of the city of New Orleans hit by Katrina [4]. The summer of 2006 did not prove as disastrous for the U.S. coastline as few storms developed, perhaps due to the development of more dust storms off the coast of Africa near Sahara, which might have curtailed the growth of hurricanes. This is a topic that scientists are currently investigating. However, the Pacific rim countries did feel the effect of more typhoons as it appears that when the Atlantic is quiet, the Pacific often is not, as far as tropical cyclones are concerned.

Will super typhoons become more numerous in the future? Will more category 3 to 5 hurricanes like Katrina strike the United States in the coming years? Again, the evidence seems to be pointing to warmer oceans which will in general mean more severe storms. Global models even predict that up to now quiet areas may be subject to tropical storms in the future. Particularly telling is the prediction of models run by a Japanese team indicating that the Persian Gulf region may be subject to future storms, threatening the world’s supply of oil. Satellites can also track the development of tropical cyclones after they have formed. Satellite observations coupled to detailed modeling are becoming new tools to better understand these phenomena.

Warmer oceans are already occurring, perhaps outpacing the expected atmospheric warming. It is predicted that by 2050 there will be no polar ice during the summer season. Besides the obvious effect to polar ecosystems that this will entail, such as the possible extinction of polar bears, it may have disastrous consequences for the climate of Europe and North America as it may disrupt the flow of the Gulf Stream. Sea rise will continue as result of the warmer oceans. Although not classified as a natural hazard, sea rise will have disastrous consequences for many low-level coastal areas and islands of the world, where millions of people live. Under extreme scenarios, many major coastal cities may find themselves under sea water.

Besides sea level rise and warming of the oceans, human activities are responsible for the pollution of huge parts of the oceans. Such pollution in extreme cases kills fish and disrupts marine ecosystems. In turn, humans cannot harvest affected fish and other marine life, which means that humanly caused pollution turns in an ironic way against humans. Pollution of seas causes coral bleaching and the disappearance of vast areas of coral reefs. We still don't know the implications for marine ecosystems, which are in delicate balance with the environment, each species serving an important role for the benefit of the whole. In addition, the extreme overfishing of many seas has led to the prediction that there will be no more available fish reserves left in the open seas by 2050.

Extinction of species and collapse of ecosystems may be the way of the future and are currently on the increase. These are not directly tied to global warming but their cause is the same as for global warming: uncontrolled human activities and disregard for the Earth which sustains us all. In areas such as the Amazon, where a large percentage of the world species reside, the collapse of tropical ecosystems may have unpredictable effects for the Earth, beyond the immediate habitats. If the underlying environment is in ill health, human societies will be in serious peril. This issue is not the province of a few select activists, it is the business of all. No individual species can survive outside the rest of the biosphere, not even humans. Disregarding the health of other species comprising the biosphere may ultimately be the most foolish act that humans can perform, turning in a way Nature against us.

Along with the effects of natural hazards, the Earth's environment is subject to increased pollution. As with natural hazards, this undeniably anthropogenic pollution knows of no boundaries. Aerosols from dirty coal burning plants, smoke aerosols from agricultural practices or burning of forests, city pollution and dust storm aerosols, are all on the increase. Their combination can prove particularly harmful and even deadly to many humans. Megacities of the world such as Beijing, Cairo, and regions such as the Indo-Gangetic plains of India housing more than 600 million people, are subject to the deadly combination of all natural and anthropogenic aerosols. No major city is free of all aerosols. Scientists are now studying the propagation of such pollutants and their effect on and feedback mechanisms from regional and global climate.

Scientists are increasingly using the many available satellites to study hazards and the developing climate changes. Models are a necessary complement to observations. Support for these scientific efforts is most important now and in the future. However, no matter what scientists do, the above problems cannot be addressed by science alone. Societal involvement and decisions that increasingly will require global approaches and international agreements, as the problems themselves are global, are paramount.

The scenarios painted here are not alarmist or beyond realism. Whether or not we will be able to sustain our way of life and have our brothers and sisters in other developing countries enjoy the same, which require the very energy production which threatens the environment and ultimately all of us, is still an open question. However, one thing is clear: If we do nothing and continue things as they are, a catastrophe of possible monumental proportions awaits us and future generations. Besides the direct threat of global warming and associated hazards, dwindling agricultural production, massive famines, vanishing water supplies, and economic collapse may turn nations against nations. The greatest threat to humanity, according to British scientist Smith, namely global warming, may lead societies to the use of war which may take global proportions and may accelerate the demise of global civilization.

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# EDUCATIONAL EXPERIMENT KIT STUDIES ON RENEWABLE ENERGY SOURCES

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## Abstract
In this paper, experiment kits powered by renewable energy sources are designed for students. Experiment kits involve photovoltaic solar panel, wind generator and PEM type fuel cell systems. Hydrogen is produced from solar and wind sets by water electrolysis. Output characteristics (current –voltage (I-V) ) of both solar cell and wind generator can be defined and then modelled for different irradiance and wind speeds respectively. A fan is used for wind excitation. For PEM electrolyser, input I-V characteristic and hydrogen formation curve can be measured. According to model results, operating points of PEM electrolyser on the solar and wind sets are predicted with 1-2 % relative errors. As a generalization, for different sized similar systems each set is defined in MATLAB/Simulink program. The kits are suitable for both indoor and outdoor use.

**Keywords:** *photovoltaic, wind, hydrogen*

## 1. Introduction
Recently, problems such as global warming, greenhouse effect, pollution, have caused the interest in renewable energy systems (solar, wind, etc.) to increase. Furthermore the hydrogen which is a popular and clean energy source, can be produced from electrical energy in these renewable energy systems using water electrolysis. Electrolyser is a device that is used to produce hydrogen from water via electrolysis. In return, fuel cells convert stored hydrogen and oxygen /or air to electricity directly. Hence, renewable energy and hydrogen systems are employed in integrated form [1,2,3,4,5]. In this paper, an educational experiment set is prepared in order to inform new generation and students about clean and renewable energy applications. Experiments and other details on the set are given in below sections.

## 2. Experiment Set
The educational experiment set consists of three main parts that are the photovoltaic (PV) solar panel, a wind generator and proton exchange membrane (PEM) type fuel cell/electrolyser systems. The PV panel used can deliver approximately 700 mA at 2 V under 45 $^oC$ during typical sunlight test. Open circuit voltage ($V_{oc}$) is about 3-3.5 V. A lamp 100 W is used as a solar simulator for indoor tests. In wind generator system, 0.3-12 V permanent magnet direct current (DC) motor is used as dc generator. Wind turbine is made from hard plastic and thin material with 7cm radius, four wings. A fan is added to the wind set for wind excitation. The PEM hydrogen system is used as both generator and electrolyser. In this study, the PEM hydrogen system is operated as electrolyser for hydrogen production by water electrolysis. The PEM is single cell with max. 2 V - 1 A. for electrolyser mode. The principle schema of the set is given in Fig.1.

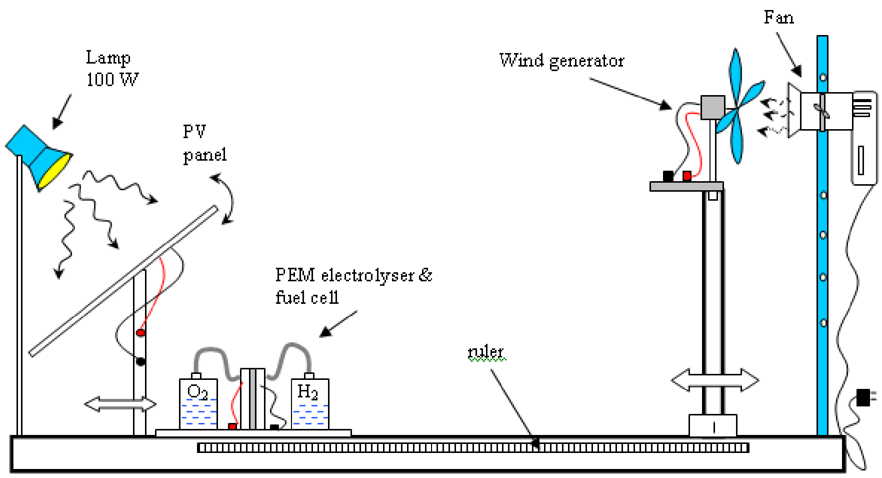


**Figure 1.** The principle schema of the renewable energy set

The distance between fan and wind turbine is variable and it is scaled according to different wind speeds (m/s) using by a ruler. Similarly, the irradiance level for solar system can be changed by varying distance (or angle) between PV panel and the lamp. In order to measure hydrogen formation, oxygen and hydrogen tanks are scaled. The electrolyser system can be maintained by both PV panel and wind generator sets under different irradiance levels and wind speeds. Output current-voltage (I-V) characteristics of PV panel or wind generator, can be defined using a variable resistive load bank with 2-1000 Ohms.

## 3. Measurements on the Wind Generator and Modelling

Output I-V characteristics of the wind generator are measured under different sampled wind speeds. For a given wind speed, measured I-V curve, can be modelled as a linear function. This is similar to output characteristic of a typical dc source with specific inner resistance. Values of open circuit voltage and short circuit current on characteristics change with wind speeds. Equations for the wind system with permanent magnet dc generator can be defined as following.

$$V = K.\omega - I.R_s \tag{1}$$

$$T_{rw} - K.I = B.\omega \tag{2}$$

From (1) and (2):

$$V = K.\frac{T_{rw}}{B} - I.(\frac{K^2}{B} + R_s) \cong V_{oc}(wind) - I.R_{eq} \tag{3}$$

where, K: generator parameter for voltage coefficient (V.s/rad) and it is equal to torque coefficient for permanent magnet machine, ω : angular speed (rad/s), $R_s$ =armature winding resistance (ohm), $T_{rw}$ : Rotational net torque by wind, B: friction coefficient of the system and $R_{eq}$ : equivalent inner resistance that causes to voltage drop. The $T_{rw}$ depends on wind turbine configuration (radius, wing schema, area and etc.) and wind speed for a generator. The V is related with rotational speed, the torque $T_{rw}$, affects the current I. Hence both I and V, depend on wind mechanical power which is transformed from wind power. Values of torque and rotational speed are defined according to wind speeds for a wind turbine and generator machine [6]. In the study, open circuit voltages and short circuit currents on measured I-V curves, are scaled to sampled wind speeds and then linear approach is applied to I-V curve modelling. I-V curves of both model and measurement are shown in Fig.2 for different wind speeds.

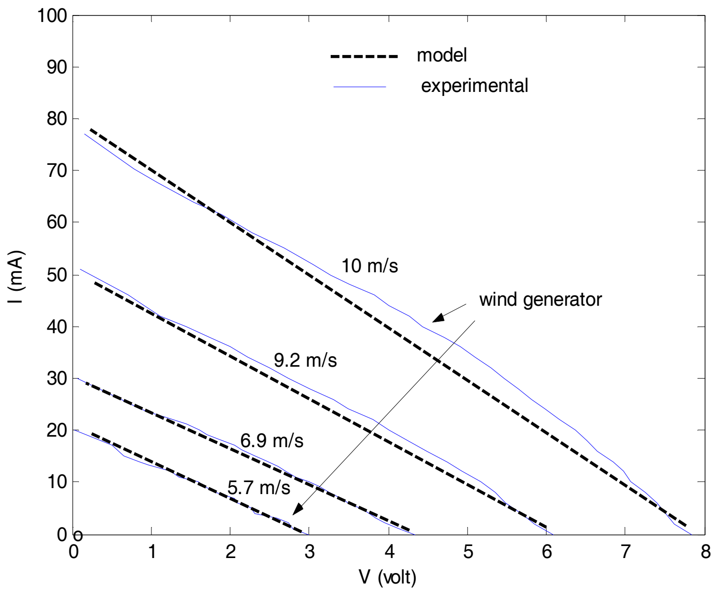


**Figure 2.** Wind generator I-V curves for experimental and model

## 4. Tests on the PV Panel and Modelling

A PV panel has a dc electrical output. I-V characteristic is non-linear and changes with irradiance and temperature T. Short circuit current ($I_{sc}$) of the PV panel is proportional to irradiance. The open circuit voltage ($V_{oc}$) is more affected than $I_{sc}$ from temperature. The $V_{oc}$ increases with irradiance, in contrast decreases with temperature. PV panel I-V characteristics are measured for different irradiance levels on our set. Also variation of T-$V_{oc}$ at the same irradiance and variation of $I_{sc}$-$V_{oc}$ at constant T, are measured. According to T-$V_{oc}$ test, the voltage coefficient per temperature variation dVt (V/$^{o}$ C) is approximately -0.014 V/$^{o}$C as shown in Fig.3.

Using curve fitting, variation of $I_{sc}$-$V_{oc}$ at a constant T=37$^{o}$C can be modelled by (4) where, $I_{sc}$ is taken as mA.

$$V_{oc}(I_{sc}) = 3.27 + 0.1686.\ln(\frac{I_{sc}}{258}) \tag{4}$$

$I_{sc}$-$V_{oc}$ curves of measurement and model are given by Fig.4. When effect of temperature on the $V_{oc}$ is added to (4), the term of $V_{oc}$ can be defined as function both $I_{sc}$ and T by (5).

$$V_{oc} = 3.27 + 0.1686.\ln(\frac{I_{sc}}{258}) - 0.014.(T - 37) \quad (5)$$

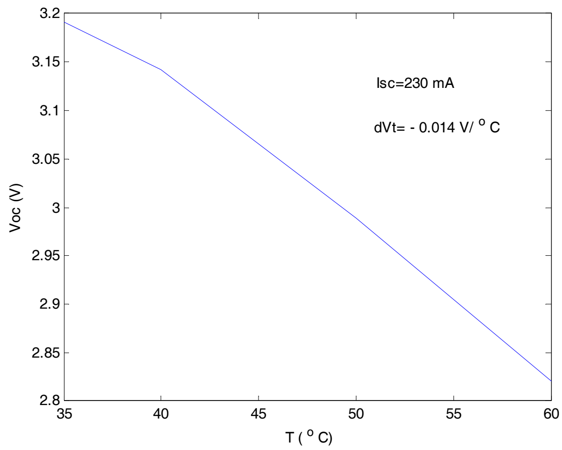


**Figure 3.** T-$V_{oc}$ variation at $I_{sc}$=230 mA

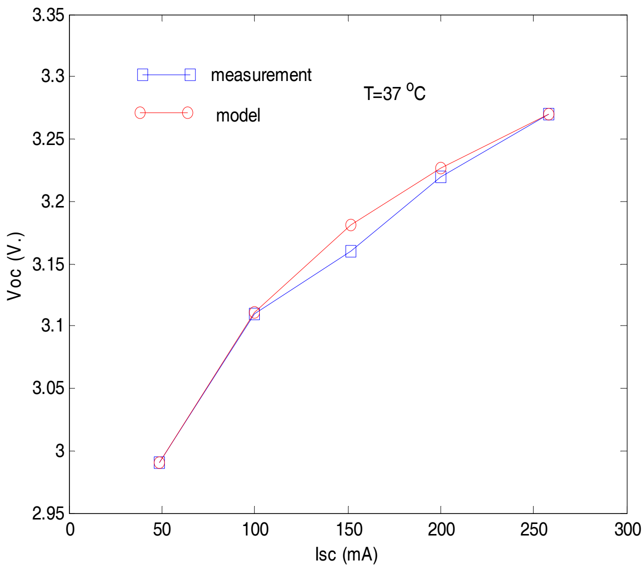


**Figure 4.** $I_{sc}$-$V_{oc}$ curve at T=37°C.

According to these tests, I-V characteristic of the PV panel can be modelled by (6) for given $I_{sc}$ and T values. In (6) the $V_{oc}$ , is defined by the expression in (5).

$$I = I_{sc} - I_{sc}.e^{K_p.(\frac{V}{V_{oc}}-1)} \quad (6)$$

The $K_p$ is a coefficient that enables the characteristic of the model to pass near maximum power region in a measured reference I-V curve under an irradiance level condition at $I_{sc}$=258 mA, $V_{oc}$=3.27 V and T=37 °C. For different irradiance (or $I_{sc}$ values) levels and temperatures, the $K_p$ is constant in the modelling. In the study, the $K_p$ is 12.9432 for our PV panel.

Figure 5 shows both measured and model I-V curves of the PV panel under sampled different irradiance levels at T=37 °C.

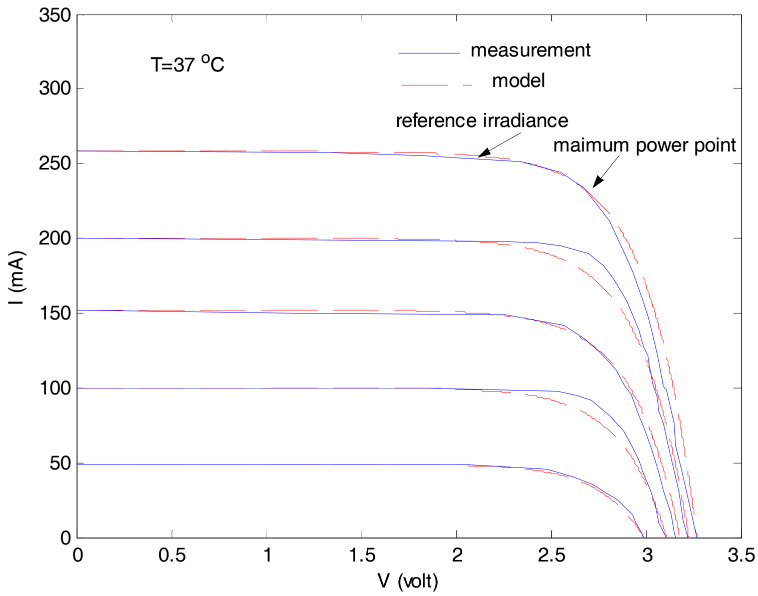


**Figure 5.** I-V curves of measurement and model for our PV panel

## 5. Tests on PEM Type Electrolyser

The input I-V characteristic (response) of PEM type electrolyser is measured using an adjustable power source. Input currents are defined at different applied voltages (0-2 V.) In this characteristic, there is a critical voltage at which the current flow starts. According to this test, input characteristic of the PEM electrolyser is modelled by (7). Characteristics of experimental and model are given in Figure 6.

$$I = \begin{bmatrix} 0 & V < 1.49 \\ 40 + 3064.5.(V - 1.49) & V > 1.49 \end{bmatrix} \text{(mA)} \quad (7)$$

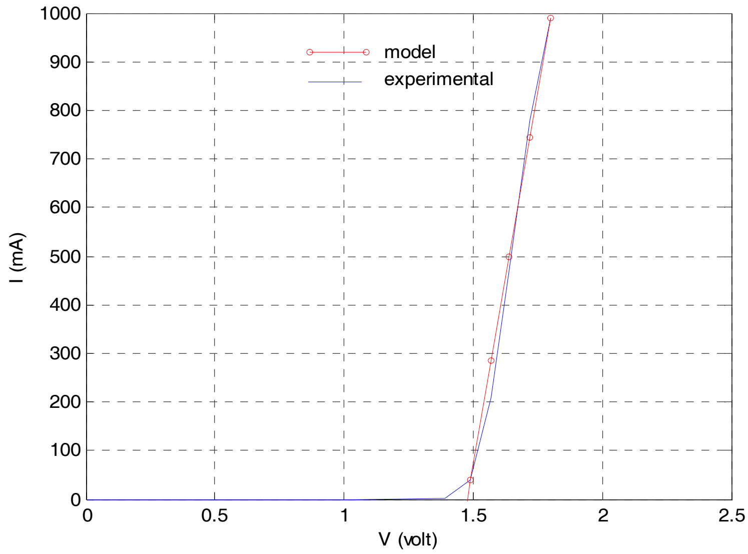


**Figure 6.** Input I-V characteristics of the PEM electrolyser for measurement and model

The rate of hydrogen formation (ml/min) is noted down according to input power (V.I=watt). Figure 7 shows the variation of rate of hydrogen formation with the input power.

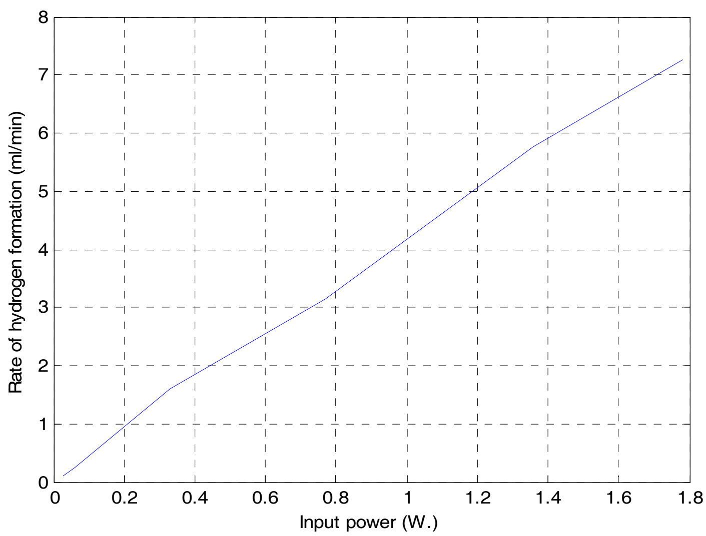


**Figure 7.** The rate of hydrogen formation versus input power

## 6. Operation of Electrolyser with Wind and PV Sets

The PEM electrolyser is fed by wind generator or PV panel for hydrogen production. Operating points of the electrolyser are measured and also can be predicted by general system modelling for different wind speeds and irradiance levels. PEM electrolyser operates at intersection points between output I-V curves of the renewable source and input I-V characteristic of the electrolyser. Model equations of wind, PV and electrolyser sets, are defined in MATLAB/Simulink program for prediction analysis. Fig.8 and Fig.9 show Simulink models for wind and PV system respectively.

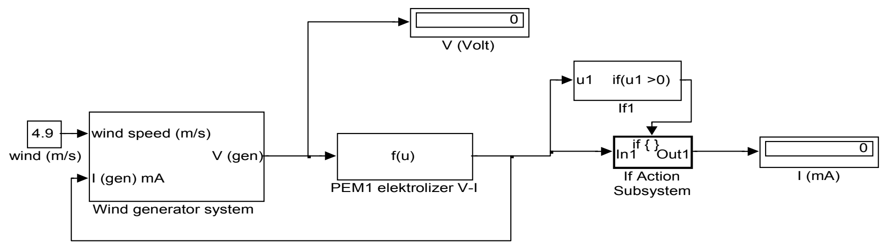


**Figure 8.** Wind generator- PEM electrolyser system in the Simulink

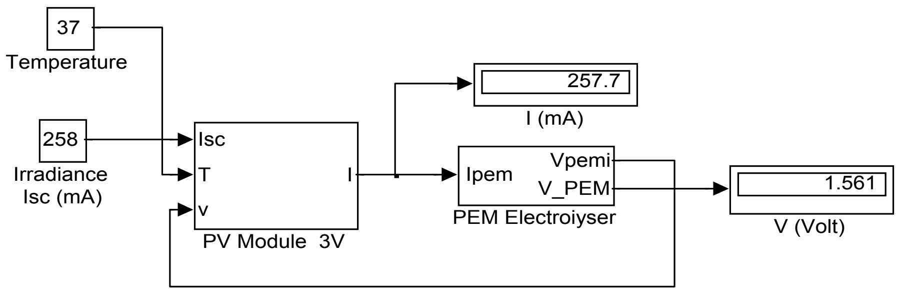


**Figure 9.** PV panel- PEM electrolyser system in the Simulink

According to analysis results, both measured and predicted operating points are given in Fig.10 and Fig.11 for wind and PV panel sets respectively. Also these figures show that, operating points of the electrolyser match electrolyser response characteristic to the input. The relative errors between measurement and model are very small. From these operating points, rate of hydrogen formations can be predicted according to wind speeds and irradiance levels.

## 7. Conclusion

An educational experiment set is prepared for renewable energy applications. Experimental data on wind generator, PV panel and PEM electrolyser kits are defined and then each kit is modelled separately. For hydrogen production, electrolyser is operated with wind and PV kits. To predict the operating points, general system is modelled in MATLAB/Simulink. According to model results, operating points of PEM electrolyser on the PV and wind sets are predicted with maximum1-2 % relative errors. Also wind and PV kits can be together as a hybrid system for hydrogen production. The set is portable and also it is proposed for renewable energy education.

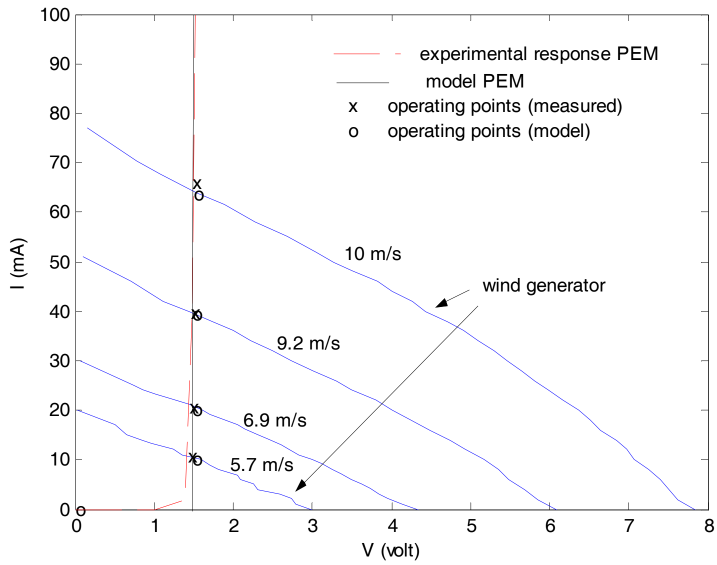


**Figure 10.** Operating points of the PEM electrolyser on the wind generator set.

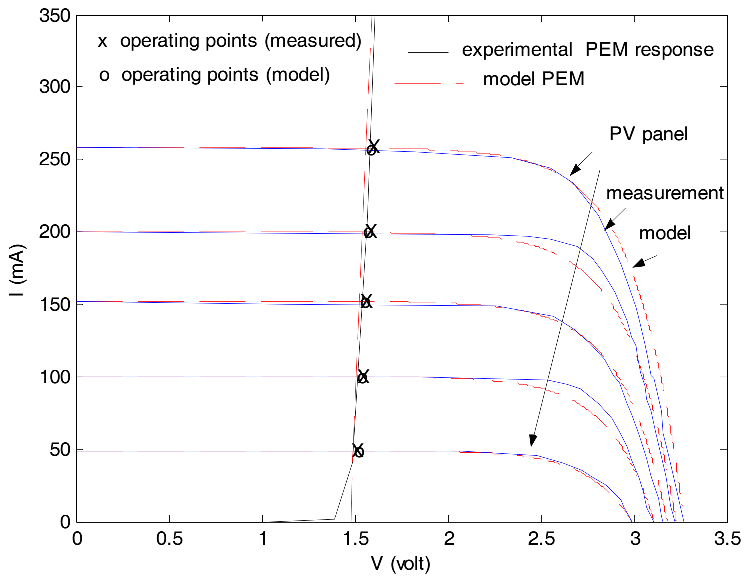


**Figure 11.** Operating points of the PEM electrolyser on the PV panel set

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# AN EFFECTIVE SET OF I.C.T. TOOLS FOR TEACHING & LEARNING OF RENEWABLE ENERGY SYSTEMS (RES)

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## Abstract
The paper describes the features of the e-Learning approaches designed, developed and introduced in the Mechanical Engineering Curriculum of the T.E.I. of Patra, Greece and specifically in the R.E.S. courses. It discusses the needs of the target groups-clients (students, lecturers, others) that should be satisfied. An attempt is made to present the e-courses in a modular way, so that web based applications are effectively and friendly available, while users' needs, log files etc. are easily managed. Finally, the paper discusses the level of friendliness to the user and the manager of the three types of ICT tools, the load paid to reach a high performance level for the e-courses, and for a thorough e-system with adequate information to sustain and support a wide spectrum of requirements for RES Teaching and Learning.

## 1. Introduction
Since year 2000, the Mechanical Engineering department of the TEI of Patra, has been involved in several projects concerning the introduction of I.C.T. tools in the Teaching & Learning process of its curriculum with special emphasis to RES. The target was to encourage staff members and students to collaborate and build an efficient, effective and flexible e-learning environment for Teaching and Learning, that could trigger students self-learning process and improve their talent and skills to search and innovate. The main projects which gave a significant impact were:

1. the **e- library** project [1], concerning the development of a friendly to use I.C.T. tool, serving as a library and as a teaching and learning tool in general. The R.E.S. was its pilot topic. The project was funded by the Greek Ministry of Education Operational Programme EPEAEK, and its section Upgrading Library Services.
2. The development of a **C.D.A.** project (Advanced Curriculum Development) titled "Solar Energy: Technology and Management". It was funded by the E.C. SOCRATES Program, 2000-2003 [2, 3]. This project whose output is outlined in http://solar-net.teipat.gr has adopted that the e-learning tools should be integrated in the curriculum, developed as such at MSc level.
3. The L.d.V. project titled "ICT tools in R.E.S Teaching & Learning" [4]. This project designed, developed and tested e-material for R.E.S. Target groups were: professionals, authorities or individuals, distinguished into 3 discrete levels of comprehension, expertise and interests; which are Basic, Design and Advanced levels.
4. The Intensive Programme "ICT tools in PV systems: Teaching & Learning" funded by E.C. SOCRATES Programme; see www.teipat.gr/socrates-ip2006. and http://solar-net.teipat.gr This is a 3 year project 2003-2006. The project's objective was to develop a scheme with a combination of conventional and e-Learning tools, using on-line course transmission, or tele-education.
5. The project "Improvement of Mech. Engineering undergraduate Curriculum by introducing I.C.T. tools". This is an on-going project, since 2004, funded by the EPEAEK Operational Programme.

Qualitative Issues on the ICT tools Developed and Used in the R.E.S Curriculum

The concept of e-Learning is one of the key issues discussed in high political documents such as:

- the White Papers on ‘Open and Distance Learning’ [5]
- on the ‘Knowledge Society’ [6, 7]
- the Educational and Training programs of the E.C. SOCRATES and LEONARDO da VINCI, as well as the DELTA program, in the past [8]

The deployment of these projects on the development and use of I.C.T. tools and e-technologies, in general, give a clear picture of the policy put forward by the Mech. Engineering Dept. and especially the R.E.S. Lab of the TEI of Patra. The common position is that I.C.T. tools may largely contribute to build an e-Learning environment structured in a way that is intelligently convolved with the conventional methods. This effort has forged a multi-lateral and multi-dimensional policy in which e-tools are used by lecturers, students and trainees in a balanced way according to the curriculum objectives and the teacher/learner needs, as well as on their interests and talents.

The whole Teaching & Learning environment in the domain of R.E.S. with e-tools as a major factor, satisfies the requirements set by all players, services recipients, and stake holders on:

1. the effective management of the educational objectives of the curriculum
2. the training objectives, as diversified for the various target groups the Curriculum is addressed to.
3. Research and innovation issues, as the combination of the e-library with the ever updated e-lectures, see www.teipat.gr/socrates-ip2006, provide a dynamic tool to the learner to master the new subjects, methodologies and technological developments, while developing searching ability.
4. The effective integration of foreign students in the R.E.S Lab and Curriculum, as the e-platform http://eclass.gunet.teipat.gr includes an English version of the lectures and Case Studies. Thus, the I.C.T. tools bear an added value, in favour of the students mobility to countries of the least spoken languages, since the e-tools described above may be customized to the learners’ needs, while being embedded in the Department’s educational/training learning strategy. The rich experience acquired all these years in the R.E.S curricula is to be presented below along with some data.

The ICT tools developed either within an e-library form or in an e-learning platform, or as independent tools, addressed to learning sub-processes, such as:

- Information & Communication Interactivity between trainees & trainers
- Tests, marking and tutoring by distance
- e-lecturing
- case studies and similar issues
- bibliography and additional available software for use by students
- e-learning in a class (via LAN), problem solving or other explanatory/ introductory affairs
- comprehensive presentation of complex engineering systems using photos, animation, videos, demos etc.
- virtual laboratories or virtual plant environment

All these may work at synchronous and/or asynchronous modes. However our e-learning strategy was targeted to serve the asynchronous mode.

## 2. The Development and Use of the e-Learning Tools

The policy for the introduction and integration of e-tools promotes the e-learning environment per RES course using various ICT tools developed by mixed working groups which consist of lecturer(s), e-expert(s), student(s) familiar to e-tools who join the groups.

A variety of ICT tools are available now:

1. An e-library on RES: Solar Thermal Engineering, PV, Wind, Hydro etc., whose operational structure is shown at the site: www.lib.teipat.gr. For the case of major issues, a menu offers a set of items to be answered in a way that the learners become masters of the topics via web navigation:
   - Definition
   - Description; photos, diagrams, tables etc.
   - Measurements: methodologies, measurement devices, specifications
   - Impact and Management
   - E.U. Policy
   - Economic aspects
   - Examples, elaborated, case studies, design and sizing aspects for a variety of applications
   - Pilot or demonstration projects per case, applications in several fields
   - References
   - Other

2. An e-learning approach based on an e-platform: http://eclass.gunet.gr. This e-learning platform is the **eclass** as modified into the Greek language from the Claroline University e-platform offered as an open source. Each e-course consists of the e-docs to meet of the main or key topics. The main set of e-activities in this platform are a set of questions, exercises, tests for students, announcements, links, case studies. Such a version of the eclass was prepared with the collaboration of the university of Blagoevgrad, Bulgaria (www.swu.bg), that has given a much flexible version of the eclass.

3. A new e-platform was designed and uploaded at the site http://epeaekres.teipat.gr/eplat/ This was jointly developed and designed by the ICT (Institute of Computer Technology) of Patra. The e-approaches in 1, 2 and 3 differ in the several aspects clarified below.

   <u>The e-library:</u> offers itself for learning during a conventional course. In addition, due to deep linking, the user while in the text, may reflect directly and click on keywords where a window provides information, data, examples and other information loaded, thus providing a complete understanding of basic modules.
   <u>The eclass platform:</u> The e-courses uploaded in GU-net http://eclass.gunet.gr, are of the e-reading style while links are off text. This approach does not really simulate the learning process. However, this e-platform is quite easily accessed. In time, as more users visited the eclass, there was developed more e-material according to their needs which in this case are the case studies and RES applications. In short, it has offered a creative e-environment.

   <u>The epeaekres e-platform:</u> The management of the epeaekres e-Learning platform is done through a server hosted in the Renewable Energies Lab of the T.E.I. of

Patra. Users may enter through the web server. The system's basic parts are the Data Base, which manages the e-material, the system's and users' data, the log files etc., and the web based applications provided via a server. The platform supports three levels of users the Administrator, the Tutor/Lecturer, and the Student/Learner. The learning ICT tools provided for each course are shown in the main page in the site. Such ICT tools are: Chats, Glossary, Labels, Assignments, Record of activities, Sources, Selection, Quiz – multiple choice Q/A. One may select from the popup menu more activities available in it, to make the learning process more interesting and dynamic. System's processes according to the three types of users are given in the Table I below.

4. Three CDs (handed to students/learners) with advanced issues on PV technology and R.E.S. in general. The Cds include lectures, software, special Case Studies, Good Practice projects and various field applications of the R.E.S.

**Table 1.** System processes for ther 3 types of users of the epeaekres e-platform

| Student | Teacher | Administrator |
|---|---|---|
| Reads and/or prints parts of teaching material | Reads and/or prints parts of teaching material | Performs all the activities students and teachers perform |
| Exchanges messages using Forum and Chat | Adds and changes parts of teaching material | He is responsible for all the modulations of the e-platform |
| Downloads documents, useful material for the lesson | Exchanges messages using Forum and Chat | Defines the teachers and the creators of the lessons |
| He/she is informed about the activities of the lesson | Adds and watches the announcements | Creates and manages categories of lessons and categorizes the lessons |
| Manages the lessons he/she is registered in | Enriches the glossary | Defines the roles of every user of the system |
| Sees the connected users in the lessons and the platform | Controls the movements of the students in the platform | Keeps safety copies for the e-platform |
| Uploads documents, projects | Manages the marks of the students | |
| | Keeps safety copies of the lesson | |
| | Accepts or rejects students in the lesson | |
| | Defines assistants for the lesson | |
| | Defines new web meetings (chat meeting) | |
| | Modifies the appearance of the pages of the lesson | |
| | Participates in the teaching team | |

## 3. Technical Requirements

The most important part of the e-platform is the one of the central server, located in the RES Lab of the TEI of Patra. The technical specifications must conform with:

- Operational System: Windows (2003 Server XP-2000) or Linux.
- Web Server Software: Apache or any other which supports PHP as the IIS of Windows.
- PHP support (edition , at least, 4.1.0)
- Data Base Server: MySQL, at least 4.1.16

A remote user should have web connection and installed a web navigation, such as Microsoft Internet explorer, Mozilla, Netscape Navigator, Opera etc.
Table II below gives a summary of the technical terms to be satisfied by the e-approaches.

**Table 2.** A summary of technical specifications for the optimum solution.

| The Optimum Solution | |
|---|---|
| **CPU** | Dual Processor Intel XEON 3.2GHz |
| **RAM** | 2000 MB |
| **Hard disc** | 4.8 GB HDD |
| **Drive** | CD-ROM or DVD-ROM |
| **Network card** | Ethernet network interface |
| Least Requirements | |
| **CPU** | >550 Hz |
| **RAM** | >384 MB |
| **Hard disc** | >4 GB |
| **Drive** | CD-ROM or DVD-ROM |
| **Network card** | Ethernet network interface |

## 4. Discussion and Conclusions

The three e-approaches and the complete set of ICT tools are available to be used by two RES courses and one Intensive course, in Greek and in English. Lecturers within the e-working group felt confident enough, although not e-experts and developed the e-material in collaboration with 4 students who joined the working groups. The new technologies triggered the learning senses. In 4 years more than 11500 entries are recorded in the e-library, while the number of those subscribed to the eclass and the epeaekres is increasing.

An assesment of the main avenues of the e-tools developed concludes that the e-library and the new e-plattform (epeaekres) developed initially for the Renewable Energy Systems are friendly and handable. The e-library is more sophisticated in structure and needs a permanent development group. More skillful staff is required to manage and develop it. On the other hand, the epeaekres platform can be more easily managed. It is more professional and lecturers may easily handle all its available ICT tools. As the users of the e-approaches have increased, the updating in e-material comes often and a permanent management group is required. The whole e-environment is efficient and effective [9, 10].

The benefits drawn are:

- The RES Lab of the TEI of Patra, is e-active, and this has contributed to receive more foreign students, while on the other hand this policy opened new collaboration schemes in SOCRATES [11], Leonardo Da Vinci and other E.C. e-projects.

- Students play and learn, especially, when projects and assignments are concerned.
- Exploration: dynamic, transparent, especially in the epeaekres e-platform which monitors the learning path of each one registered in it.
- Repeatability: student is welcome to read as many times the e-text and use all possible navigation paths towards the objective of the task or assignment undertaken.
- chat, etc.

Students are actively involved in the Learning efforts by:

a. using the explporation dynamism of the I.C.T. tools for deeper understanding and analysis.
b. working in an education environment where conventional and e-tools offer a pluralism in the learning tools which may well be adopted to each learner's interests and talent.

The new e-platform is certainly more dynamic and provides many more friendly and useful tools for effective learning and assessment. It provides an overall T & L management system.

The pluralism of the ICT tools does not allow students to get bored. "Traveling exploration" in the www is a fascinating learning process. However time mis-management by the learner might occur if self-control is not tried. In general the e-approaches create an enthusiasm and the newness and owness feeling which has a weighted impact towards effective learning.

## Acknowledgements

The authors express their appreciation to the EPEAEK programme of the Greek Ministry of Education, on the "Improvement of Mech. Engineering Curricula by the Introduction of I.C.T. tools", which funded the project and gave the opportunities to explore more on the benefits and the empowerment of the Learning process through e-technologies.

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SOCRATES programme: Community Action Programme adopted 15 March 1995.

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[3] C.D.A. Development of Advanced Curriculum; a sub- programme within the SOCRATES –ERASMUS E.C. Action Programme. Its target was to bring H.E.I.s from the eligible European countries to work together to develop curricula at M.Sc level.

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[6] http://www.prometeus.org

[7] The *e*Learning Action Plan, Designing tomorrow's education, Brussels, March 2001.

[8] Delta programme: Telematic Systems for Flexible and Distance Learning. European Commission, March 1992.

[9] Strategy, Planning and Effective Funding for the Universities & the H.E.I. in Europe, Prof. S. Kaplanis, member of SOCRATES, Sub-Committee for Higher Education, Patra 28 June 1997.
Efficiency = Resources actually used
a. Resources planed to be used
Effectivity = Actual output
b. Expected output

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# A GIS WEB – APPLICATION FOR POWER SYSTEM OF CRETE

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## Abstract
Geographical Information System (GIS) applications are very helpful tools for displaying and analyzing information for several technological fields. The research group of Electrical Power System Lab (EPSL) of TEIC is developing a GIS software application for displaying the operational conditions of the power system of Crete, presenting also critical information and statistical data for system's characteristics. This work is a part of a project which is co-funded by the European Social Fund and Greek National Resources, "EPEAEK II – ARXIMIDES". This tool is intended to help training of engineers in the Electrical Department of TEIC to simulate and visualize power system operation and characteristics. Besides, this tool is very helpful for a power system engineer in observing the whole system operations and system's data. All data used are derived from a database developed by EPSL. This database includes electrical and operational characteristics such as generating plant, substation, transformers, transmission-distribution lines, cables, wind parks, substation's load and unit's power production recordings etc. Digitalized maps of Crete Island use this data and display them optionally according to user's demand or choice. So, an authorized user can decide which data will be displayed on the map, and with a simple mouse click on a selected element of the map he can b informed about its characteristics. Furthermore, this application is being uploaded on web. This means that this application runs on a server of EPSL,ehich can serve distant users after authorization procedure. That distance user could be a trainee in his desk, o am engineer, or a researcher in the lab. One of the services that this application provide is the load flow calculation on a specific part of the system, or for a specific scenario of system's operation.

**Keywords**: GIS applications, Power Systems observation, power systems web-applications

## 1. Introduction
Crete's electrical power system is a large autonomous system with large wind power penetration. The customer's power & energy demand is increasing with high rates. The operation of the whole system is in charge of the Greek PPC (public power corporation) control center, located in Iraklion, where a SCADA system has been installed. In terms of integration of dispersed generation new methods and computer applications are adopted toward adaptation of the critical information of system's operational conditions. Mapping and Geographic Information Systems (GIS) are key to a utility's business. These software applications store and map a vast amount of information about the utility's electric system and other outside plants. People and applications across the organization typically require information from the GIS.

The benefits of adaptation of a GIS for a power system are many. Descriptive presentation of data (graphics, maps, tables etc) and presentation of data in real space are offered. They offer, also, convenience concerning data processing since, as well as to examine them in different layers. It analyzes and presents information related to spatial places. It can combine elements – data from digital data base, GPS for concerning the specific definition of places, sampling and distant measurements. The relation between the data basis and the maps give the chance to the user to interact with the system of an interactive communication between the user and the system. Moreover many data basis can be connected and combined improving the flexibility of the system.

Using specific tools of software design (like map objects) we can display the results of a load flow test on the digital map of Crete.

It's possible to use GIS to define the number of people as well as forecast of load demand. Further more if we know the density (people, space) we can rate the places per load demand.

The amount of data can be presented on maps for a quick estimation of the network-system operational condition.

The GIS can observe external factors such as weather conditions. For example if we know the temperature of an area, we're able to predict the load demand there, for the next hours.

GIS is a helpful tool for new types of energy management.

## 2. System Modelling - Technical Information

**2.1 Power Production**

The power system of the island of Crete is the largest autonomous power system in Greece with the highest rate of increase nation-wide in energy and power demand. The conventional generation system consists of three major power plants one in Linoperamata, one in Chania and one in Atherinolakos (the latest). The first two power plants are located near the major load points of the island. There are 20 thermal, oil-fired generating units with a total installed capacity of about 742 MW.

The power system comprises the following power stations:

- Six steam turbines in Linoperamata
- Four diesel engines in Linoperamata
- Four gas turbines in Linoperamata & five gas turbines in Chania.
- One combined cycle in Chania of 133.4 MW (2 gas turbines and 1 steam turbine)
- Two diesel engines in Atherinolakos

**2.2 Load demand**

The base load is mainly supplied by the steam and diesel units. The gas turbines normally supply the daily peak load. Until 1988 the annual peak load demand always occurred in winter, from then on it always appears in summer evenings. Figure1 shows the increase of energy demand and peak load since 1964. One characteristic of the load profile is the large variations (low night valleys – high evening peaks). Gas turbines have a high operating cost that increases significantly the average cost of electricity being supplied.

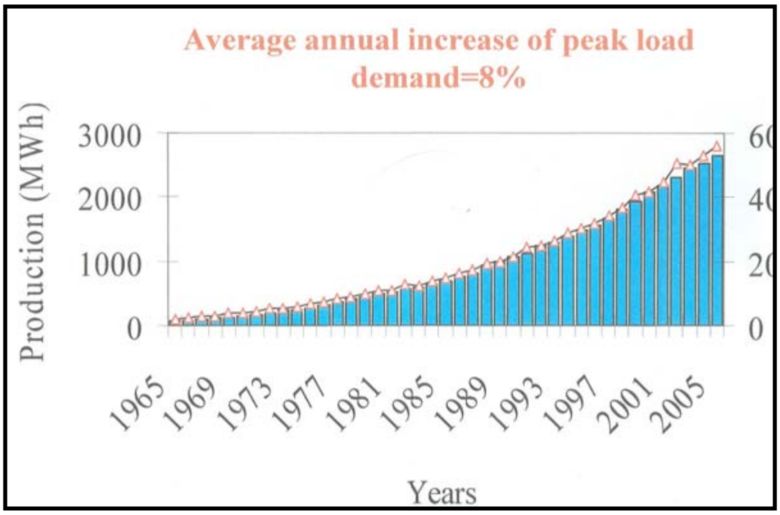


**Figure 1.** increase of energy and peak load demand

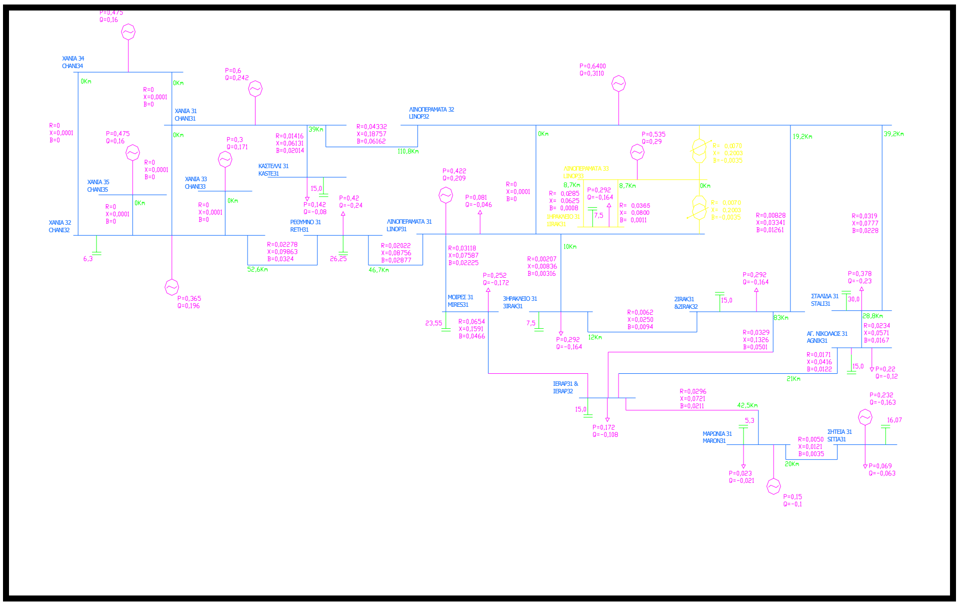

**Figure 2.** Single–line drawing of 150kV power system

### 2.3 Transmission system

The transmission network (Figure 2) consists mainly of 150 kV lines. There are only 2 lines of 66kV from Linop33 (production sub) to 1Irak31 (substation). The distribution network consists of 20 kV (21 kV) and 15 kV (15.75 kV) lines. The generation system and the transmission network are supervised by a control center located in one of the substations in Iraklio (2IRAK), using a SCADA system.

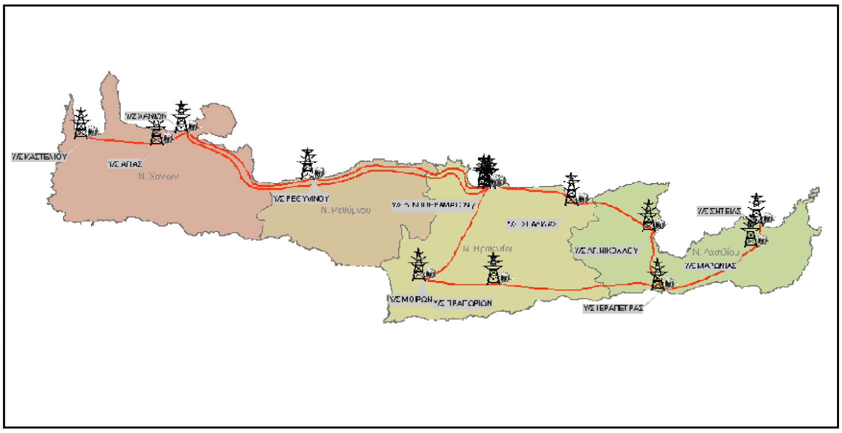


**Figure 3.** Single–line drawing of 150kV power system on the map of Crete

**2.4 Wind Parks**

A number of Wind Parks (WPs) have been installed in Crete since 1995 of total capacity of up to 134.7 MW and there are plans for more WPs in the next years. The peak wind penetration was up to 41.2%, and in kWh 12%. Most of the wind parks have been installed at the eastern part of the island (Sitia) that presents the most favourable wind conditions. As a result, in case of faults on some particular lines, the majority of the wind parks will be disconnected.

Furthermore, the protections of the WPs might be activated in case of frequency variations, decreasing additionally the dynamic stability of the system. Extensive transient analysis studies have therefore been conducted in order to assess the dynamic behaviour of the system under various disturbances and with different combinations of the generating units.

**2.5 Technical constraints**

The start up preparation time of a generator depends on its type. The gas turbines require 6-12 minutes for preparation. The steam turbines require 1-2 hours in 'hot' state, and 8 or more hours for the 'cold' state. The diesels require about 20 minutes. In addition, the increase rate of power of each generator also depends on its type. For the steam turbines is low. For the gas turbines it is 16-17 MW/min. Diesel' s rate is also high, as they react rapidly to load variations. In order to avoid undesirable frequency increase, the generator is at its technical minimum when it is connected to the system.One of the biggest problems of the system is the high fuel cost. Gas turbines consume diesel oil which is expensive and increases the energy cost per KWh. Steam turbines and diesel engines consume crude oil. (diesel engines consume diesel oil only at the start up state and the stop state) Diesel engines, steam turbines and wind parks reduce the cost per kWh.

## 3. Creation of GIS

The first part of this project was the creation of GIS maps that represent the Electrical Power System of Crete. For this reason we created a Geographical Information System (GIS) using ArcGIS and Microsoft Access. Using ArcGIS and

Microsoft Access we represented substations, transmission lines, renewable sources, power plants of Crete presented over a digitized map.

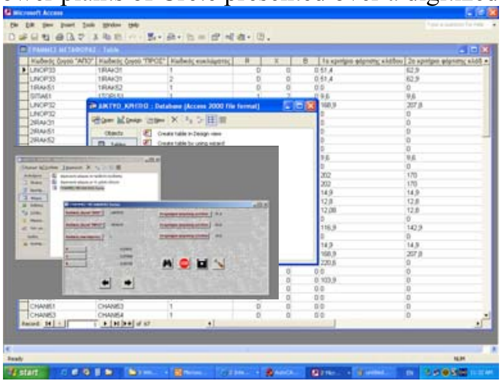

**Figure 4.** The access data base for Crete power system

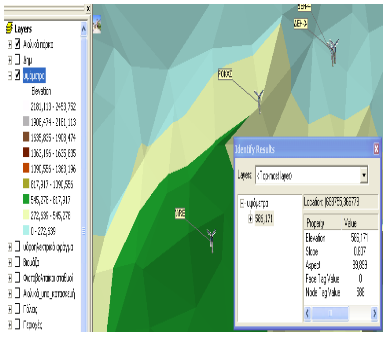

**Figure 5.** Detailed Geographical data for Wind Park

After the completion of the first part of the project, the result was the creation of digitalized maps of Crete where the user can work with, using programs such as ArcGIS or other similar programs. One simple program which presents system's data is cmd01 (Fig.7). It has been developed by EPSL using ESRI's map objects. The user chooses the layers (data) he wants to be displayed on the map of Crete. He can also zoom in or zoom out in order to observe the desired area of the network.

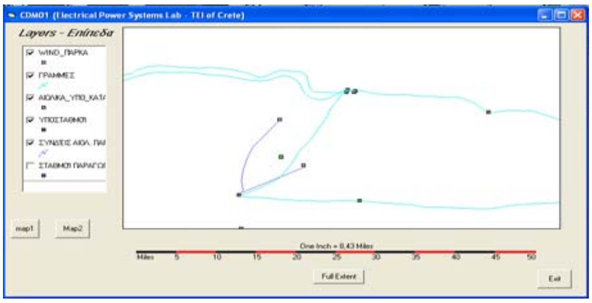


**Figure 6.** The cmd01 GIS application (Based on map objects)

## 4. Web Part

On the second part of this project our aim was to transform the digitized maps that were created with the use of ARCGIS in a format that can be viewed in Web. For this reason we used technologies such as Apache, MySQl and SVG (Scalable Vector Graphics).

We developed a Web server on a Linux SuSe 10.0 Server where Apache Web Server was installed.

The second step was to import the database that was analyzed in step 1 from windows access to MySQL. The choice for MySQL was based on the fact that is a database capable to work on Web environment.

The third step was the transformation of GIS maps in a format that can be viewed in Web explorers. Our choice was by default SVG. SVG is a platform for two-dimensional graphics. It has two parts: an XML-based file format and a programming API for graphical applications. Key features include shapes, text and embedded raster graphics, with many different painting styles. It supports scripting through languages such as ECMAScript and has comprehensive support for animation.

SVG is used in many business areas including Web graphics, animation, user interfaces, graphics interchange, print and hardcopy output, mobile applications and high-quality design.

SVG is a royalty-free vendor-neutral open standard developed under the W3C Process. It has strong industry support; Authors of the SVG specification include Adobe, Agfa, Apple, Canon, Corel, Ericsson, HP, IBM, Kodak, Macromedia, Microsoft, Nokia, Sharp and Sun Microsystems. SVG viewers are deployed to over 100 million desktops, and there is a broad range of support in many authoring tools. SVG builds upon many other successful standards such as XML (SVG graphics are text-based and thus easy to create), JPEG and PNG for image formats, DOM for scripting and interactivity, SMIL for animation and CSS for styling.

SVG is interoperable. The W3C release a test suite and implementation results to ensure conformance.

The tool that was used to transform the GIS maps to SVG format was the MapViewSVG from UisMedia. The result was the creation of digitized maps of the Power System of Crete were a user using a Web explorer such as IE of Firefox can interact with the map and decide which parts of the Power System to be shown (Power Plants, substations etc).

## 5. Load Flow Analysis

The Last part of the project is the creation a Load Flow Analysis of the network where the user can interact with the SVG map and perform a Load flow Analysis of the power system of Crete. This application is under construction and it will be accomplished till May 2007. The Gauss-Seidel Algorithm is used and it has been performed on a simplified 9-buses model of the network.

An authorized distant user will be able to input in a appropriate form the load demand (P(MW) and Q(MVar)) data for the 9 specific high voltage buses (High Voltage/Low Voltage Substations) and generators' production. The server will execute the Gauss-Seidel load flow calculations. Results will be displayed on web, on the specific elements (substations) of the map of Crete.

The realization of the algorithm is going to be constructed using PHP and Jscript that will use the data elements of the Mysql database described above.

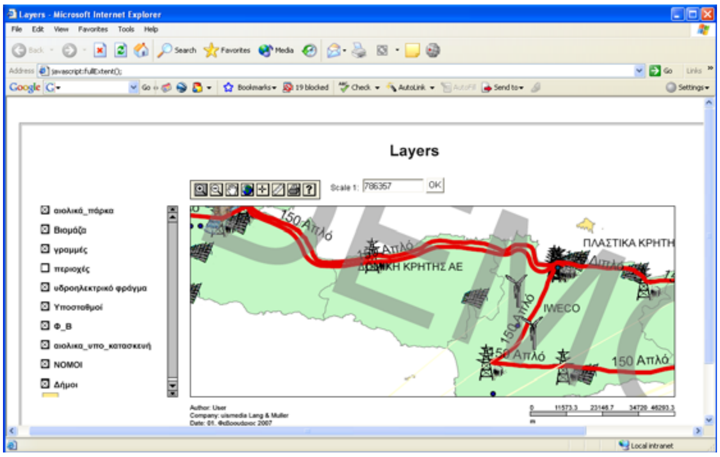


**Figure 7.** The GIS web-application for power system of Crete on a web browser (Internet Explorer)

## 6. Conclusions

GIS applications are very helpful in displaying a variety of data for power systems' characteristics and operation. EPSL has developed a database and a GIS tool for the power system of Crete. This work has been uploaded on web. Students of Electrical Department of TEI of Crete can be training on power systems' operation and can observe systems' electrical characteristics. There is a complete model of a real autonomous power system on web, featuring all related data such as transmission lines, generators, capacitors etc. Besides an authorized user can apply changes to the model in case of changes of the power system (for example new capacitors, transmission lines, substations etc).

The above mentioned system will be capable to support load flow analysis based on real data of the Crete Power System. For the end user(for example a student) there will be the capability to accomplish that Load Flow Analysis without the need to use specialized software.

## Acknowledgements

This work is a part of a project which is co-funded by the European Social Fund and Greek National Resources, "EPEAEK II – ARCHIMIDES"

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# DIAGNOSTIC REVIEW OF A BLACKOUT IN RHODES

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## Abstract

A technical review of the incident of the 21st March 2007 that began at 00:50 am leading to a two-hour duration blackout of the Rhodes island Electric Power System is made. The complete sequence of events is presented including all relevant registered operational data as well as the on-site field findings. A technical analysis of the disturbance is attempted including reasoning for the probable causes as well as the factors that contributed to the persistence of the disturbance. The system being an isolated one is particularly vulnerable to perturbations. The role of system protection is considered. The role of the wind generation during the incident is examined. Conclusions of practical importance are drawn including recommendations for corrective measures to be implemented in preventing disturbances of this kind from occurring again in the future.

## 1. Introduction

Isolated island Power Systems are of interest, from the technical point of view, in that they exhibit notable characteristics, i.e. when having considerable penetration of wind generation exhibit at times under certain conditions greater vulnerability to operation perturbations.

The electric power system of the Greek island of Rhodes is an isolated system with 234 MW installed thermal units (5 diesel, 2 steam, 4 gas turbines) plus 15 MW wind generation. However, due to some technical problems and the characteristics of the thermal generating plant, the actual capacity of thermal generation is only about 192 MW. In the year 2006 the mean average hourly generation had a peak at 192.6 MWh. This means that the system has not appreciable reserve power at all times.

In what follows the system disturbance incident of the 21st March 2007 that began at 00:50 a.m. leading to a two-hour duration blackout of the Rhodes Island Electric Power System is considered.

At the time just before the incident, the system was operating with 2 steam units at 10 MW production each (with spinning reserve 2 MW each) and 2 diesel units: one producing 6 MW (having 5 MW spinning reserve) and the other generating 12 MW (with 5 MW spinning reserve). At the same time, the wind generation stood at 12 MW. The one-line diagram of the system is shown in figure 1. The weather conditions were severe, and played a definite role at the start of the incident.

The system disturbance began with an unsymmetrical three-phase fault not involving the ground. This fault was successfully cleared. However, due to instabilities which had been triggered by protection mechanisms, the system never really recovered, gradually loosing generation, shedding appreciable load and was finally lead to a complete blackout 2 minutes and 45 seconds after the initial fault had been cleared.

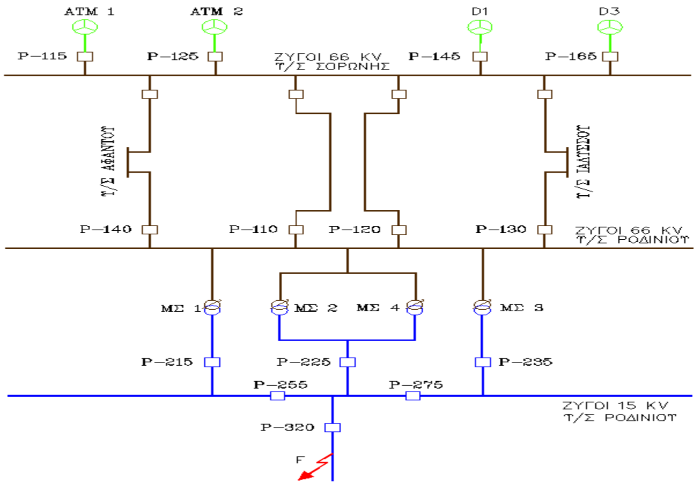



**Figure 1.** One-line diagram of the system at the start of the fault

The fault occurred on the distribution line fed by breaker P-320 at Rhodini substation – from the 15 kV bus shown in figure 1. Following the fault, the breakers P-320, P-255 and P-225 had been opened by their protection. As a result of the fault, a wooden pole of the distribution line had burned and had to be replaced later. Weather was severe at the time of the fault with strong wind bringing sea water droplets on to line insulators increasing the likelihood of a flashover. The post-mortem examination found at another wooden pole of the same distribution line the bridging-over-the-pole jumper for the middle phase conductor (in a horizontal arrangement of the 3 phases) cut. The same thing happened also to one more pole of the same line where in addition to a broken middle bridge jumper its two side porcelain insulators had also been broken. This would imply more likely that those were results of the fault current. This initial fault was finally cleared at about 13 sec after it happened. However, 19 sec after the fault clearance the steam unit # 1 was lost, and 2 min and 45 sec after the fault clearance the steam unit # 2 was lost resulting in the blackout.

## 2. Incident Analysis

At the outset one should note that the SCADA at the Control Center leaves important functionalities to be desired. As a result, real-time registration of operational is only partially possible, while in many cases significant time delays occur in data registering. Still, from judicial examination of registered events and data one is able to see the following. The fault began as an asymmetrical three phase fault not involving the ground. This was gathered by the registering of the time alternating current curves by the digital relays of the P-225, and P-255 (see figure 2) breakers which showed zero earth current. It can also be observed that the fault impedances were varying randomly with time suggesting that electric-arcing of varying span was the cause. Oscillographs 1 and 2 show the voltages at the 66 kV buses at Rhodini, and the currents at the 66 kV breaker P-110 respectively. These graphs show an oscillation developing as time progresses. Subsequent time oscillographs 3 and 4 show this (100 Hz frequency) oscillation more clearly. This oscillation is sustained to the end (as seen in oscillograph 5). This could indicate that the automatic voltage regulators are in need of adjustments.

From the voltage oscillographs one can calculate the voltage magnitude as a function of time, from the occurrence of the fault up to the voltage collapse, which is shown in Figure 3.

In the course of the disturbance wide frequency swings were registered. The respective data are shown in Figure 4. In this Figure, one can see the minimum frequency of 47.7 (2s after the start of the disturbance), and the maximum frequency of 54 Hz (16 s after the start).

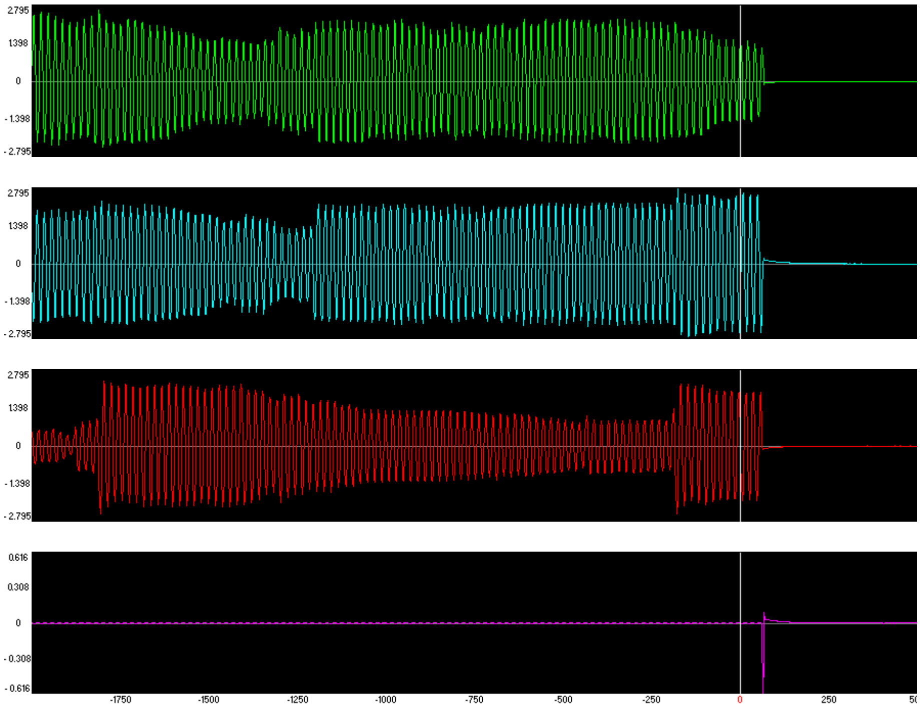
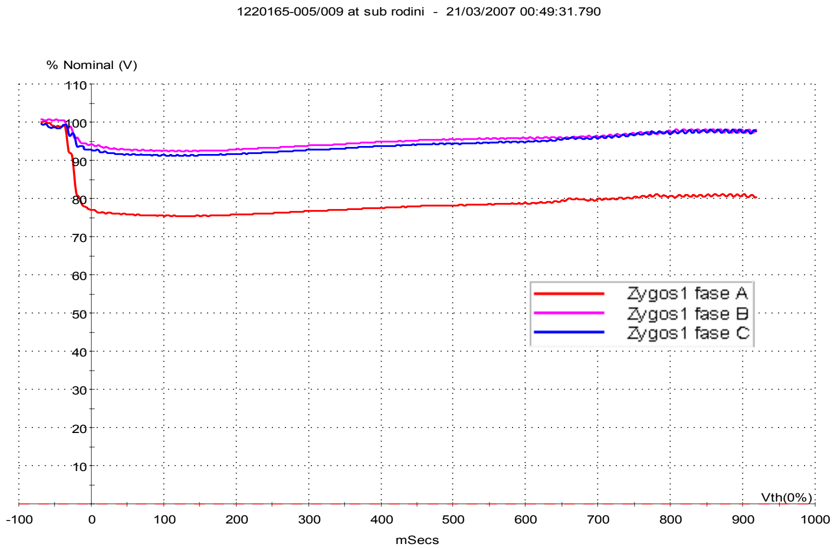


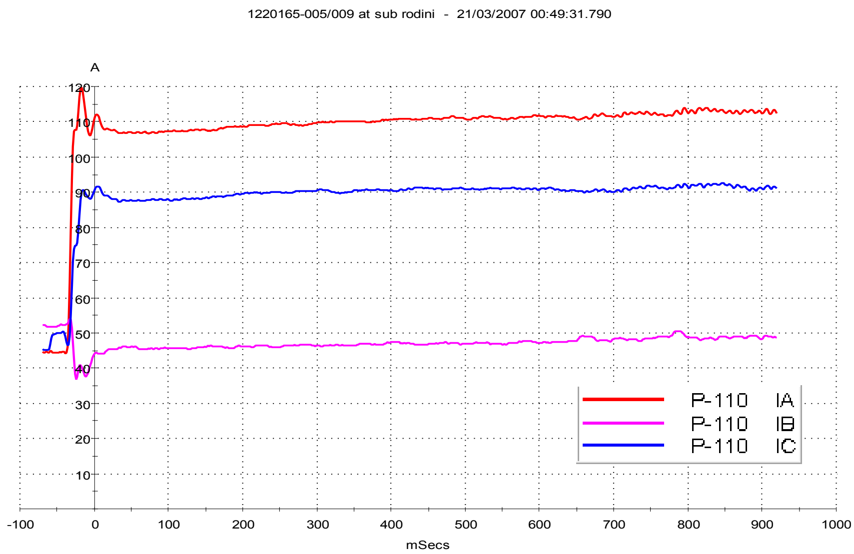
**Figure 2.** Time curves of alternating currents of phases a,b,c, ground at breaker P-255

In the course of events, three additional factors are shown to be crucial. The under-voltage protection settings for the wind park, as well as for the individual wind generators resulted in the loss of wind generation (24 % of the total generation). The under-excitation limiters protection settings of the Diesel units resulted in the loss of those units. The shedding of 40 MW of load, due to the operation of the automatic under-frequency protection, resulted in a remaining load of 10 MW fed from the steam unit # 2 in the final moments just before collapse.

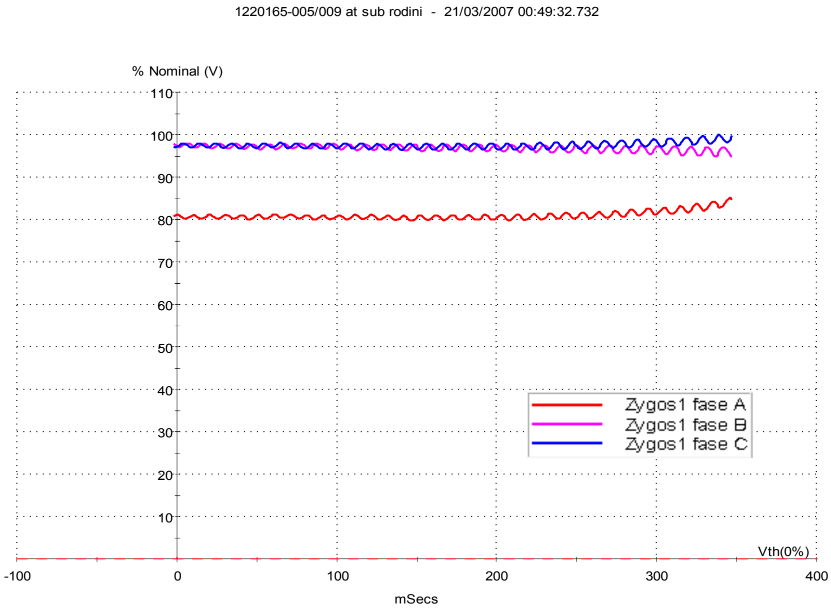
Oscillograph 1 Voltages at 66 kV bus at Rhodini (the fault begins) :



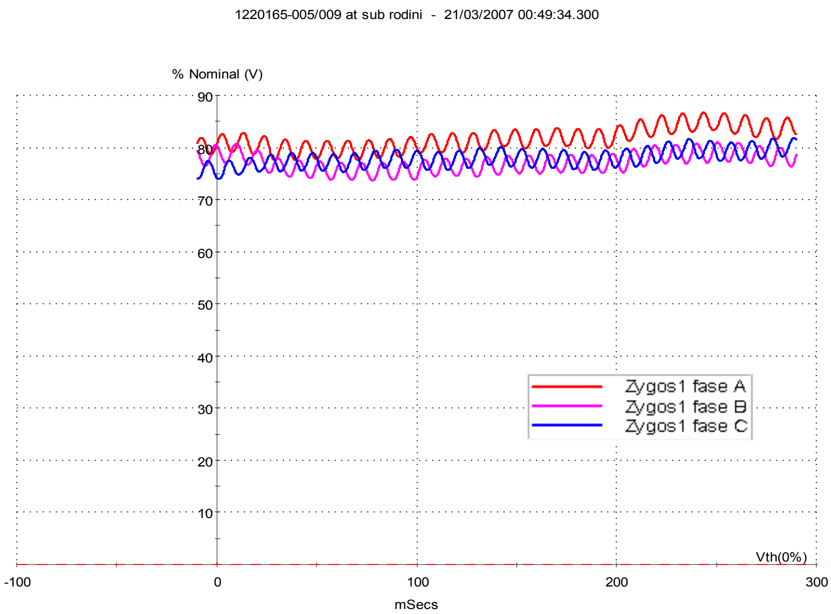

Oscillograph 2 Currents registered at 66 kV Breaker P-110 at Rhodini:



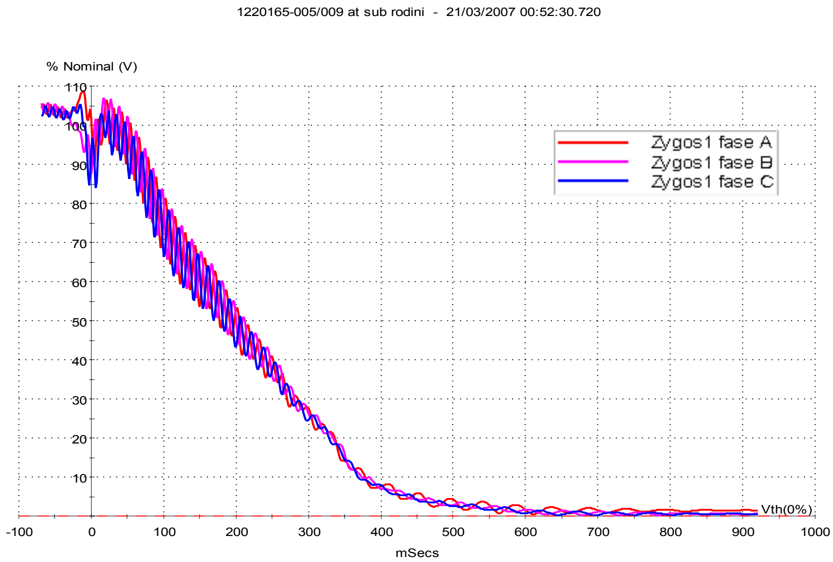
Oscillograph 3 Voltages at 66 kV at 66 kV bus Rhodini:




Oscillograph 4 Voltages at 66 kV bus Rhodini:



Oscillograph 5 Voltages at 66 kV bus Rhodini (blackout seen at the end):




## 3. Conclusions

The system of Rhodes island, as an isolated system, exhibits vulnerability to disturbances. The MV OHL distribution system, in the vicinity of the coast, is also vulnerable to the effects of sea salts that affect the reliability of insulation.

The sensitivity of wind generation to voltage swings as well as the overall system protection played a critical role in the sustained growth of the perturbation leading to the blackout.

In view of the fact that the transmission system in Rhodes island is currently considered for an upgrade from the present 66 kV to 150 kV, scheduled for the next two-to-three years, it is important that the SCADA system is upgraded, too. The protection scheme should be upgraded, also.

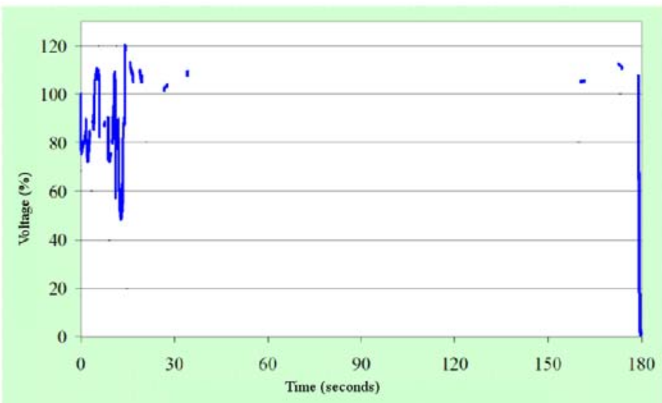



**Figure 3.** 66 kV bus Voltage variation (in %) during the disturbance

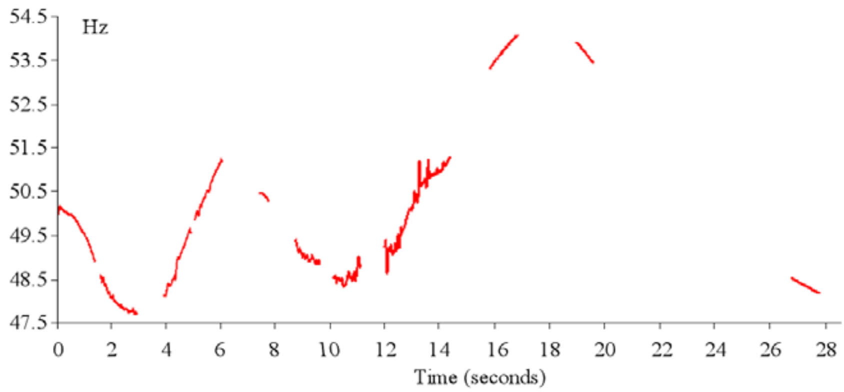



**Figure 4.** Frequency variation trend registered during the disturbance

## Acknowledgements

The first author is indebted to Michael Papazoglou, researcher at the Electric Power Systems Lab of the Technological Educational Institute of Crete, for his valuable assistance

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# REAL-TIME TRANSFORMER DYNAMIC LOADING APPLICATION-IMPLEMENTATION AND PRACTICAL USE

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## Abstract
As a part of Data Warehouse and Power Applications project, developed by Mihajlo Pupin Institute for local transmission network company EMS, the Power transformer dynamic loading (TR-LOAD) application based on RDC warehouse, was developed and implemented at regional control centre (RDC) in Belgrade. Functionality and employed mathematical model in this software subsystem will be presented in the paper. TR-LOAD application is intended to estimate possible transformer loading, taking into account all the relevant variables and constrains that influence its loading and operating temperature, for actual or supposed working (loading before all) and ambient conditions. The calculations are based on real-time and historical data, retrieved from SCADA systems and from Historical Database part of the Data Warehouse. The numerical core of these calculations is state-of-the-art and valid thermal model for HV power transformers. The subsystem has been developed utilizing modern IT concepts, client-server architecture and open-source solutions. TR-LOAD and other supporting applications, were implemented using C++ and Tcl/Tk programming languages, are executed on SCADA operator workstations under Linux operating system, where appropriate graphical user interface and application interfaces with SCADA server and Historical Database are installed, too. Finally, paper presents realistic examples of application practical use in daily power system control centre operation.

**Keywords:** Transformer loading, Transformer thermal model, Data warehouse, Utility IT applications

## 1. Introduction
The liberalization of electricity market has led to the need for more information of different kind, which could help in decision making at every hierarchical level of power system control. The requirements are mostly addressed to operational and maintenance-related data, where majority of them is collected by the control center SCADA system. Furthermore, the complexity growth in both, technical and commercial power system business, increases the needs for better utilization of existing equipment, especially, the most expensive one, thus, protecting the large investments. As a response to these demands, the transmission network system operator in Serbia, EMS, has initiated *Data Warehouse and Power Applications* (DW-PA) project, aiming to increase the availability and usability of the data from the field and also to drive several decision support type power applications. In this paper, an application within the DW-PA project is described. Namely, *Power transformer dynamic loading* (TR-LOAD) application, based on measured load data and forecasted data about environment, calculates allowed transformer load. Both, actual and recorded historical data are acquired from the SCADA system. The

calculations are provided on the basis of standardized thermal model, thus helping the system operator to use available resources optimally. Some illustrative examples from working and testing experience are, also described.

## 2. Data Warehouse System Architecture

The data warehouse solution developed for Serbian TSO RCC's is composed from the data warehouse it self and the following software subsystems:

- Data extraction and conversion
- Post-operation analysis decision support
- Operation control decision support

whose interrelations are shown in Figure 1.

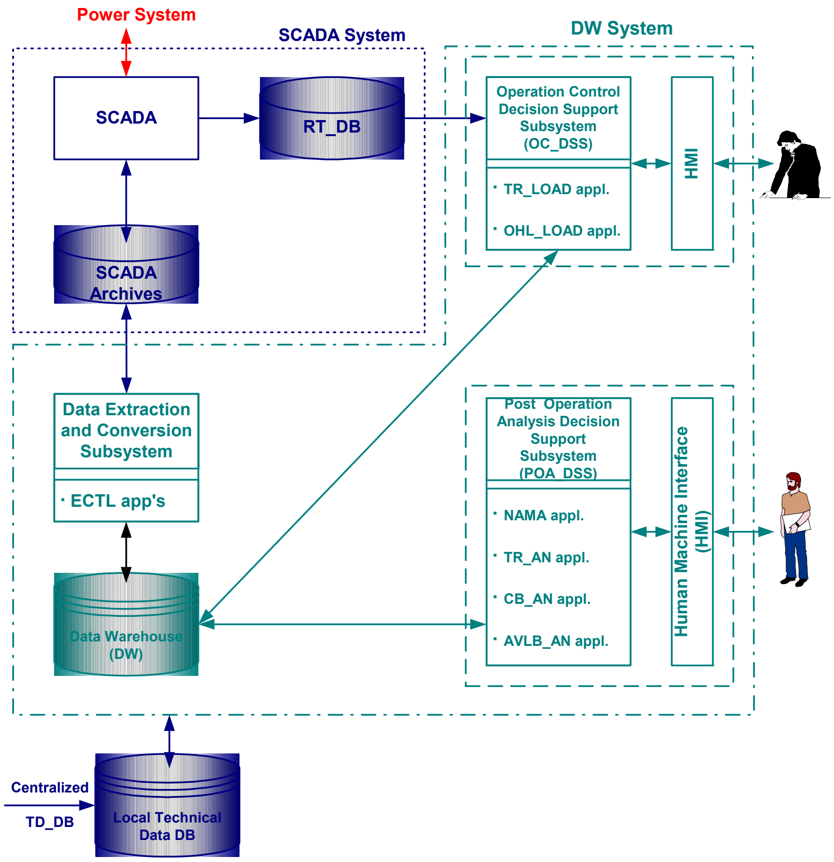


**Figure 1.** The RCC DW system architecture

The **data warehouse** represents a system's central data repository that contains all the collected operation (and some maintenance) data, their aggregations and finally, all the meta data (data about data) needed to interface the operational data sources (SCADA supplied data before all) with the DW.

**Data extraction and conversion subsystem** perform functions of the data extraction from the operation data stores (i.e. SCADA archives normally available within SCADA/EMS systems), their conversion to the required format, their transport to the new platform and load to the DW (so called ECTL function).

**Post operation analysis decision support subsystem (POA-DSS)**, based on the subject oriented data (regarding transformers, overhead lines and substations) in the DW, and performs two classes of functions. One of them implemented as a NAMA application, using historic operation data, performs different analysis tasks, with the goal to follow loading conditions, voltage profiles, ambient conditions, energies transported, external values, etc.
Other function class tracks and analyzes power system main equipment (TR, OHL, and SS) and system performance in respect of time, territory or voltage level. The subsystem is composed of the following four applications:

- Network Analog Measurements Analysis (NAMA)
- Transformer Data and OLTC Data Analysis (TR-AN)
- Circuit Breaker Data Analysis (CB-AN)
- Equipment Availability and Reliability Data Analysis (AVLB-AN)

**Operation control decision support subsystem (OC-DSS)** functions are based on the data that come from the SCADA real time database (RT-DB) and from the DW. Using suitable standard mathematical (thermal) models the subsystem performs various analysis steps with the goal to determine different quantities related to:

- Transformer Loading (TR-LOAD appl.)
- Overhead Line (OHL) Loading (OHL_LOAD appl)

These two applications are on the operators and operations planner as well disposal to support his/her decision making, regarding allowable transformer/line loading, especially during power system alert and/or emergency regimes.

## 3. Power Transformer Dynamic Loading Application

The relatively high price of the large transformers impose requirement for careful usage of their resources, in order to increase the transmission capacity and cost savings. Furthermore, in nearest future, overloading of these units could become necessary in open electricity markets due to economic reasons or simply to ensure continuous energy supply. The main problem in exploiting the transformers is the possibility to estimate allowable loading, taking into account real-life constraints and limitations, majority of these limitations are determined by their thermal state. It is well known fact that over-temperature conditions in transformers cause a loss of life of the windings insulation and, consequently, of the insulation oil. Failure to limit these temperature rises to the thermal capability of the insulation and core materials can cause premature failure of the transformer. Considering the complexity of obtaining the critical temperature values, an operable loading estimation asks for an automatization. The basic idea is to use measured data from the existing SCADA system and, based on some forecasted values for the future period and ambient conditions, to calculate allowed transformer loads.
The TR-LOAD application comprises four basic components (see Figure 2):

- Numerical application kernel, based on the relevant thermal models
- Connection with SCADA Real-time Database
- Connection with Historical Database
- Two-way Graphical User Interface

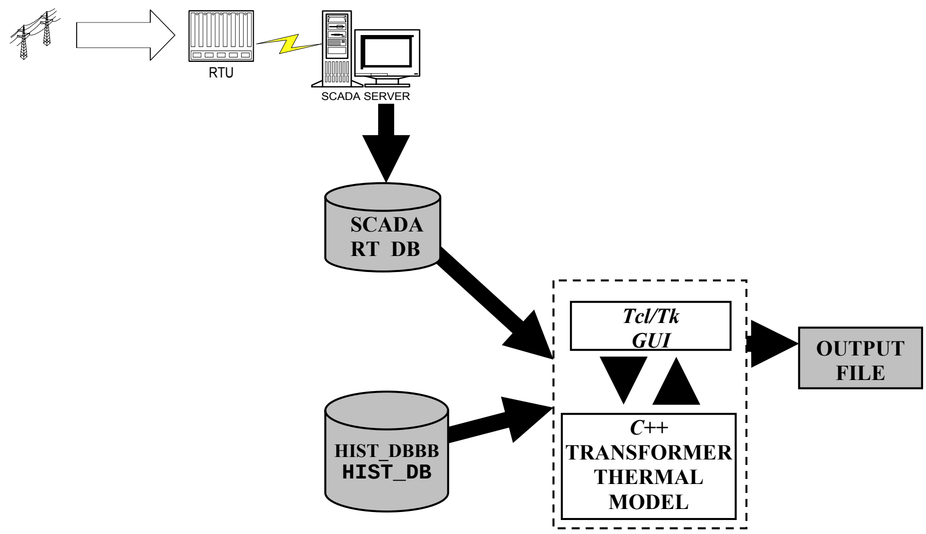


**Figure 2.** Application general architecture and position within the DW-PA

The data from the field, necessary for the calculation, are locally collected in the *Remote Terminal Units* (RTU's) by telemetry. Using some communication channel, they are, further, gathered in central stations and are placed in the *Real-time Database* (RT_DB) by the SCADA server. The applications acquire these data from RT_DB, ensuring the applications' work independency from the rest of the system. The model parameters, collected from the *Historical Database* could be, also, edited by the user. For entering the supposed and forecasted values, as well as for representing and graphically visualizing the results, the flexible Graphical User Interface (GUI) is utilized. With every application start, the output ASCII file, with all calculation results, is opened and saved. The calculations are based on state of the art, yet, practically validated thermal models of transformer. The application is realized on *Linux* platform and could be executed on *Red Hat 5.2* (or later) version. The calculation model is implemented in *C++*, while the *Tcl/Tk* script is used to realize GUI.

**3.1 Transformer Dynamic Loading Application Model**

In monitoring the thermal performance of transformers, there are two important temperatures: hot-spot, the hottest temperature spot in the transformer winding, and top-oil, temperature of the insulating oil at the top of the transformer tank. According to the IEC 60354 standard thermal model [1], implemented in the TR-LOAD application, these two variables have the same trend along the windings: they linearly rise from bottom to the top of the transform, with the constant gradient. This rise is described with the first-order model and the calculation is provided as top-oil (or hot-spot) rise over the ambient temperature for a step load change,

$$\Delta\theta_{to}(t) = (\Delta\theta_{to\infty} - \Delta\theta_{to0}) \cdot (1 - e^{-t/\tau_0}) \quad (1)$$

where $\Delta\theta_{to\infty}$ is the ultimate value, dependent on load current, and $\Delta\theta_{to0}$ is initial top-oil rise over ambient temperature. Finally, the empirical exponential expression of temperature-based transformer ageing is established.

**TR-LOAD application use**

The SCADA data, relevant for the TR-LOAD application are transformer oil temperature actual values, i.e. top-oil, ambient temperature and load current values. Application interface enables selection among substations, thus, transformers from the *Historical Database*, consequently, picking up the corresponding data from the configuration files and, finally, their inspection (Figure 3a). It is, then, enabled to enter the values for the load current and ambient temperature for the next period (up to 24h), supposing the future working conditions (Figure 3b). Based on model calculation, with actual and supposed data as input arguments, the overload capability are calculated. (The TR-LOAD application outputs are shown in Figure 3c). More specifically, TR-LOAD application enables RDC operator to calculate:

- Transformer (hot-spot or top-oil selectable) temperature in the next few hours (up to 24) based on information about actual and forecasted transformer loading and ambient conditions
- Possible transformer loading for the next few hours based on actual transformer loading and existing or forecasted ambient conditions, respecting existing constraints.
  Transformer ageing for the actual operating (loading) conditions

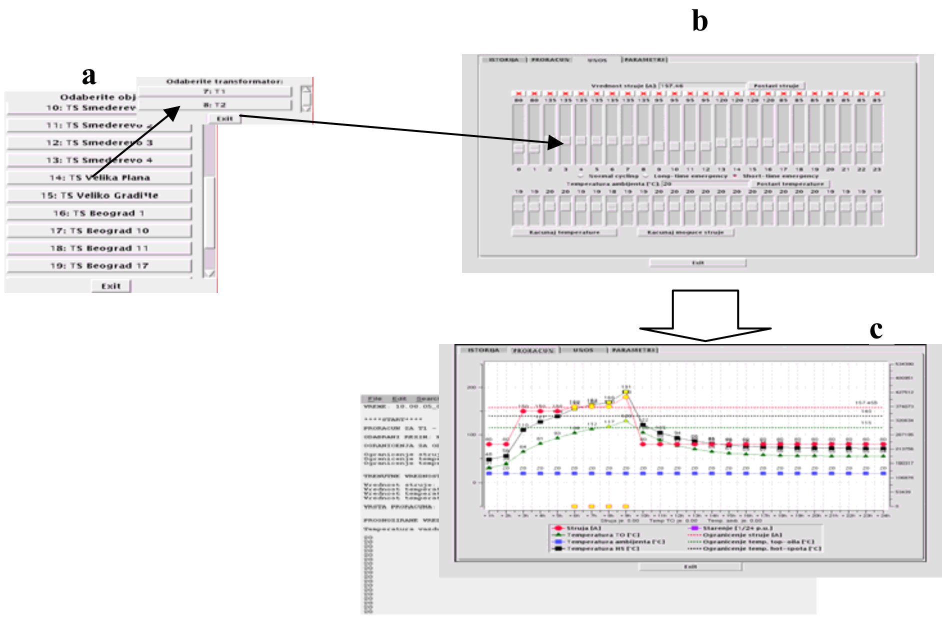


**Figure 3.** TR-LOAD application user interface navigation

### 3.2 Example of TR-LOAD application practical use: for T2 in a 110/35 kV substation Beograd 1

As a part of the DW-PA project, the applications were implemented and tested in the Belgrade RCC, where they are in practical use starting from year 2004.

Some recent situations, when one of the transformers in substation is out of service for few hours (or even days) and its load has to be taken over by the other unit, are frequent and very illustrative for the application use. The necessary current load and oil temperature values, for the 24 hours, including these period were taken from SCADA archives, with the 15-minutes resolution. The Republic Hydro meteorological Service of Serbia official average daily data was taken as ambient temperature.

Provoked by the need for oil drying, the T1 transformer in substation *TS 110/35 kV Beograd 1* was put out of service, during the period from 08.11.2004. in 08:34 h, to 07.12.2004 in 11:30h. Consequently, the whole load has to be transferred to the other transformer in the substation, T2. The 24 hours measurements, taken from SCADA, were hourly averaged and used for calculations and every third value is shown in the Table 1.

**Table 1.** Daily sample of hourly averaged values of current load and oil temperature of T2 transformer in SS 110/35 kV Beograd 1

| Date/time | T1 current load in 110 kV side (A) | Top-oil temperature ($°C$) | Average ambient temperature ($°C$) |
|---|---|---|---|
| 08.11.04/09:00 | 131 | 34 | 4.5 |
| 08.11.04/12:00 | 133 | 43 | |
| 08.11.04/15:00 | 131 | 45 | |
| 08.11.04/18:00 | 133 | 45 | |
| 08.11.04/21:00 | 118 | 43 | |
| 08.11.04/24:00 | 141 | 41 | |
| 09.11.04/03:00 | 110 | 43 | 6 |
| 09.11.04/06:00 | 139 | 44 | |
| 09.11.04/08:00 | 131 | 48 | |

The current load and ambient temperature values were used for calculating the top-oil temperature, for the purpose of application testing. The results were compared to measured values, which is represented in Figure 4. The absolute error maximum was up to $8\,°C$, which could be considered as acceptable.

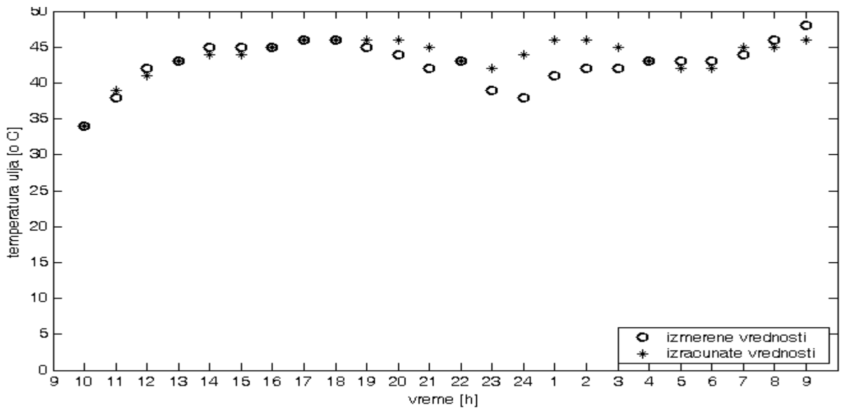


**Figure 4.** Measured (o) vs. calculated (∗) top-oil temperature for T2 transformer in Beograd 1 substation

## 4. Conclusion

The data, describing the thermal state of transformers in a power system are useful information for their effective exploitation. The analysis of possible loading and overloading of these units, for forecasted operation conditions, generates the information that could be used in decision making and planning. The *Power transformer dynamic loading* (TR-LOAD) application fully automates these estimations. Based on *real-time* SCADA and valid thermal models, they enable *real-time* access to each unit from the RCC Database. The application was implemented and tested in one of the RCC of the power system of Serbia and where it proved itself efficient and useful. TR-LOAD application, apart from the operations can also be used as a tool in other engineering and maintenance planning departments, thus enabling improved operation reliability and considerable savings.

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# A COMPARISON OF THE PERFORMANCE RATIO OF PHOTOVOLTAIC MODULES AT DIFFERENT TILT ANGLES

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## Abstract

A photovoltaic array consisting of four modules at tilt angles of 20, 30, 40 and 50 degrees was constructed in order to monitor their performance throughout a year. This hardware set-up was equipped with an automatic electronic system which was designed and realized in the Technological Educational Institute of Crete. It allows the measurement and storage of the instantaneous photovoltaic electrical characteristics (current-voltage and power curves). The daily averaged values of the maximum output power are also calculated. The actual mean daily performance ratio (PR) is determined for every module at the given tilt angle.

The global and diffuse solar irradiances are measured with pyranometers at the horizontal plane. These measurements are then converted to the irradiances expected at the different tilt angles with a simple model. The daily averaged values of the theoretical performance ratios of at different tilt angles are calculated from the daily average values of solar irradiance, air temperature and wind speed. In this work we present the first results of the actual and the theoretical performance ratio for a photovoltaic array at different tilt angles. This work is still under investigation.

## 1. Introduction

Energy from renewable sources (RES) continuously increases worldwide. Current data show that the photovoltaic (PV) energy reached an installed power of 3400 MW in 2006 in the European Union. Most of this power concerns grid connected systems. Germany is by far the country with the largest capacity of photovoltaic systems (3063 MW). Greece is currently at the level of 6700 MW, while it is expected that the new law on RES will boost the installation of new PV systems. Initiatives are also available for private users but significantly lack those for grid connected systems.

In order to promote the production of energy from PV systems, it is important to explore in detail actual data related to the performance, reliability of such systems. A careful study of a PV system takes into account the available solar irradiance, the various loads, meteorological data and other parameters as well in order to correctly size it. Thus, experimental data on the performance ratio are required along with the available solar energy resources at the installation site. In addition, the optimum tilt angle of the array is an important parameter for the overall performance of the system, either on a monthly or an annual basis.

## 2. Experimental set-up

The solar panels (Kyocera model LA361J48) are mounted on a aluminum structure providing tilt angles of 20, 30, 40, and 50 degrees. Their rated power is 48 Watts and with the following characteristics $I_{mp}$=2.88 A and $V_{mp}$=16.7 V at standard conditions. The cables from the panels run for around 2m before entering the control box housing the individual I-V tracers. In order to properly interpret the maximum power measurements the solar panels were inter-calibrated. The procedure consisted in lining up all panels during solar noon. The performance of each module was measured with an I-V tracer, while the global irradiance was measured simultaneously with a pyranometer. These data allowed us to calculate the appropriate calibrations factors.

The I-V tracers are designed and developed in our laboratory and are capable of accepting currents up to 5A. A characteristic I-V curve is sampled at 300 points providing a typical resolution of 100 mV. The signal from each dedicated tracer is transferred to an A/D card and finally, the data are stored on an ASCII file at regular intervals of 5 min. Additional data which are stored in the ASCII file consist of date, time, short circuit current, open circuit voltage and current and voltage at maximum power.

In a nearby independent weather station the global and diffuse irradiance at the horizontal plane are recorded at the same frequency along with the air temperature and wind speed at a height of 10 m above ground level. The diffuse irradiance is recorded with the aid of a shadow band and its effect is taken into account with the algorithm proposed by Muneer & Zhang [1]. The derived beam and diffuse irradiances are used to calculate the expected irradiance at every tilted plane. The algorithm used to transform the data from the horizontal plane to an inclined plane is that of Hay and Davies [2].

## 3. Observed Performance Ratio

The performance ratio is defined as the ratio of the energy produced by a panel or an array to the energy that would be produced under STC (Standard Test Conditions) but for the same irradiance level. After some manipulation the performance ratio can be written as

$$PR = \frac{E \times G_{STC}}{P_{peak} \times H_t} = \frac{P_{\max} \times G_{STC}}{P_{peak} \times G_t} \qquad (1)$$

where $P_{max}$ is the instantaneous maximum power, $P_{peak}$ is the nominal (rated) power of the module or the array, $G_t$ is the solar irradiance at the plane of module/array and $G_{stc}$ is the solar irradiance at Standard Test Conditions (1000 W/m$^2$).

We employ eq. 1 in order to calculate the experimental performance ratio of every module used in this study. In the case of the daily averaged *PR*, the energy *E* is a discrete integral of the measured power over the 5-min intervals, while $H_t$ is the total energy perceived by the area of the module/array over the day.

## 4. Modeled PR

The calculation of the theoretical PR is mainly based upon the work of Fraghiadakis & Tzanetakis [3]. These authors have shown that an average cell temperature can be calculated using average values of the air temperature, wind speed and solar irradiance at the plane of the array. The method was verified with data from a large number of PV installations and of different type (free standing, roof mounted, etc.). The daily averaged $PR_T$ is given by

$$PR_T = 1 + \gamma \times \Delta T_{c,eff} \tag{2}$$

where $\gamma$ is a parameter accounting for the effect of power losses due to increased temperatures above $T_{STC}$ and $\Delta T_{c,eff}=T_{c,eff}-T_{STC}$ is the temperature difference between the effective cell temperature and the Standard Test Condition temperature ($T_{STC}$=25 °C).

All other factors that affect the overall performance of a module/array are assumed, to a first approximation, constant within a year. These factors are related to reflection losses (e.g. Martin and Ruiz [4], low irradiance losses, polarization losses, spectral losses (e.g. Parretta et al. [6]), cable/connection losses, etc. This implies that the final performance ratio will be given by the product of the individual PRs, i.e.

$$PR = PR_{REFL} \times PR_{LI} \times PR_{POL} \times PR_{SPECTR} \times PR_{CON} \times PR_T \,.$$

A more detailed modelling would allow for daily averaged variations of these factors as a function of day within a year.
The effective cell temperature is calculated by the empirical formula

$$T_{c,eff} = a_1 + a_2 \times T_{a,D} + \left(F_1 + F_2 \times G_{t,D}\right) \times k(ws_D) \times G_{t,D} \tag{3}$$

The coefficients $a_1$, $a_2$, $F_1$, $F_2$ are known, while the subscript "D" declares the diurnal averages of the corresponding quantities. The values of the coefficients that appear in the work of Fraghiadakis & Tzanetakis [3] are based on monthly averaged values, while here we are interested in daily averaged values. Solar and meteorological data are used to calculate the appropriate averaged quantities which are then reduced to calculate the new coefficients.

Finally, Eq. (3) can be substituted in (2) to calculate the daily average value of the performance ratio. This modeled $PR_T$ is subsequently multiplied with the corresponding PR of the processes mentioned above and is compared with that determined from the data acquired by the I-V tracers.

## 5. Discussion

The current work refers to the experimental study of the major parameters describing the actual operating conditions of solar panels at different tilt angles. The electrical characteristics of each panel are recorded by a dedicated I-V tracer, while the panels are mounted on a specially developed support structure. Data have been recorded over different weather conditions (summer/winter, clear/cloudy) but in the current study we utilize only clear sky data. In all cases the data are recorded at 5-

min intervals and this allows us to calculate the instantaneous performance ratio as well as the daily averaged PR. Typically, grid connected systems are characterized by PRs in the range of 0.6 to 0.8 (Mau and Jahn [5]), while stand alone systems with back up storage are characterized by PRs in the range of 0.3 to 0.6.

Usually, when data from grid connected systems are acquired, it is assumed that the current and the voltage are set at the maximum power point (MPP) conditions. However, an inverter may not always work at MPP conditions and this may lead to an effect of the order of a just few percents. Since the data presented here are recorded by I-V tracers, it is clear that they are free of this uncertainty. These data are used to calculate the PR of each panel under a variety of time scales (weekly, monthly, annually). In this work, we focus on daily averaged values and their correlation with those determined theoretically through the empirical relations determined by Franghiadakis & Tzanetakis [3].

In Figure 1 we plot the experimental *PR* as a function of the daily averaged diurnal temperature which enters Eq. 3. The *PR* decreases with increasing $T_{a,D}$ temperature as it would be expected. However, note that the diurnal temperature is indicative of the meteorological conditions and not of the actual cell temperature which clearly depends also on the incoming irradiance. Figure 1 shows data from panels at tilt angles of 20$^{\circ}$ and 50$^{\circ}$. Typically, during summer time where high $T_{a,D}$ temperatures are usual and the sun elevation is above 70$^{\circ}$, the module at a tilt of 20° intercepts significantly more energy than the module at 50$^{\circ}$. Consequently, the corresponding cell temperatures will also differ.

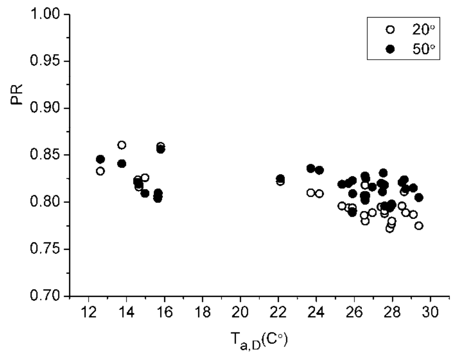


**Figure 1.** Experimental performance ratio vs $T_{a,D}$ for two panels at tilt angles 20° (open circles) and 50° (closed circles).

In Figure 2 we plot the experimental PR for two panels used in the measurements, these at tilts of 20$^{\circ}$ and 50$^{\circ}$. The filled squares correspond to the PR of the panel at a tilt of 20$^{\circ}$, while the open circles correspond to the data of a panel at a tilt of 50$^{\circ}$. It is evident that during the summer season the increased energy absorbed by the panel at 20$^{\circ}$ leads to a lower PR, although the differences are relatively small, of the order of 5%. During the winter time where the temperatures are lower and the sun maximum elevation is also reduced, the PR of the 20$^{\circ}$ panel is slightly higher than that of the panel at 50$^{\circ}$.

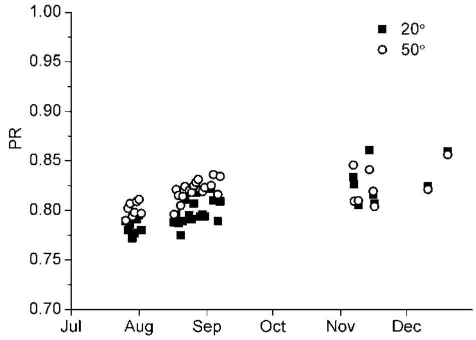


**Figure 2.** Experimental performance ratio vs time for two panels at tilt angles 20° (open circles) and 50° (closed squares).

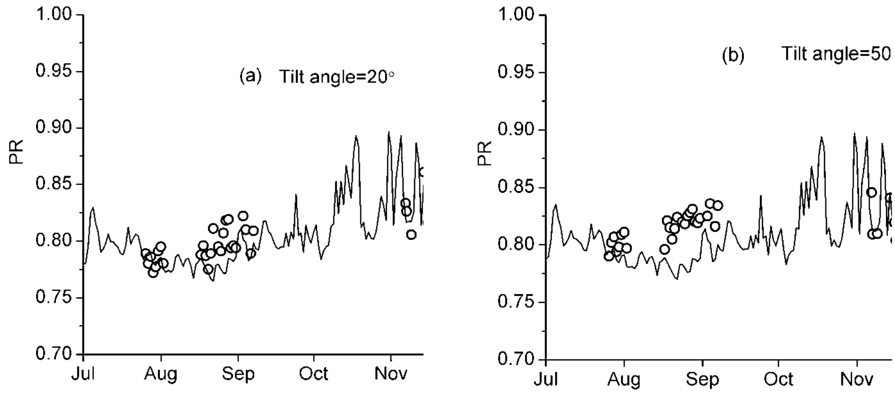


**Figure 3.** Experimental (open circles) and calculated (line) performance ratio vs time for two panels at tilt angles 20° (a) and 50° (b).

Figure 3 shows the comparison between the observed PR (open circles) and that determined with the aid of Eq. 2 for different tilt angles (continuous line). The agreement is quite good considering the statistical nature of the equations involved into the calculations. There appears to be a small difference in the PR during the summer season for the module at a tilt angle of $50^{\circ}$ and this is under investigation, although it is well within the errors of the measured irradiance. It is clear the Eqs. 2 and 3 provide a very good description of the experimental data and can be used to describe PV systems and their energy output using daily or monthly averaged values of the diurnal air temperature, wind speed and solar irradiance.

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The Project is co-funded by the European Social Fund and National Resources – EPEAEK II – ARXIMIDIS II

# ON THE MAXIMIZATION OF THE COST-EFFECTIVENESS OF A PV PLANT

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## Abstract
This paper outlines three methodological approaches in order to reach the most cost-effective PV configuration to meet the power loads. An evolution of PV sizing methodologies with an increased level of intelligence is presented, so that the PV system configuration is reliable, while at the same time cost-effective. Comparison of results is presented and argued. In addition, for Grid-tied PV systems, the concept of cost-effectiveness is discussed taking into account the PBP and the IRR issues with parameters the angle of inclination to horizontal and the width of the PV arrays.

## 1. Introduction
The policy to introduce PV electricity in buildings is an issue of growing importance, based on the E.C. Directives, [1,2] and the White Paper on a Strategy and action plan for Renewables [3]. However, the issue of cost-effectiveness has not received enough attention. Instead, a concern has been expressed about the max. final Yield, $Y_f$ (kWhe/kWp), on an annual basis, of a PV plant which is installed in a given land or area [4], or of a PV system with given installed Peak Power.

According to all these aforementioned issues, the design of a PV plant shall have as an objective a plant to be able to produce and deliver the maximum output at the minimum cost, with a small Payback period, PBP, [5] and a high Performance ratio, PR [6, 9].

In addition, the PV plant shall meet the loads effectively, with a high degree of reliability, which is dealt with proper sizing methodologies [7]. In this paper, the Stand Alone and the Grid tied PV plants are considered in 2 possible scenarios:

1. The PV plant is designed to meet the loads of either a building, eg. State, commercial, private, or a farm or of another application. These are, usually, small to medium scale plants [4]. Hence, it is required that not only the maximum power is produced, but also the right amount of energy is delivered to the loads, $Q_L$, on a daily basis. Such a design approach may increase the PR [5].
2. The larger PV plants need a given land, an extended roof or terrace to be installed. This has to be studied carefully, in order to install the maximum possible Peak power in the most effective scenario.

## 2. On the Principles to Maximise the Yield and Cost-effectiveness
In order to reach the above objectives various methodologies have been developed, suitable to each case. The steps should be:

a. to determine the optimum angle of inclination as well the azimuth of the PV arrays, especially when there are shadowing problems to happen by nearby buildings, and the other geometrical factors concerning the PV arrays for any orientation.

b. to determine the least power losses in cables, chargers, due to the margin in their operation [10] and in the inverter(s), especially, when a group of inverters is used. The effect is crucial if the DC/AC inverter operating domain does not match the characteristic i-V of the PV array connected to it. In such cases, the efficiency of the inverter drops much below the 90% .
c. the sizing of the Battery bank, so that to provide realistic corrections to the system's total Capacity, $C_L$ (Ah), as otherwise the system might be either oversized or undersized [11].

The latter requirement has introduced the concept of **d** days of energy independence in the S.A. PV installation [12].
In order to satisfy all the above requirements, 3 general approaches to design reliable PV systems with various configurations have been developed:

**1st Approach:**
The **static-conventional PV sizing methodology**, where the main quantities: Peak Power, Pm, and Battery system Capacity $C_L$ (Ah), are determined by the following formulae:

$$P_m = \frac{Q_L \cdot d \cdot n_{BOS}}{PSH} \tag{1}$$

$$C_L = \frac{Q_L \cdot d \cdot F \cdot n_{BOS}}{V \cdot DOD} \tag{2}$$

$n_{BOS}$ is the efficiency of the Balance Of System, V is the voltage DC power is transferred, and DOD is the Depth of Discharge of the batteries used. F is a coefficient to account for the losses in the battery and PSH is the Peak Solar Hour, as defined in [12].

**2nd Approach:**
**Statistical fluctuations Introduced into PV sizing, [7, 8]**
In this approach the statistical fluctuations of the daily solar radiation are studied from the T.M.Y. data and are introduced into the PV sizing analysis. This results in more economic $P_m$ and $C_L$ values, while keeping the reliability of the PV plant high. In this approach, the standard deviation, $\sigma_{Hm(nj)}$, of the mean daily solar radiation on the horizontal for the mean or rather the representative day of the month for which the PV plant is to be sized, is determined by the expression:

$$\sigma^2_{Hm(nj)} = [\sigma^2_{H(nj)1} + \sigma^2_{H(nj)2} + \ldots + \sigma^2_{H(nj)N}]/N^2 \tag{3}$$

$H(n_j)$ is the global solar radiation at horizontal for the mean day of the month. N is the number of years for which data were collected.

Then, the $P_m$ and $C_L$ are determined by a relationship derived in [7]:

$$P_{m,d} = P_m \cdot \left(1 + 2 \cdot \sigma_{H_m(n_j)} \cdot \sqrt{d} \Big/ H_m(n_j)\right) \tag{4}$$

$$C_{L,d} = \frac{Q_L \cdot \left(1 + 2 \cdot \sqrt{d} \cdot \sigma_{H_m(n_j)} \Big/ H(n_j)\right) \cdot F}{V_{SS} \cdot DOD} \tag{5}$$

A comparison of the 2 approaches provides that for a given load, (Wh/day), the Pm and the $C_L$ values of the second approach, are more cost-effective compared to the conventional sizing methodology results [7, 8].
Results of the comparison are given in Figs. 1 and 2. A measure of the comparison is the ratio $C_R$ given by the capacity $C_{L,d}$ determined by the statistical approach (2nd Approach) over the $C_{L,d}$ determined by the conventional approach (1st Approach), see eq. (6).

$$C_R = \frac{C_{L,d}(statistical)}{C_{L,d}(conventional)} = \frac{P_{m,d}(statistical)}{P_{m,d}(conventional)} = \frac{1 + \dfrac{2 \cdot \sqrt{d} \cdot \sigma_{Hm(nj)}}{H_m(n_j)}}{d} \tag{6}$$

Similarly for $P_m$, $P_m$(statistical) over $P_m$(conventional) the ratio is given by the same parameter, CR, as shown in eq. (6).

In this case, the performance ratio of the PV array increases and this leads to substantially smaller pay back period. PBP can be determined by:

$$\frac{C}{CI} \cdot \left(\sum_{i=1}^{12} (PSH)_i \cdot N_i\right) \cdot PR \cdot \left(\frac{(i+1)^{PBP} - 1}{i(i+1)^{PBP}}\right) = 1 \tag{7}$$

where, C is the buying price of the $kWh_e$ and CI is the capital investment for each kWp of the PV plant. Here, **i** is the annual discount rate.

The value of the Peak Solar Hour, (PSH) depends on the month and on the site, latitude, φ, too. In this expression, (PSH) takes values for each month for the site the PV plant is to be installed. Its value is equal to the daily global solar radiation in $kWh/m^2$ on the inclined plane of the PV arrays that the system design will determine.

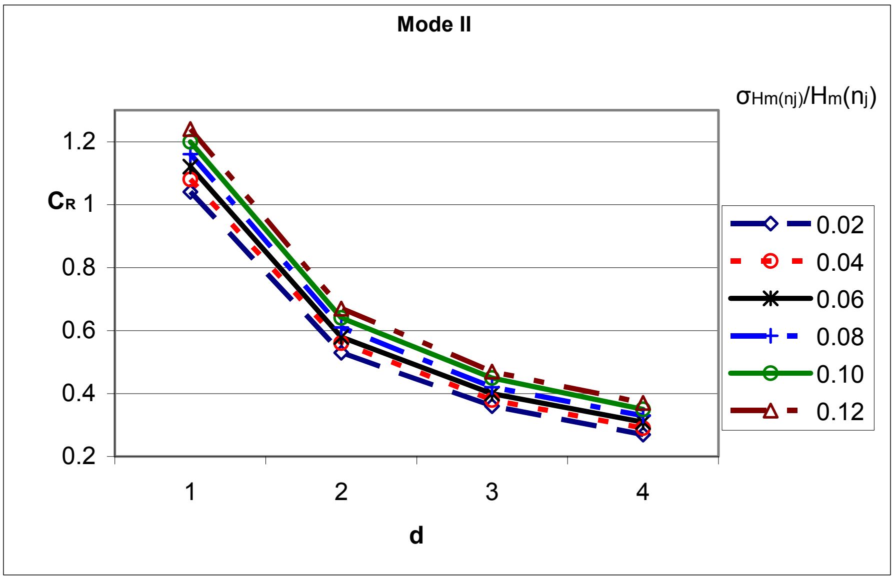


**Figure 1.** Ratio $C_R$ vs d days of independence, with $\sigma_{Hm(nj)}/H_{m(nj)}$ as a parameter. $\sigma_{Hm(nj)}/H_{m(nj)}$ takes low values for Summer time and increases along the way to Winter. For more about this methodology, see results presented in [8].

**3rd Approach:**
**Intelligent PV + Buildings system Management**
The third methodology towards PV sizing involves a higher level of management and intelligence of the overall PV& Building system.

This approach requires:
1. a solar intensity prediction model, presented in [13]. This leads to the determination of the daily electric energy to be produced by the PV-plant.
2. a data acquisition system, which is tailored to the model management parameters opted e.g. solar intensity, temperatures (indoor, outdoor), humidity, wind velocity etc
3. a micro-processor control unit

According to all these, the system takes the following configuration, which provides the topology of the communication network and its sub-networks, [14].

The whole communication network is split in two basic parts: the sensors' sub-network and the PC sub-network. The interface between them is the so called master node. The topology of the communication network and its sub-networks is drawn in Figure 2.

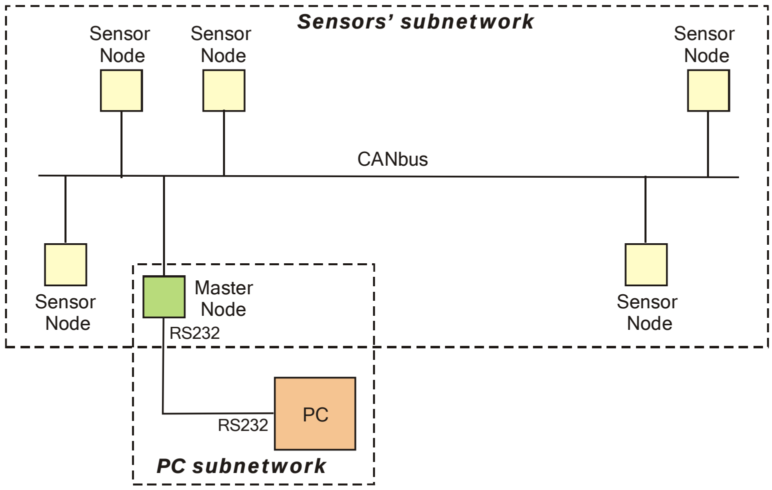


**Figure 2.** Communication Network topology with the two sub-networks.

Each sensor node will include a microcontroller (Microchip PIC16F786) that will introduce the upper layer network control and manage a CAN controller (Microchip MCP2515) through SPI protocol.

Several alternatives were examined for the implementation of the sensors' sub-network, e.g. 802.11, 802.15.4, CAN, etc. Among them**,** the Controller Area Network (CAN) protocol – or CANbus, was found to fit best the technical and economical needs of the application.

The system outlined in this methodology, may overcome cases where the conventional design of a PV plant and the PV sizing with the statistical fluctuations incorporated, may fail to meet the loads. In this case, the whole PV + Building system is intelligent enough to predict the PV output. It may shift the loads, especially those of lower priority, using a micro-processor system, which determines the loads to be powered in a day, using the following formula:

$$Q_L(Wh/day)=Q_{L,crit}+e_1Q_{L,1}+e_2Q_{L,2}+\ldots \quad (8)$$

$Q_{L,crit}$ are the critical loads (Wh/day) which the PV-plant is permitted to fail to meet them by less than 1% of the annual time (87 hours/year). Loads $Q_{L,1}$ , $Q_{L,2}$ , etc. are assigned importance weights $e_1$, $e_2$ , etc., respectively.
The system load management operation targets to satisfy the load requirements over a period of d days. Such a management policy described above increases obviously the PR value.

## 3. The Maximisation of the Yield in a Given Surface of Land Where the PV is to be Installed

In this case, the project has to examine the possible scenarios which provide results about the maximum power installation of PV arrays in a given land.

**Figure 3.** A configuration of PV arrays with distance to each other and shadow. The arrays should not shadow one another, even when the sun's altitude, α, takes its lowest value.

The parameters to be taken into consideration for this purpose are the angle of inclination, **β**, and the width, **W**, of the PV array, while its length**, L**, is determined by the geometry of the land, where the PV plant is to be installed.

A simple software analysis for a given site at latitude, **φ**, provides the optimum angle of inclination, which for Patra, Greece, is $28^0$ to get the maximum annual global solar radiation on a PV array, in $MJ/m^2$. However, the max Power to be hosted by a given surface of land has to take into account the width, **W**, of the PV array. A proper value of **W** may result to an increase in the number of the PV arrays that a given land may accommodate. This is due to the minimum distance, **l**, between arrays, calculated by the formula:

$$l = W \cdot \frac{\sin(\beta + \alpha)}{\sin(\alpha)} \tag{9}$$

so that the arrays do not shadow each other, when the solar altitude, α, takes its smallest value. For **l** values which divide **L,** which is the length of the piece of land, the number of arrays becomes max and therefore the PV peak power gets a maximum. Finally, the **PBP** has to be determined for each scenario of:
**β, W,** in order to get to the most cost –effective result.

A Case Study for Patra has shown that for the most cost effective scenario W= 3 m and $\beta=26^0$-$28^0$.

Here, the concept of the optimum angle **β** is not absolutely valid, as this holds for a PV of a given Peak Power, while here, the max. power to be installed and the max. energy to be delivered are of prime concern, especially when a given surface of land is the case.

## 4. Conclusions

This paper provides a set of methodological approaches for a cost effective PV sizing. A comparison of the results for the 3 approaches towards PV system sizing, are discussed. The following are compared: the reliable operation with the results obtained by the conventional sizing method, the method that introduces the solar radiation statistical fluctuations in a place, and an intelligent management approach, which may combine the statistical approach with a load management scenario, based on the Prediction of the daily solar radiation profile.

On the other hand, in cases where the PV system is to be grid-tied and has to be installed in a piece of land of given surface profile, one has to study the possible geometrical configurations of the PV arrays. In this case, various β angles are examined with the width W of the arrays, as a parameter. However, the cost–effectiveness concept is the issue which leads to determine the scenario to be adopted for the optimum investment, and not just the max. Power is accommodated in the land. For this, the matching between the i-V of the string of modules on the PV arrays with the domain of operation of the DC/AC inverter is the other crucial issue to be considered.

## Acknowledgements

This paper presents a work which is part of the ASETILEN project. The authors would like to express their appreciation to the EPEAEK Programme of the Ministry of Education in Greece and specifically the Archimides Program, which has funded the ASETILEN project.

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# INTEGRATED SOFTWARE, FOR IMPULSE VOLTAGES ESTIMATION, IN HIGH VOLTAGE NETWORKS WITH DISTRIBUTED GENERATION

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## Abstract

In this work was created functional software for quick calculation of impulse overvoltages caused from lightning incidents in electric energy distribution networks. Aim of the work is to facilitate the potential investors for the optimal installation place choice for Renewable Energy Sources distributed production. The application is practical because it obtains all data from already stored data in a geographic information system. Also it is accurate because of the using of ATP-EMTP, a powerful transient phenomena calculation program. In this paper they are presented the theoretical background, the tools that were used and an application for the prefecture of Laconia, Greece.

**Keywords:** Distributed generation, Renewable Energy Sources, impulse overvoltage calculation, ATP-EMTP, GIS

## 1. Introduction

The release of the energy market has made optimal network management, fast damage repair and continuous network extension for the connection of new producers or consumers of paramount importance. The improvement of electricity services underlines the need for the development of informed digital maps with user-friendly management combined with power flow programs and programs for the calculation of overvoltages and faults. The ultimate goal of such applications is the optimum exploitation of distributed production from renewable energy sources and reliable network extension due to the continuous addition of new product units and consumers.

In this cohort an interface between a Geographic Information System, which has been developed by the High Voltage Laboratory (Dept. Electrical and Computer Engineering, University of Patras) for the study and designing of electric distribution networks that operate under high voltage of 20 kV (GIS - Zeus), and the ATP - EMTP. The aim of this interface is the rapid and effective calculation of impulse overvoltage as a result of lightning incidents to installations of distributed production from renewable energy sources; in essence this program calculates the exact voltage waveform at the preferable nodes of the circuit.

The aim of the present study is to provide the necessary theoretical foundation and the properties of the aforementioned interface followed by an example of its implementation on the 20kV electric distribution network of Laconia Prefecture, Greece, where the installation of production stations by renewable energy sources is expected in the foreseeable future. Under this scope the current can function as the manual.

## 2. Geographic Information Systems and the Electromagnetic Transients Program ATP-EMTP

The free electric energy market requires excellent network knowledge, optimal economic exploitation, fast extension and direct damage repair. The electric networks are constantly extended due to the continuous addition of new loads and producers (small hydroelectric stations, wind parks and distributed generation of energy from renewable sources in general), rendering network follow-up with informed and distinct maps indispensable. Using conventional methods, this process involves the constant creation of new imprintings (traditional maps or sketches) in paper that require large operational costs, waste great amounts of time and effort and cause delays in the briefings and deceleration of investments due to delayed customer service. Obviously, this problem is intensified in regions where the network growth is rapid because of the increasing number of connections of new distributed generation plants.

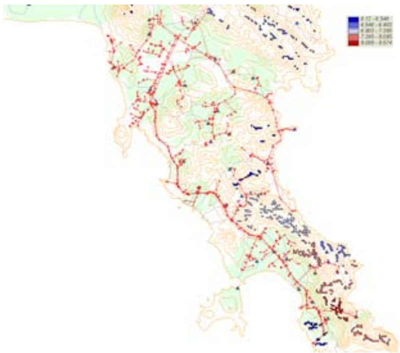
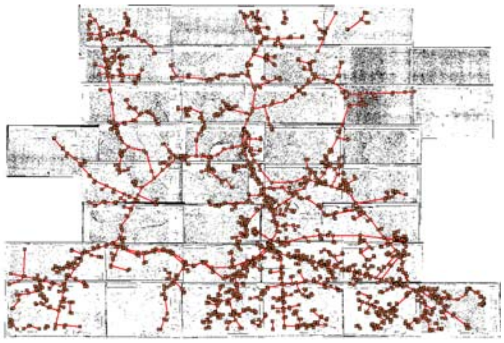
Taking into account the aforementioned points, the electric companies are driven to the development of applications that organize and record the necessary information with modern solutions of informational technology. Such programs are described on the whole as GIS. The science of geography describes the objects and overlays the information of the surface of the ground; essentially it is a frame of knowledge format. A GIS is an analysis and projection system of geographic information. This information can be drawn in the form of maps, parcels of geographic information (tables) and results of calculation analysis. The GIS systems practicality stems from the fact that data management is organized in layers.

The GIS is often confused with the maps [1]. The maps however are only one from the three GIS subsets. Comprehensively, the GIS are comprised of:

i. The database of the geographic data.
ii. Map creation: These systems offer dynamic mapping creation and provide functions that can determine the relations among the various elements on the surface of the ground.
iii. Model creation: Using individually adapted tools, they can provide geographic information management and conclusion exporting.

Moreover, various GIS systems are available that provide an array of different functions that can be adapted to the individual needs of each user. For example, if the objective is simple area mapping, imprinting of geographic information is adequate. But if the objective comprises network study and conclusion export of steady and transient condition, the electric information and apparatus characteristics imprinting is also required.

The GIS program developed by the High Voltage laboratory [2] fulfils the purpose of creating a complete system that can both record a medium voltage network for simple mapping production and at the same time perform complex studies on the calculation of network condition. Network digitalization is essential for recording all the necessary ground and electric elements (Fig 1a, b).

a. b.

**Figure 1.** a. GIS map and Medium Voltage (20kV) Distribution lines in Prefecture of Laconia, Greece b. GIS map and Medium Voltage (20kV) Distribution lines in Prefecture of Arta, Greece

The following layers have been selected to be stored in electronic format [3]:

i. The political map of the studied region
ii. The region wind potential
iii. The contour lines
iv. The aquatic flows
v. The road network
vi. The electric network
vii. Lightening curves of the area

The electric network, which represents the most important part for this application, includes the nodes and the lines. Each node includes the following information:

i. Node type (branch, change of line type, end node, earth node, production, Low Voltage, Medium Voltage)
ii. Region
iii. Area
iv. Network owner
v. Main or secondary
vi. Main line
vii. Nominal Voltage
viii. Insulation level
ix. Observations
x. Medium voltage load
xi. Active power
xii. Reactive power

The electric characteristics (per length ohmic, inductive and capacitive resistance,) have also been recorded for each type of line (Fig 2).

| Line_Type_nan | Material | Name | D | Insulation | Resistance | mmH_m | mmF_m | Comments |
|---|---|---|---|---|---|---|---|---|
| 3*16ACSR | ACSR | | 0 | 0 | 1.268 | 0.422 | 0 | |
| 3*35ACSR | ACSR | | 0 | 0 | 0.576 | 0.397 | 0 | |
| 3*35AAAC | AAAC | | 0 | 0 | 1.071 | 0.393 | 0 | |
| 3*95ACSR | ACSR | | 0 | 0 | 0.215 | 0.334 | 0 | R,X TIMES SE OHM/KM |
| 3*185AAAC | AAAC | | 0 | 0 | 0.204 | 0.337 | 0 | |
| 3*70AAAC | AAAC | | 0 | 0 | 0.562 | 0.37 | 0 | |
| 3*35NHKBA | NHKBA | | 0 | 0 | 0.576 | 0.1 | 0 | den exoume sygekrimena stoixeia |

**Figure 2.** Medium Voltage Lines Technical Characteristics

The proposed application was developed in order to achieve minimum renewal times of electric map and at the same time to record all the essential information to perform network studies. The load flow analysis is materialized using the program PSS/E, [4] while the transient situations are studied using the EMTP-ATP [5], [6].

For the resolution of transient phenomena the EMTP is used, a powerful but at the same time complicated program. The program of electromagnetic phenomena analysis EMTP has its roots in Bonneville Power Administration (BPA), collaborator of American Service of Energy, USA. EMTP have been developed using government funds for more than one decade, dedicated for free distribution. In 1984 became an attempt was made to trade the program and consequently BPA was excluded from further development of EMTP. By that time, a non publication commercial of EMTP, the ATP, was created. The ATP is distributed without authorization fees from those users that do not participate to the EMTP trading.

ATP is a universal program system for digital simulation of transient phenomena of electromagnetic as well as electromechanical nature. With this digital program, complex networks and control systems of arbitrary structure can be simulated.

ATP has extensive modeling capabilities and additional important features besides the computation of transients. It has been continuously developed through international contributions over the past 20 years.

Trapezoidal rule of integration is used to solve the differential equations of system components in the time domain.

Non-zero initial conditions can be determined either automatically by a steady-state phasor solution or they can be entered by the user for simpler components.

Interfacing capability to the program modules TACS (Transient Analysis of Control Systems) and MODELS (a simulation language) enables modeling of control systems and components with nonlinear characteristics such as arcs and corona. Symmetric or asymmetric disturbances are allowed, such as faults, lightning surges, and any kind of switching operations including commutation of valves.

Frequency response of phasor networks is calculated using FREQUENCY SCAN feature. Dynamic systems can also be simulated using TACS and MODELS control system modeling.

## 3. Admissions Considered for Program Design

In order to facilitate the calculations, without importing serious error, the following admissions were considered during program development:

i. The single-phase equivalent of the line was used (Figure 3).
ii. Every distribution electric energy network tower was considered, for calculating reasons, as a circuit node.
iii. Lines were considered not to be protected by shield wire, because the medium voltage lines in Greece do not bear shield wire.
iv. No further disturbances were considered to be present, such as single pole, bipolar and three polar short-circuits and interruptions that can lead to potentially grave situations for calculations simplification.
v. The impulse wave damping caused by the skin and corona effects was considered negligible, because deviation is minimal and the obtained results are on the safe site.
vi. The impulse wave damping caused by the interaction with adjacent installations was considered negligible.
vii. The overvoltage was considered to be less than the maximum value (125kV) that the regulations for the 20kV lines predict and any breakdown on the line was not considered [8].
viii. The impulse overvoltage form was considered to be 1,2μs/50μs, as the regulations predict [8].
ix. The current concept was applied only on medium voltage lines, because distributed producers in Greece are connected to such lines
x. The operation voltage was not considered at the calculations.
xi. Any installed surge arresters are not considered at the calculations.
xii. Both high to medium voltage and medium to low voltage transformers were considered as open circuits for the impulse overvoltage.

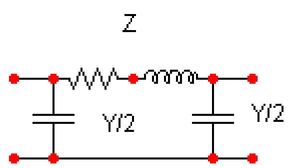


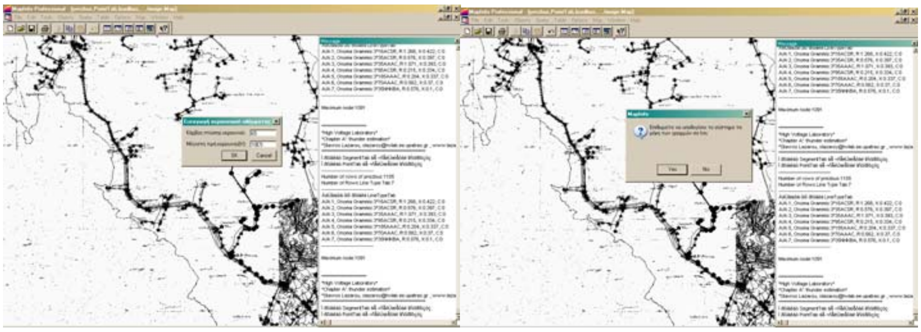

**Figure 3.** Single phase equivalent for distribution lines

The single-phase equivalent of the line was used and the inductive overvoltages that may occur at the remaining phases of the line were not taken into consideration; this decision was taken in order to decrease the requirements in the calculating load and to conform to current practice. The choice of towers as circuit nodes serves in the direct connection of distributed production at the desirable point of the network with relatively good precision. The operation voltage is considerably smaller than the disturbance impulse overvoltage and consequently no serious error is introduced to the calculations. The transformers for high frequency signals, such as the disturbances under examination can be considered as open circuits without fault.

## 4. How the Program was Developed

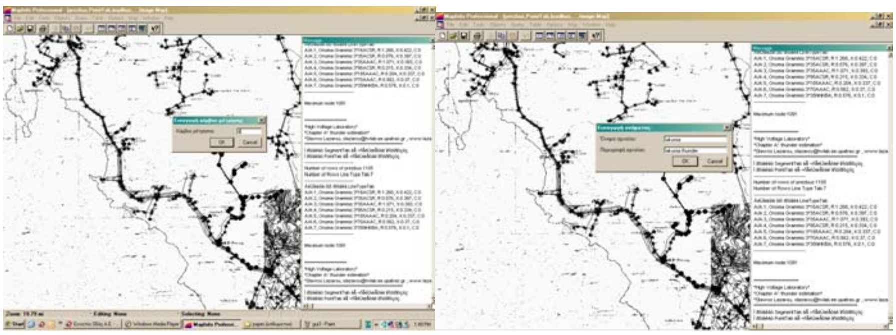
The initial application of High Voltage network recording was materialized in MapInfo environment using the programming language MapBasic, an adapted language for geographic information system applications planning. High Voltage laboratory had already recorded the territorial data with complete technical characteristics of the medium voltage electric network equipment, as previously reported in chapter 2. In order to carry out all the necessary calculations, a concrete process of program concretization was followed. Initially the following graphic user interfaces for data importation were manufactured:

i. the node number that the overvoltage appears and its amplitude in Volts (Figure 4.a)
ii. an option is given to calculate again the length of the lines as draw in the geographic information system and to re-estimate their technical characteristics (Figure 4.b)
iii. import of measurement node (Figure 5.a)



a. b.

**Figure 4. a)** Graphic User Interface to import the node that the impulse overvoltage appeared and the impulse overvoltage amplitude in Volts in the area of Prefecture of Laconia, Greece **b)** Graphic User Interface that informs the user that the program is going to calculate the length and the technical characteristics of the studied line

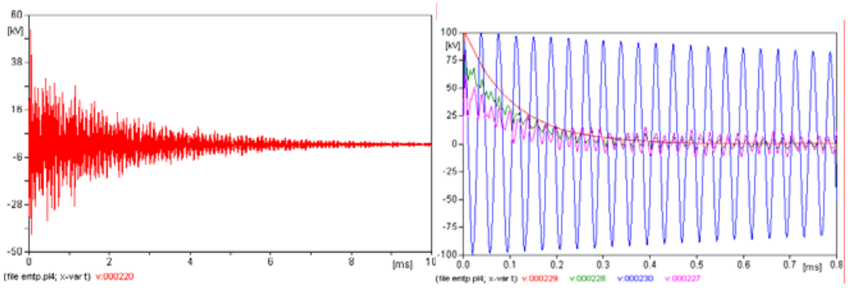


a. b.

**Figure 5. a)** GUI for measurement node importing
**b)** GUI for file description and file name importing

Then the program draws all the essential equipment data and makes all the essential calculations. The final stage includes the creation of the ATP-EMTP entry file, which uses concrete format. In this file information about the simulation, like date, place and program author, is entered. Then the types of the lines with their technical characteristics are entered; it is noteworthy that this program can calculate up to 106 nodes. In the end of this file the measuring nodes and the characteristics of the overvoltage are entered. For the completion of the simulation this file is imported in the ATP-EMTP for process.

The program provides the possibility of two different options of operation. The usual operation calculates the expected overvoltage in the node of the line that is connected to the distributed production following a hypothetical lightening incident of known amplitude in the line, possibly in an area of high mountains or in regions with intense lightening activity (Figure 6.a). According to the alternative operation, the program can also calculate the effect of an impulse disturbance, which occurred in a specific node, at up to 10 near neighboring nodes (Figure 6.b).



a. b.

**Figure 6**. **a)** Effect of the impulse overvoltage at node 220. The lighting incident occurred at the network node 229. **b)** Effect of impulse overvoltage caused from lighting at network node 229(red color), to the neighboring network nodes 227(violet color), 228(green color), 230(blue color)

Program reliability was checked by using two different ways:

i. With the analytic resolution and confirmation of a small circuit.

ii. By checking the required time for the fault to reach a node at a known distance.

## 5. The Interface

The program was manufactured in order to calculate the impulse wave in given network with two different ways. The process of calculation begins with the electric network selection. Then using the algorithm that was already described in the previous paragraph, the renewable energy source in the desirable area is spatially placed and connected into the electric network. The node of circuit that is in lightning danger is selected and the amplitude of the overvoltage is considered. Finally the node that has been connected to the renewable source of energy is selected. Eventually the program calculates the precise impulse voltage in the node of installation connection.

The alternative program operation is recommended when the production unit is located in a region of high lightning danger. For example it is desirable to install the renewable energy source plant in the top of a mountain; intense danger of impulse overvoltage appearance at the installation exists and consequently a sophisticated decision for node connection in the network is of outmost importance. In this case a hypothetical overvoltage is considered at an adjacent to the installation node and the program calculates the precise waveform for the near nodes.

## 6. Using the Program in the Prefecture of Laconia, Greece

For demonstration reasons we selected to apply the two different operations of this program in the electric distribution network of Laconia prefecture, Greece, which is property of Power Public Company (PPC) (Fig 1.a). The Laconia area was selected due to its rich aeolian potential [10] and the relatively weak electric network. Except from the prefecture of Laconia, it is currently possible to use this program in the prefectures of Arta, Lesvos, Achaia in Greece and the provinces of Limassol and Orounta in Cyprus. The laboratory of High Voltage has also undertaken the arduous task to cover all areas in Greece and Southern Cyprus.

As previously mentioned, a distribution network node of Laconia that it is likely to present impulse lightning overvoltage was considered initially. The network node with serial number 229 was considered of high lightning risk, because it is located at the highest point of mountain Chionovouni. This mountain is located at the centre of the map in figure 1.a. Impulse overvoltage with amplitude 100kV and form 1.2μs/50μs was considered, which is representative for lightning incidents (figures 4, 5). Then a renewable energy sources production station was hypothetically installed at the network node with serial number 220 that is found eastwards. The simulation results are presented in figure 6.a. From the above waveform continuous and absorbed reflections caused by the structure of the network were observed. It is anticipated that the highest voltage amplitude the node 220 will receive is about 55kV.

Moreover taking advantage of the program's capability to calculate the precise voltage waveform at the near nodes of disturbance appearance, the figure 6.b for nodes 227,228 and 230 is generated. From this figure it can be deduced that the node 230 (in blue color) strained more than the node 229 where the disturbance occurred. This interesting finding underlines the importance of the proposed application. It is worth mentioning that even for a simple line of certain kilometers, simulation time unfortunately exceeds 20 minutes with the use of the usual personal computers.

## 7. Conclusions and Future Work

The importance of this application is summarized in the following points:

i. For the first time an interface between two completely different programs was developed.
ii. The program can accurately calculate the final voltage wave.
iii. It can estimate in a short period of time the largest impulse voltage that can be observed in the installation
iv. Ultimately it assists optimum lightning design of RES installations.

Certain improvements of the program are scheduled for the future:

i. The option of surge arresters incorporation in the line
ii. Automatic determination of optimal installation place of distributed generation
iii. Adaptation to Transmission Network.
iv. Upgrade for more than 106 network nodes.
v. The option of introducing additional faults, such as short-circuits and interruptions

Notably the High Voltage Laboratory has already begun researching the possibility of using Wavelet and Fractal analysis for network studies using data that are drawn from this work.

## Acknowledgement

This work was in part supported by the European Union and the Greek Government. PENED 2003, code number 03ED158. Also this work is dedicated to our Professor Dimosthenes Agoris.

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# NEW 400 kV INTERCONECTION OHL KOSOVO - ALBANIA AND TRANSMISSION NETWORK CONCEPT OF KOSOVO

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## Abstract
The paper describes the results from feasibility study of the Kosovo – Albania 400 kV interconnection transmission line to realize economic benefits from power exchanges between Kosovo and Albania and other countries of SEE Power Market. The new interconnection will provide these two complementary systems (Kosovo as thermal oriented and Albania as hydro oriented) with an adequate transfer capability necessary to implement the least-cost generation investment plan and to perform an appropriate short-term and long-term coordination of their respective systems. Based on multi steps energy and power evaluation for touched systems as well as wider systems in region and aided by modern software tools for medium-term hydrothermal scheduling and simulation of coordinated operation, interconnection was justified. Analyses of the reliability of composite interconnected system have shown benefits for wider region.
The long term concept of 400 kV network in Kosovo has been developed as important infrastructure in the framework of new thermal power plants Kosovo B/C and economical development of Kosovo, respectively. This concept enables to enhance reliability and flexibility of network operation. The formation of 400 kV and 110 kV loops are resulting as needed solution.

**Keywords:** Interconnection, Power exchange, Regional electricity market, Network concept, Power Plant.

## Background
Several technical-economical studies [3], [4], [5], [7], [8], [9], [12] have analyzed the situation in energy sector and have defined the future of energy sector development in Kosovo and Albania. The White Paper on Energy Strategy and Policy of Kosovo is prepared in respect of Energy Community Treaty [11].
As a part of the SEE interconnected system, the power sector of Kosovo is passing a transition period and there are a number of major challenges outstanding that must be addressed aiming at the establishment of a reliable and efficient energy sector capable to operate and to contribute within the Regional SEE electricity market. There are large investments required in power generation and transmission, and there is a need to develop a framework to support mobilization of required financing.
Some of the highest priority projects in energy sector in Kosovo with national and regional interest are:

1. Interconnection transmission line 400 kV Kosovo - Albania;
2. Project of new 2000 MW TPP Kosovo C;
3. Definition of Kosovo’s transmission network concept to support the rapid increase of internal demand and the future export of electric energy from Kosovo and cross-border trade.

Power efficiency and reliability can be improved in the SEE region if the energy is dispatched on purely economic basis and all obstacles to commercial development of interconnections are eliminated.

The South East Europe Regional Electricity Market (SEE REM) would provide for: (i) a more efficient supply to meet the regional demand by better use of resources, (ii) possibility of development of large-scale projects, (iii) increased competition, (iv) increased market liquidity, (v) reduced supply risks, (vi) improved supply quality and reliability, and (vii) reduced environmental impact; and last but not least (viii) facilitate their participation in the internal market of the EU.

The market participants are most concerned about transmission expansion because changes to the transmission system can dramatically change their ability to access the market, and/or the price at which electricity can be either bought or sold. The establishing electricity exchange between the Kosovo and other regional electric power systems is of a crucial importance for the future development of the Kosovo power system. A new 400 kV line between Kosovo and Albania enabling future power exchanges was estimated to be of a common interest in both directions and is economically more profitable than other variants considered. The new 400 kV line would strengthen the regional interconnections and greatly enhance Kosovo's options and therefore its bargaining position in reaching beneficial electric energy exchange arrangements.

The following methodology is applied for the feasibility study: a) technical and economic comparison of all proposed interconnection variants; b) the selected variant is analyzed in detail for the economic and financial viability of the project together with a preliminary design and environmental impact.

## 1. Study Methodology

The study [1] has considered six variants with different topology and different line routing. The following activities have been carried out:

- Establishment of computer models for analysis of interconnected transmission system including regional transmission network.
- Development of scenarios of economic power exchange between Kosovo and Albania;
- Development of inter-regional, North – South and East – West power exchanges scenarios. The role of Turkey power system as exporter country is taken into consideration in 2020.
- Detailed transmission network performance analyses aimed on evaluation of load-ability of each interconnection alternative;
- Determination of Total Transfer Capability (TTC) and Net Transfer Capability (NTC), between Kosovo and Albania power systems for each interconnection reinforcement alternative;
- Economic evaluation of each interconnection alternative based on cost/benefit analyses under technical and economic points of view;
- Selection of the best alternative of interconnection reinforcement.

The analysis of loadability of the interconnection line between Kosovo and Albania in particular, and the performance of the transmission network in general, is based on computer simulations of the annual operation of the interconnected transmission network.

The simulations are performed for target years 2010, 2015 and 2020. Each simulation represents a year of the operation of the future interconnected network based on the projections of the following main factors:

- Projected Customer Demands
- Generation Dispatch: Albanian and Kosovo generators are optimally dispatched to meet the annual hourly load curves.
- System Configuration: For target years the transmission network and the new interconnections projects of the so called “Common Interest Projects” have been considered.
- Base Scheduled Transfers: Based on the result of generation dispatch, the projected exchange of power between KEK and KESH are modeled as economic power transfer between two power systems. The impact of power transfer of the third countries on the region is considered modeling various scenarios of bilateral power exchanges.
- System Contingencies: For steady state security analysis and transfer capability determination a significant number of contingencies of transmission systems are analyzed.

The study has evaluated the increase of transfer capability between Kosovo and Albania is based on calculation of the TTC and the NTC of the interconnected transmission network identifying the most restrictive limitations of thermal and voltage limits for both sound network (N criterion) and after loss of any single element (N-1 criterion).

Transfer capability is determined by simulating transfers from Kosovo to Albania and vise-verse non-concurrently with other area transfers (“non-simultaneous” transfers) and assuming different levels of North - South and East -West transits (“simultaneous” transfers).

## 2. Histograms of Network 2000 – 2006

Historical data on transfers realized by 400 kV transmission lines of Kosovo shows great variations from year to year and the tendency is that the volume of power and energy transfers is increasing year by year.

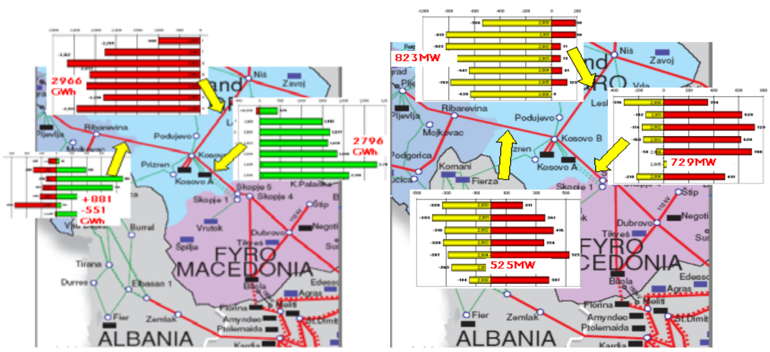


**Figure 1.** Trend of annual electric energy wheeled through Kosovo (today)

Figure 1 depicts the trend of annual energy and peak loads of 400 kV lines during the period 2000 – 2006. At the end of period, taking as a reference year 2001, the volume of energy wheeling was increased 300%.

## 3. Scenarious of Power Exchange on the See Region

The loading of interconnection lines depends on the level of electrical energy trades on the region and varies with load growth. All regional studies have reached at conclusion that at the present time the inter-country electricity trade electricity is at very low level and the electricity market has not enough developed. Nevertheless the present level of exploitation of 400 kV transmission system of Kosovo is quite high and the tendency is towards an increasing of the energy wheeling through Kosovo. In additional the development of the electricity market will require more transfer capabilities for energy exchanges among SEE countries.

In our approach two main scenarios were considered regarding to inter-regional transfers:

**Scenario A:** Only natural power-flow circulation, i.e. null power exchanges between other power systems.

**Scenario B:** For each target year, a grid of bilateral transactions between power systems is prepared and each of them is assumed to be a base-load, 24 hours per day depending from seasons of the analyzed year.

In Figure 2, the power exchange scenario in 2020 is illustrated.


**Figure 2**. Scenario of power exchanges in 2020

## 4. Evaluation of the Loadability of the New Interconnection Line

The evaluation of the loadability of the new interconnection line is performed based on the load models of each system called sequential hourly Weekly Load Diagram (WLD). The WLD are calculated from sequential hourly variation of forecasted annual load curves of the target years, of the analyzed period.

In order to quantify the loadability of the different variants of the new 400 kV interconnection line, the utilized methodology considers the steady-state behavior of the power system taking into account the all load levels of WLC of each representative week for aggregated system Kosovo – Albania and load models of other countries.

The method simulates the performance of the system in target year by calculating a large quantity of AC power flow scenarios, for each load level in sequence for the normal condition of the transmission network and applying for each load level the corresponding generation dispatch.

For implementation of coordinating operation (hydro-thermal dispatch) of Kosovo and Albanian power system the needed transfer capability between Kosovo and Albania is estimated to be on the range 690 MW (year 2010) and 810 MW (year 2015).

From energy and power transfer point of view the best interconnection reinforcement variant is the Variant V1: Kosovo B – Kashar through Prizren. The worst variant is Variant V3 a line between Skopje (FYROM) and Elbasan (AL). The priorities of the first variant are the ability to realize an annual volume of energy transfer of about 70 % more and the relief of North – South corridor through a decreasing of about 27 % of the energy transits in critical section 400 kV Ferizaj (KS)– Skopje (FYROM).

## 5. Technical and Economical Comparison of Alternatives

The interconnection alternatives first are tested to satisfy the planning and reliability criteria and requested technical performance indexes and finally compared on an economic basis. The results of comparisons are used in the decision-making process. The technical performance is assessed by evaluating the loadability of the new line, improved reliability and fulfillment of planning criteria, increase of system transfer capability, and reduction of transmission losses.

The recommendation for interconnection variant is based upon NPV economic criterion considering the annuity of the investment cost of the new line and evaluating the annual benefits resulting from their integration in the interconnected system.

The best alternative of interconnection reinforcement is the one that presents the best technical performance and with the highest profitability ratio.

The methodology compares and ranks various options based on a set of indicators evaluated for each variant. Indicators are defined as measures of relative “goodness” of a particular technical and/or economic attribute of an alternative.

The following technical performance indicators are considered:

**A) Loadability**

This set of indices takes into account the main reason of the construction of the new line, i.e., the ability to transfer electric energy from generation resources to load under a wide variety of operating conditions.

**B) Transfer Capacity**

The aim is to assess the ability of the new line to improve overall transfer capability of the system allowing economic exchange of electric power among systems. The NTC [MW] is representative of the evaluating index.

**C) Energy Losses**

This index evaluates the benefits from reduction of power and energy losses from introduction of the new line. The whole annual reduction of the energy losses (ELR) is used as index.

**D) Transmission network performance**

This set of indicators assesses the improvement of the quality and reliability of the transmission network due to introduction of the new line.

**E) Environmental Impact of the line**

This index take in consideration the direct impact of each variant based on: kilometers of new. The new transmission Right-of-Way (ROW) required (km) from the line.

Taking into account results of investigations carried out and the comparison of defined technical and economic indicators evaluated for each of the alternatives of the new 400 kV line, it is selected the Variant V22: a new 400 kV line from Kosovo B(KS) to Kashar (AL) as the most advantageous Variant. This variant illustrated in Figure 3 represents the best combination of technical indicators and economical ones.

## 6. Assesment of Economic Exchange of Electric Power among Kosovo and Albanian Systems

The aim second phase of the study was to determine electrical energy transactions along the proposed transmission lines simulating different policies of joint operation and generation scheduling. Also potential revenues from export-oriented additional power generation capacities (new TPP Kosovo C) is estimated in the framework of competitive electricity markets in both countries and in the regional level` taking in consideration that both systems will operate within the liberalized SEE REM.


**Figure 3.** Line 400 kV Kosova B – Kashar.
Route Kosovo B - Morinë - Fierzë - Vau Dejës - Tiranë

The following activities have been carried out:

1. Development of integrated modeling framework consisting of computer models for the power market analysis [10] including:
   - **PROMED** computational tool for medium-term hydrothermal scheduling and simulation of coordinated operation of Albanian system mainly hydro-production, and Kosovo system as thermal-production.

- **GRARE** software tool to perform a probabilistic analysis of the static reliability of composite interconnected systems. It will be used to evaluate the amount of power and energy transactions that can be transferred in an economical and reliable manner between partners of interconnected system.

2. Simulation of different annual operation scenarios necessary to evaluate benefits resulting from bilateral electric energy exchanges.
3. Determination of amount of power transfer on interconnected transmission network and assessment of loadability existing on new transmission lines between two countries and in the region.

The cost savings are identified to be due to:

- Hydro-thermal dispatch of resources and electricity trade enabling power systems to lower their annual generation costs over the study period (up to 2020);
- Non-coincidence of peak loads and lower need for additional capacity;
- Reduction of the cost of instantaneous reserves and spinning reserves for two power systems joined together;
- More efficient dispatch and utilization of water resources due to lower specific consumption of water for any kWh produced by hydro units;
- More efficient dispatch and utilization of thermo power plant resources due to higher efficiency of boiler and turbine units working at optimum operation regime;
- Improvement of reliability of system operation, etc
- Macroeconomic benefits providing electricity at lower prices to the customer.

In order to assess the benefits that could be directly attributed to the new 400 kV interconnection lines Kosovo – Albania the simulations with GRARE are performed for two basic configuration of the transmission network:

- Without new interconnection line (Reference Case) and
- With the new 400 kV interconnection line Kosovo - Albania.

The transmission network analysis considers the role of new Kosovo – Albania interconnection not only for electric energy exchanges between two countries, but also for wheeling of power between SEE REM members analyzing different inter-regional, North – South and East – West power exchanges scenarios.

The results of PROMED simulation are summarized in Table 1 regarding target year 2015. Because of the difference between their respective structures, we can observe a reduction of generation cost through a close cooperation between the electric systems of Kosovo and Albania. The general benefit for the whole aggregated system, if no transmission limits are considered, is estimated in the range of 91 M€/year in 2015, which was mainly due to fuel cost reduction.

**Table 1.** Results of PROMED simulation in 2015

| Year 2015 ALBANIA & KOSOVO | Reference Scenario | | Joint Operation | |
|---|---|---|---|---|
| | Annual Prod GWh | Annual Costs k€ | Annual Prod. GWh | Annual Costs k€ |
| Hydro Albania | 4,900 | 0 | 4,898.3 | 0 |
| Hydro Kosovo | 80.83 | 0 | 80.8 | 0 |
| Thermal (lignite) KS | 6,493, | 76,857 | 8,953.9 | 106,787 |
| Thermal (gasoil) AL | 4,226.5 | 180,910 | 1,820.5 | 72,535 |
| Import peak/high | 62.42 | 2,185 | 0 | 0 |
| Import med/low | 52.65 | 1,580 | 0 | 0 |
| Total Import | 115.1 | 3,764 | 0 | 0 |
| Load Curtailment | 25.5 | 5,111 | 0 | 0 |
| Forced Export | 89.4 | 0 | 0.8 | |
| TOTAL (GWh) | 15,752 | 270,406 | 15,753 | 179,322 |

## 7. Additional Scenario

For target year 2020 the role and impact of Kosovo export-oriented additional power generation capacities has been investigated through the simulation of a regional liberalized electricity market where IPP in Kosovo and other generation companies compete. The competition is taken into account assuming that generation companies sign physical bilateral contracts and bidding on a Power Exchange implementing a day-ahead hourly energy market, characterized by a system marginal price and by a market-splitting zonal congestion management. In this case, PROMED has determined the hourly zonal market prices of the energy sold on the Power Exchange. Different scenarios have been analyzed characterized by different volume of electric energy exported in neighboring countries, Greece, and Italy (through DC cable Greece- Italy).

It was considered that the time band prices are equal to the fuel cost for the typology of marginal thermal plant in the same time band.

For this scenario the following different simulations were performed:

1. **Base Case**
2. **IPP of new TTP Kosovo C** where there are two units of 500 MW
3. **Bilateral Contract for** exporting 100 MW (fixed along the whole year) to Italy
4. **Bilateral Contract for** exporting 200 MW (fixed along the whole year) to Italy

A summary of the simulation of a competitive framework in the entire SEE region is given in Tables 2 and 3 in case of the new TPP Kosovo C 2x500 MW. The tables summarized the production together with fuel costs, electric energy transaction on the regional market and the associated income (export) and costs (import) for Albania, Kosovo and aggregated system.

**Table 2.** Summary of the results in case of Kosovo C 2x500 MW

| IPP Kosovo C 2x500 MW | Albania | Kosovo | Albania & Kosovo |
|---|---|---|---|
| Thermal [GWh] | 1,947 | 13,188 | 15,135 |
| Hydroelectric [GWh] | 5,322 | 81 | 5,402 |
| Net Export/Import [GWh] | -4,407 | 6,305 | 1,898 |
| Thermal Averaged production cost [€/MWh] | 38.82 | 10.87 | 14.38 |
| Total Fuel Costs [k€] | 75,574 | 143,342 | 218,746 |

**Table 3.** Balance from Export/Import in case of Kosovo C 2x500 MW

| Balance Export - Import IPP Kosovo C 2x500 [M€] | Time Band 1 | Time Band 2 | Time Band 3 | Total Fuel Costs |
|---|---|---|---|---|
| Albania | -29.3 | -59.3 | -58.2 | 75.6 |
| Kosovo | 48.7 | 87.3 | 78.7 | 143.3 |
| Albania&Kosovo | 19.4 | 27.9 | 20.5 | 218.7 |

In this competitive electricity market the production of Kosovo increases in all the time bands in respect to the Base Case. In Albania the thermal production decreases of 1,868 GWh in order to use the cheaper generation of Kosovo. The production of the Kosovo + Albania system increases of 278 GWh.

## 8. Concept of Kosovian Transmission System

In the line with a new interconnection between Kosovo and Albania it was analyzed by holistic approach the concept of transmission network development inside Kosovo power system [13, 14]. Considering to the optimal hierarchy of the four voltage levels 400/110 /20/0.4 kV (contrary to present 6 levels) as future economical solution in Kosovo and with comparison to the present situation as well as new generation development plans, the long-term concept of transmission network development have been developed. As depicts at the figure 4 it is obviously that 110 kV loop have to be formed soon and 400 kV loop in long-term period. This concept brings a much better conditions for power quality for customers.

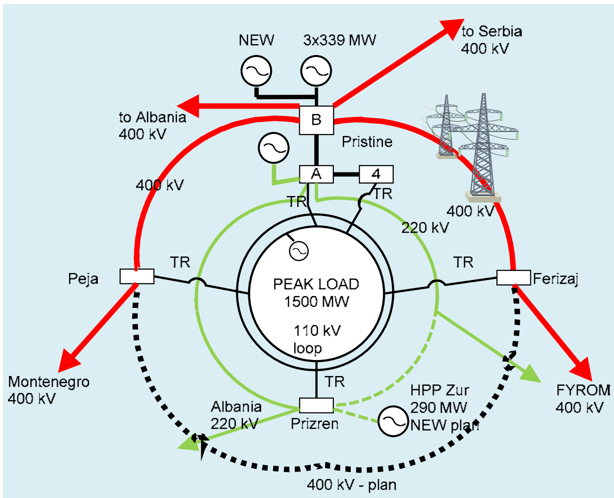


**Figure 4.** The long-term development concept of Kosovian Transmission network

## 9. Conclusions

- The South Eastern Europe Regional Electricity Market (SEE REM) would provide more efficient supply to meet the regional demand by better use of resources, increased competition and improved supply quality and reliability,
- The new interconnection Kosovo – Albania 400 kV interconnection is found to be profitable due to systems complementarities (thermal-hydro),

- The new Kosovo – Albania interconnection, will also enhance exchanges and wheeling of power between SEE REM members as well as increase NTC capacity between two neighboring countries,
- In line with a new interconnection it have been developed a new concept of the Kosovian Transmission network considering strategy development of new Thermal power plans in Kosovo. The long-term concept consider an own 400 kV/110 kV loop and from economical point of view development of 400/110/20 kV voltage level hierarchy.

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# DEREGULATED ELECTRICITY MARKET IN SOUTH – EASTERN EUROPE: ACTIVE NETWORKS

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## Abstract
Active networks are an integral part of the European energy technology plan that is envisaged to play a vital role in the years to come in breaking once and for all the link between economic development and environmental degradation, by ensuring sufficient clean, secure and affordable energy.

Electricity networks of the future are to evolve in the direction of supporting distributed decision-making and bi-directional flows. This anticipated change in the operation of the electricity networks would lead to control being distributed across nodes spread throughout the system. Not only could the supplier of power for a given consumer vary from one time period to the next but also the network use could vary as the network self-determines its configuration.

Such active networks would require advanced hardware and management protocols for connections, whether for suppliers of power, for consumers or for network operators. The market structures and regulatory mechanisms need to be in place to provide the necessary incentives.

This type of active network would ease the participation of distributed generation (DG), renewable energy sources (RES), demand side management (DSM) and flexible energy storage and would also create opportunities for novel types of equipment and services, all of which would need to respect the protocols and standards adopted. New business and trading opportunities can be envisaged- based on new power sources, new power consumption habits and new regulation, all of which favour cleaner and more efficient generation and consumption as well as the development of a flexible, multi-user connected network which establishes power and communication transfer possibilities among all players.

Active two-way flow of energy and information between customer and supplier will heighten efficiency and lead to cleaner electricity generation.

**Keywords:** Active network, distributed decision, smart networks, bi-directional flow, demand side management, distributed control, distributed generation, distributed systems, distributed intelligence, power electronics, energy storage systems, innovative technologies, microgrids, self synchronizing algorithms, responsive system, self-healing system, plug and play.

## 1. Introduction
Electricity networks have provided the vital links between electricity producers and consumers with great success for many decades. The fundamental architecture of

these networks has been developed to meet the needs of large, predominantly carbon-based generation technologies, located remotely from demand centres. The energy challenges that the world is now facing are changing the electricity generation landscape.

The drive for lower-carbon generation technologies, combined with greatly improved efficiency on the demand side, will enable customers to become much more inter-active with the networks. More active networks are the way ahead, but these fundamental changes will impact significantly on network design and control.

The European Commission's (EC) Energy Package of January 2007 emphasises that,

- Europe has entered a new energy era,
- Innovation in energy technology shapes society,
- Greenhouse gas emissions are the greatest and widest-ranging market failure ever seen,
- 21st century technology shall break once and for all the link between economic development and environmental degradation.

From the EC Energy Package the overriding objectives of European energy policy are to be **sustainability, competitiveness and security of supply**, necessitating a coherent and consistent set of policies and measures to achieve them. The electricity networks lie at the heart of the energy system and must evolve to meet the new challenges. The future electricity grids must provide all consumers with a highly reliable, cost-effective power supply, fully exploiting the use of both large centralised generators and smaller distributed power sources in a seamless way with adequate flexibility to attract small customers to exploit the benefits of smarter equipment in their premises.

## 2. The Driving Factors to Change

From the vision of the SmartGrids Technology Platform[1] the current climate demands change in the way electricity is supplied. As the internal market develops, European citizens will start to benefit from greater choice and lower costs. Fossil fuels are running out and the security of electricity supplies is under threat. Environmental issues have moved to the fore and the EU must meet targets set. As a consequence the driving factors to change are,

- The European Internal Market
- Security and Quality of Supply
- The Environment

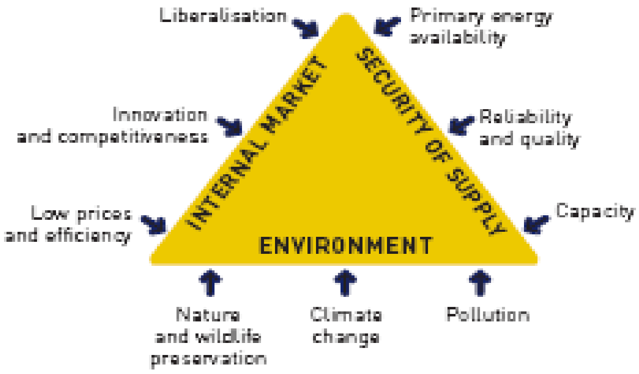


**Figure 1.** The driving factors to change

## 3. Evolution of Active Networks

The evolution of active networks with the corresponding management issues that are involved, summarised in the figure 2 below, can be described as follows:

- **Initial stage:** Extension of Distributed Generation (DG) and Renewable Energy Sources (RES) shall be experienced, with monitoring and remote control to facilitate greater connection activity. Some connections will rely on bilateral contracts with distributed generators for ancillary services. Rules are to be developed to outline physical and geographical boundaries of contracting.

- **Intermediate stage:** A management regime is developed capable of accommodating significant amounts of DG and RES. Local and global services are introduced and trading issues are managed based on adaptability without information overload and other control issues.

- **Final stage:** Full active power management shall be experienced. A distribution network management regime shall be in operation using real-time communication and remote control to meet the majority of the network services requirement. The transmission and distribution networks are to be both active, with harmonised and real-time, interacting control functions and efficient power flow.

When the final stage is achieved, the users of the network will expect a responsive system. They will experience connection according to simple and defined standards. They will also expect accurate billing – to pay for what they use and to be paid for what they supply. Connection to the system will be simple “plug and play” with effective real-time trading.

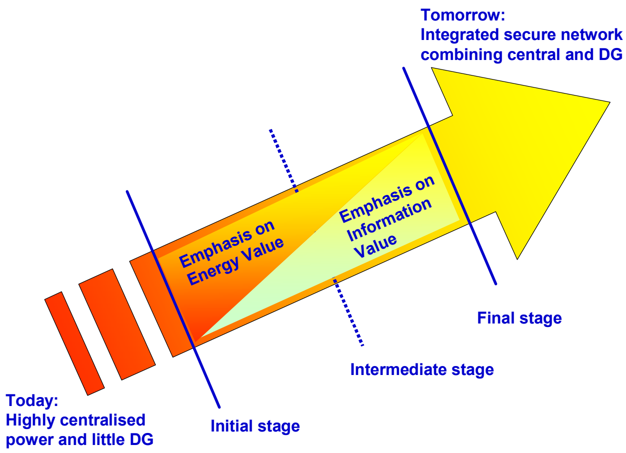


**Figure 2.** The gradual change from Centralised to integrated generation with effective operation of DG and RES

## 4. Technologies to Make it Happen

Analysing system architectures is an important early step in setting the direction for future grid development. Delivering an adequate architecture will require the development of a number of ‘enabling’ technologies. Many of these are already available to some extent; some are currently being employed in other sectors. Other new technologies currently available are further away from commercialisation and widespread deployment on grid systems. The resources needed to bring totally new products into use in grid systems are often significant. In these situations, success will most likely be achieved through combining efforts and resources within a co-operative research, development and demonstration programme. In the absence of a central planning regime, this can only be accomplished if all stakeholders form a shared vision for future grids and develop an implementation framework that is consistent with the liberalised business model of the electrical industry in Europe.

- Active distribution networks, revealing characteristics of today’s transmission grids;
- New network technologies that facilitate increased power transfers and losses reduction (e.g. gas insulated lines, superconductivity, high operating temperatures, Flexible AC Transmission Systems (FACTS) technologies, etc.);
- Wide deployment of communications to enable grid automation, on-line services, active operation, demand response and Demand Side Management (DSM);
- Power electronic technologies for quality of supply;
- Stationary energy storage devices.

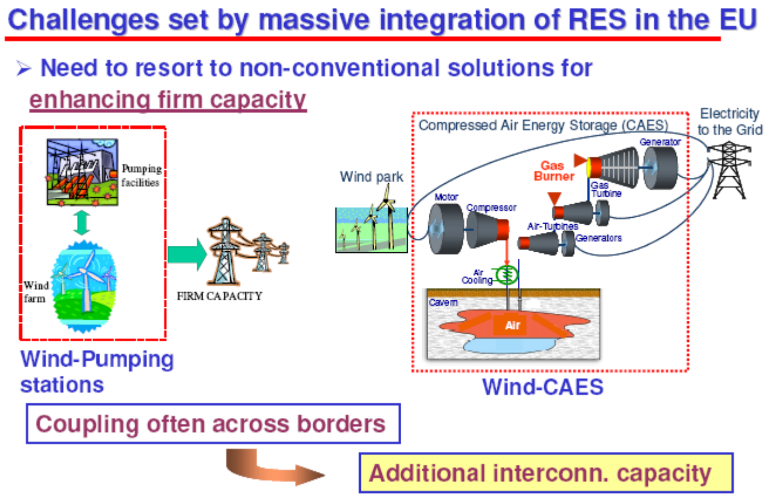


**Figure 3.** New innovative solutions for transmission network

## 5. Points to Consider

To enable the concepts for change to be realised and the benefits to become a reality, the change of the electricity supply structure towards progressively more DG, RES and active grids requires that a number of wider factors be addressed. These include:

- Improvements of security standards in the context of critical infrastructures;
- Integration of both central and distributed generation;
- Integration of innovative technologies into existing grids;
- Harmonisation of equipment standards to allow "plug-and-play";
- Increased funding for large research incentives, including public and private sharing;
- Higher education and skills issues.

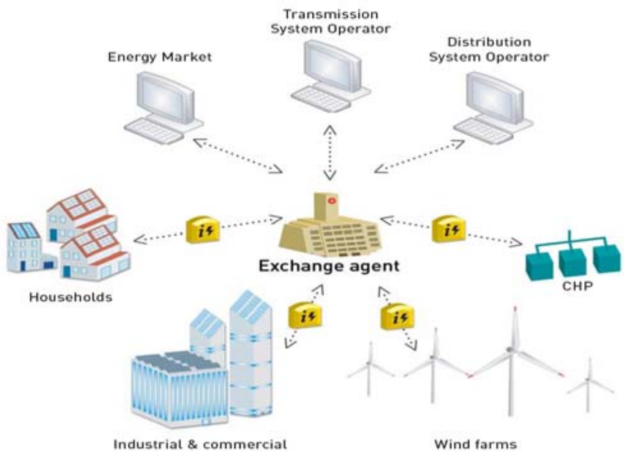


**Figure 4.** The control of an active network

In this process and in order to enhance grid flexibility and robustness it is important that,

- A toolbox of proven technical solutions is created that can be deployed rapidly with the necessary system reliability that will allow universal acceptance,
- Interfacing capabilities are looked at in detail to facilitate the connection of new technologies on existing systems allowing the full exploitation of existing equipment but at the same time enhanced with the added capabilities of the new,
- Technical standards and protocols should be established that will ensure open access to all manufacturers of reliable equipment and at the same time safeguard the deployment of grid equipment, metering systems and control / automation architectures that will evolve gradually as the system transforms into the new based on the old and proven,
- Information, computing and telecommunication systems are developed hand in hand with the electricity network requirements to facilitate innovative service arrangements in line with the two way communication that is envisaged for the future.

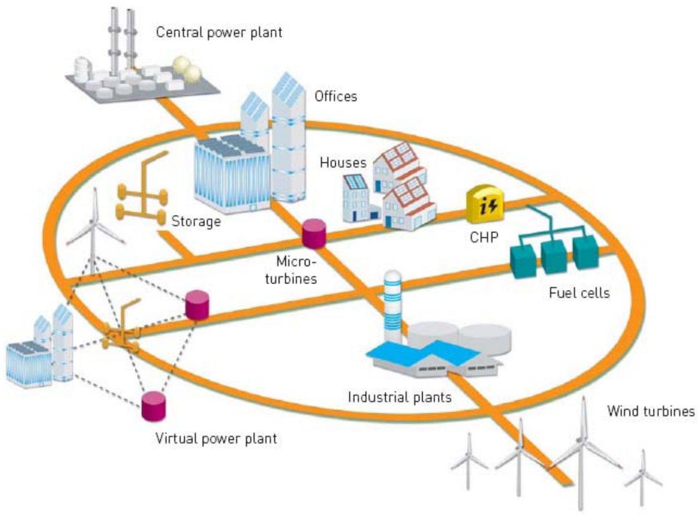


**Figure 5.** The seamless interconnected system of the future linking central generation and DG with effective distributed control

## 6. Conclusions

The electricity networks have managed over the years to serve the electricity industry with flexibility and high reliability. However, the traditional high capacity central generation away from the load centres is to gradually be replaced by new generation technologies that support the sustainable path that EU has set out as a requirement. To a great extent these technologies are of low capacity and are best integrated at distribution voltages. It is envisaged that in years to come all users of electricity are going to be potential generators as well. The progress to this new environment can only materialise if the electricity networks become more active facilitating bi-directional flow of energy with distributed control throughout.

The vision for the networks of the future described in the above paragraphs can materialise with added benefits to all users as complementary to the high reliability standards that the industry and the customers are experiencing today.

Along this route for the development of the new grids, communication at every level is essential. Effective dialogue between stakeholders will ensure that relevant information influences the system design. The latest technologies will be incorporated into the network and the approach will remain flexible to accommodate further developments. Along these lines it is expected that once the networks are up and running, two-way flows will exist between provider and user.

Many factors will shape future electricity networks and the actions and decisions taken today will influence longer-term outcomes. It is therefore important to recognise that a flexible approach and regular interaction with stakeholders is required to respond to future challenges and opportunities.

During this process all the stakeholders should be aware that a two-way flow of energy and information between customer and supplier will heighten efficiency and lead to cleaner electricity generation.

Above all, the thoughts and aspirations of everyone involved should be active enough in breaking once and for all the link between economic development and environmental degradation, by ensuring sufficient clean, secure and affordable energy.

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# CO2 EMISSIONS FROM THE USE OF FOSSIL FUELS IN CRETE – GREECE

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## Abstract

The use of fossil fuels for energy generation results in $CO_2$ emissions creating serious environmental problems. In Crete oil is mainly used for power generation, heat production and transportation. In addition apart from oil, small quantities of LPG are used as well as various renewable energy sources (RES) . In 2000, power generation contributed 53% of the $CO_2$ emissions, industry 1,35%, the transport sector 37,33% and the dwellings (for heating) 8,32%. The mitigation of $CO_2$ emissions in the future in the island makes necessary the promotion of various polices, focused on.

a) Improvement of energy efficiency in various sectors
b) Increasing the share of renewables in power generation, for heating and cooling and in the transport sector.

It is found that the $CO_2$ emissions per capita in Crete is lower than the corresponding $CO_2$ emissions on National level.

## 1. Introduction

The use of fossil fuels today results in increased $CO_2$ emissions creating severe environmental problems. The island of Crete presents high growth rates (3-5% annually) in power demand, which results in growth of $CO_2$ emissions every year [1]. Oil is mainly used in Crete for electricity generation, for heating buildings, in industry and in transportation. Wind power, solar power, hydropower and biogas are used for electricity generation, and solar energy and biomass for heat generation. Wind electricity covers today approx. 10% of the power consumption in Crete. Small quantities of LPG are also used in Crete. Governmental policies for energy savings and the promotion of RES are focused in state grants using the European structural funds. Various investments of the private sector are heavily subsidized mainly in Energy saving technologies and in Renewable technologies. However the public sector lags behind in the use of the abovementioned technologies. Although there are various applications in Wind energy, solar thermal energy, photovoltaics and solid biomass burning, very little effort has been made in the promotion of Rational Use of Energy (RUE) and improving the energy efficiency in various sectors of the economy.

## 2. $CO_2$ Emissions From The Use Of Fossil Fuels In Crete

### 2.a Electricity Generation

The electricity generation and the $CO_2$ emissions in Crete (2000) are presented in Table 1.

**Table 1.** Electricity generation in Crete (2000)

| | GWH | % |
|---|---|---|
| Thermoelectric plants | 1934,11 | 90,43 |
| Wind farms | 203,77 | 9,53 |
| Small hydroelectric plants | 1,02 | 0,04 |
| TOTAL | 2138,9 | 100,00 |
| $CO_2$ emissions | 1,584,517 tn | |

In the thermoelectric plants in Western and Eastern Crete, oil (Diesel and heavy oil) is used as fuel.

**2.b CO2 Emissions From The Use Of Fossil Fuels In Buildings**
Diesel oil is used as main fuel for heating the buildings and additionally some small quantities of LPG. It is estimated that (year 2000) 248.822 tn of $CO_2$ were emitted because of its specific use.

**2.c $CO_2$ Emissions From The Use Of Fossil Fuels In Industry**
Diesel and heavy oil are used in industry together with biomass (olive kernel wood) and small quantities of LPG, for heating purposes. It is estimated that (year 2000) 40.302 tn of $CO_2$ were emitted from that.

**2.d CO2 Emissions From The Transport Sector In Crete**
Gasoline and diesel oil are used in vehicles, airplanes and boats in Crete. It is estimated that (year 2000) 1.116.186 tn of $CO_2$ were emitted from such activities.

In table 2 the emissions of $CO_2$ in Crete from various activities are presented.

**Table 2.** Emissions of $CO_2$ from various activities in Crete (2000)*

| **Activity** | **TN $CO_2$** | **(%)** |
|---|---|---|
| Electricity generation | 1,584,517 | 53,00 |
| Industry | 40,302 | 1,35 |
| Transportation | 1,116,186 | 37,33 |
| Households | 248,822 | 8,32 |
| Total | 2,989,827 | 100,00 |

* Emissions from biomass burning are not included.

## 3. Comparison of Co2 Emissions in Crete and in Greece

The $CO_2$ emissions in Crete during 2000 were 5,44 tn/ capita. This is lower than the National average, which was 8,49 tn/capita in 2004. The low $CO_2$ emissions per capita in Crete are related with various reasons that include:

a) The low $CO_2$ emissions during power generation since oil instead of lignite is being used.
b) The mild climate in the island and the low requirements for heating buildings
c) The rather few and small size industries that exist in Crete
d) The high penetration of biomass (olive kernel wood) as a fuel for heating purposes.

In table 3 the distribution of $CO_2$ emissions in Crete and on Nationwide is presented.

**Table 3.** Distribution of $CO_2$ emissions in Crete and in Greece

| SECTOR | % $CO_2$ EMISSIONS | |
|---|---|---|
| | CRETE | GREECE |
| Electricity generation | 53,00 | 51 |
| Industry | 1,35 | 18 |
| Transport | 37,33 | 23 |
| Households | 8,32 | 8 |
| Total | 100 | 100 |

## 4. Policies for the Mitigation Of CO2 Emissions In Crete

Although Greece has a very centralized policy making system, there are opportunities for creation of regional, local and municipal policies concerning the RUE and promotion of RES. The improvement of Energy efficiency and the increased use of RES in all sectors of the economy are necessary for mitigation in the future the $CO_2$ emissions. In table 4, the main recent EU directives for RUE and promotion of RES are shown. The Greek legislative framework has not complied until now with some of these directives like 2002/91/EC and 2006/32/EC related with the improvement of energy efficiency. However it is well accepted today that, achievements in energy savings in every sector of the economy is a prerequisite for mitigating the $CO_2$ emissions. Therefore the regional energy policies in Crete should be focused.

a) In the promotion of RES
b) In improving energy efficiency [2]

**Table 4.** Main EU directives for RUE and promotion of RES [3-7]

| Directive | Field |
|---|---|
| 1. 2001/77/EC | Promotion of electricity from RES |
| 2. 2002/91/EC | Energy performance in buildings |
| 3. 2003/30/EC | Promotion of Biofuels |
| 4. 2004/8/EC | Cogeneration of heat and power |
| 5. 2006/32/EC | Energy end – use efficiency andEnergy services |

### 4.1 Promotion of Res

The development of wind energy in Crete is considered satisfactory. In addition the use of solar thermal systems for hot water production is well developed compared with other Mediterranean regions but it can be improved a lot more.

There is also a boom in photovoltaics after the attractive feed-in tariffs that the new law 3468/06 offers [8]. The use of solid biomass for heating purposes is satisfactory, but in can be further improved. Solar thermal energy can be further used for space heating and (with new innovations) in solar cooling. Summarizing the use of RES in Crete, mainly solar energy, wind energy and biomass, are well developed in comparison with other regions in Greece, but they can be further improved in the future. Geothermal energy and hydropower have limited possibilities for deployment in Crete.

### 4.2 Improving Energy Efficiency

Very little actions have been implemented in Energy saving policies in Crete [9]. Since the annual growth rate of energy demand in Crete is very high, it is difficult to mitigate the $CO_2$ emissions in the future without an effective action plan for improving energy efficiency. The absence of a legislative framework makes such an effort more difficult. In addition, the absence of Energy service companies (ESCOs) in Greece does not favor such activities.

The existing financial schemes for promotion energy savings and RES are presented in table 5.

**Table 5.** Main financial schemes for promoting RUE and RES in Greece

| | FINANCIAL SCHEME | FIELD |
|---|---|---|
| 1. | Bank loans* | - Energy savings<br>- Renewable energy sources |
| 2. | Investment Grants ** | - Energy savings<br>- Renewable energy sources |
| 3. | Feed – in tariffs*** | - electricity generation and selling to the grid |

*Commercial loans
** Use of European structural funds (Ministry of Development, Ministry of Economy)
*** Law 3468/06

Although the utilization of EU structural funds for energy purposes in Greece is satisfactory, there is obviously a lack of innovative financial tools in order to promote RUE and RES.

## 5. Conclusions

1. Oil is the main fossil fuel that is used for energy generation in Crete and it results in $CO_2$ emissions. The $CO_2$ emission per capita in Crete is lower than the country's average.
2. The reasons for low $CO_2$ emissions in Crete are related with the use of oil instead of lignite for power generation, the mild climate of Crete and the low development of the industry in the island.
3. In Crete there is a high growth rate of power demand annually. Solar energy, wind energy and biomass could have a wide variety of applications for power and heat generation.
4. Although RES have been satisfactorily deployed in Crete, very few activities in the field of improving the energy efficiency have been implemented.
5. The mitigation of $CO_2$ emissions in the future in Crete, requires the development of efficient projects which obtain energy savings, in parallel with further deployment of RES.
6. The creation of regional and local energy policies and the promotion of innovative financial tools in energy sector will help to obtain in the future the desired targets related with the share of RES in total energy consumption.

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# SURVEY OF POWER EXCHANGES – ORGANIZATION AND RESPONSIBILITIES

**Report from CIGRE JWG C2/C5-05**

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## 1. Introduction

The JWG C2/C5-05 Development and Changes in the Business of System Operators has its main working area within the changes the system operators (SO) face in the changing liberalized market system. The terms of reference for the JWG states that it shall focus on the developments and future trends of the system operators in the competitive electricity market environment, monitor the evolution of the system operator activities and describe different development paths and compare actual solutions. The working group has published several papers related to the changes and challenges for the TSO in the new competitive environment [1, 2, 3, 4 & 5]. Other related work is a recent survey paper on the Classification of Energy Markets Worldwide describing current types of Markets [12].

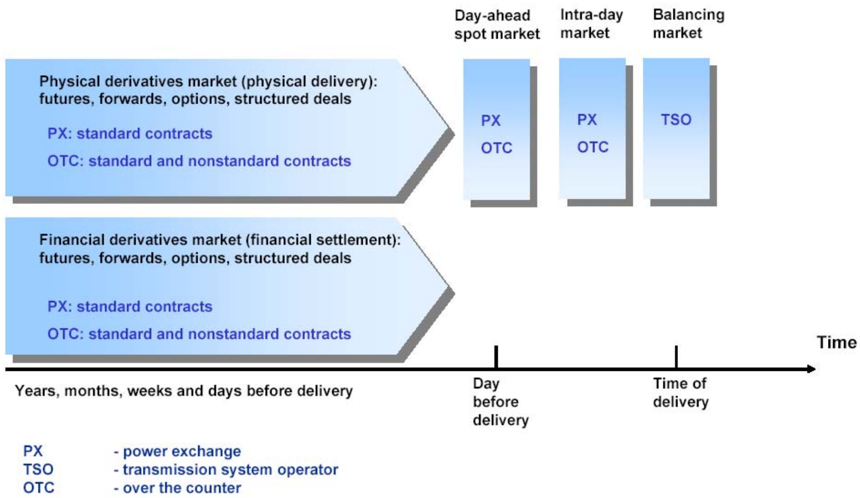


**Fig 1:** Structure of wholesale trading markets

The figure 1 shows the principal structure of the wholesale trading markets divided into the main groups with markets for physical deliveries and markets for financial settlements. The markets for physical deliveries are further divided into markets with different time horizons where responsibilities are indicated. The organization of power exchanges are therefore important for the new environment the SOs are facing. This paper gives a summary of on-going work on the topic of how the Power Exchanges are organized, their responsibilities and to some extent the interface to the other market actors. Major responsibilities, owner structure, regulation aspects and participants are discussed. The purpose of the paper is to give an overview of the most important activities of PXs, how the activities relate to each other and how it impacts the system operators.

## 2. Power Exchange (PX) Responsibilities

The core business of all electricity markets is energy trade. This energy trade can be either physical or financial. The physical energy trade is the end-product and in principle all processes are organized "around" this. This is especially the case in the most mature markets.

There are many different ways to organize a market, depending on how prices, periods, participants, kind of bids and offers, etc, are considered. From the point of view of the prices, there are two main principles: *Uniform-price auctions* and *Bilateral trading*. In many cases both co-exist in the market design, but may address different time periods.

***Price auctions***

There are two main principles of price auctions: Uniform price auctions and Pay-as-Bid. In uniform price auctions, all participants bid different quantities at different prices and a price is determined, which gives the balance between supply and demand. This price is Market Clearing Price (MCP). This will be the price for all exchange of energy. Uniform price auctions are the most commonly used on Power Exchanges. For some markets, especially for ancillary services, Pay-as-Bid is also used. The participants then get paid according to bid price and not the market clearing price.

***Bilateral trading***

In bilateral trading the demand is represented explicitly in the market. Offers and bids are firm. Due to the sequential process, bilateral trading is incompatible with optimization through centralized dispatch. There is also a lack of transparency of prices to end-users. Rules governing the trade are typically derived from practice and based on industry agreements. Transactions are carried out bilaterally, and counterparty risk is born by the market participants. Increasingly, transactions on OTC electricity markets, are cleared by third parties, such as brokers or the power exchanges, thus improving liquidity [6]. The typical processes that can be found in the PXs are the following:

- Day-ahead market
- Intra-day market
- Financial trade
- Clearing
- Congestion management

### 2.1 Day-ahead market

Uniform-price auctions may address different markets and time horizons. One particular market, where this principle is applied, is in the day-ahead market. The dispatch may here be centralized or based on self-dispatch. Both principles are used. Centralized dispatch may have advantages from a system security point of view, since this is an efficient principle for clearing of the market taking the network security into account. The main challenge is the amount of data required. The transparency of prices to end-users is better, and resolves the issues of equal market access and priority to the transmission grid. In a uniform-price auction bidding is simpler, as marginal cost is the best bidding strategy if sufficient number of market actors is present. The most important result from the day-ahead market is the Market Clearing Price and the Exchanged Quantities. PXs accept demand and generation (price, quantity) from its participants, determines the price at which energy is bought and sold (a uniform price).

The market design can be quite different. The maturity of the market is a keyword for the level of functionality and flexibility. In some systems the market can either be mandatory or voluntary. Who is eligible to participate in the market, and to which extent there is a demand participation in the market clearing process, varies. The approaches to give incentives for new capacity and the principles for compensation of ancillary services are important to get a sustainable market design. The complexity of the bids is driven by system needs.

**2.2 Intraday Market**

Intraday markets often represent a continuous trading during the day. The motivation is that the day-ahead markets are cleared at least 12 hours in advance of physical delivery. At this time there may be uncertainties in for example, wind power generations, resource available from run-off-river plants, as well as demand forecasts. The deviations of generation and consumption can be very expensive. Therefore it is quite common to make it possible for participants to adjust their schedules closer to real time or to resolve the deviation problem in some way. It is now more common to resolve such issues by running a process closer to delivery organized as an intra-day market. This may be especially important as more intermittent generation is integrated in the system. A main characteristic of such a market is that it is mainly an adjustment market, with essentially free participation among those eligible for spot market participation. However, the participation is voluntary. There may be some limitations in the participation in cases with congestions in the system. It will also be the last possibility to reduce deviation. Some of the generation participating in this market may be flexible, but due to the clearing process it may be leftover capacity from the day-ahead market.

Any deviation not accounted for here will be charged afterwards as imbalance according to the expenses the TSOs have for ensuring balance.

**2.3 Financial Trade**

Spot markets are volatile, and volatility implies risk. Financial instruments are used in the vast majority of the markets, and are usually more important (from the economic point of view) than the core business. In general we can speak about financial instruments.

There is a great variety of financial instruments that may be used for transactions on power exchanges. Financial markets for electricity do not involve physical delivery. This market is used for risk management and allows players to trade futures and forward contracts. Futures contracts can be settled daily while forward contracts are settled at the end of the contract. The contracts have different time horizons, i.e. days, weeks, seasons, etc. This allows participants to hedge price risks for up to various years [7].

**2.4 Clearing**

In many cases the clearing is an important function of the Power Exchanges from the economic point of view. The clearing is the process of transmitting, reconciling and, in some cases, confirming payment orders or security transfer instructions prior to settlement, possibly including the netting of instructions and the establishment of final positions for settlement. Sometimes the term "Clearing" is used (imprecisely) to include settlement.

Some PX´s offer clearing services for financial electricity contracts, bilateral transactions as well as balancing transactions.

**2.5 Congestion management**

The efficient allocation of scare transmission capacity is one of the main tasks of congestion management, which comprises all actions and measures applied to handle network access in the presence of congestion. In addition to capacity allocation, congestion management methodologies may also allow for alleviating congestion in real-time. The concepts can be distinguished between capacity allocation methods (explicit auctions, implicit auctions, nodal pricing) and capacity alleviation methods (countertrade, redispatching)[8].

Explicit auction means decentralized auctions of transmission capacity and involve no energy. It is used in those interconnections that usually are congested, and it is organized as an auction previously of the day-ahead market. The auction could be annually, monthly or weekly. Explicit auctions are normally managed by System Operators.

Implicit auction means a procedure to allocate capacity and energy simultaneously in the daily market. It is used in those interconnections that fairly frequently are congested. The areas are defined previously to the matching process. There are different ways to use it, as market splitting, market coupling, with or without bilateral, etc. Implicit auctions are managed by Power Exchanges. An implicit auction has many advantages, and it is one of the major marked-based methods recommended within the European Union.

## 3. Owner Structures of Power Exchanges

There are different possibilities to organize the owner structures of Power Exchanges and a comparison shows that different approaches are adopted around the world. The chosen structure may have been affected by for example:

- Previous situation to the liberalization: historical structure
- Different kind of trading: nature of trading arrangements

However, the possible stakeholders in the owner structures appear to be:

- TSOs
- Financial institutions
- Governmental ownership
- Private companies

The PXs are often owned by the System Operators. As these are quite frequently publicly owned companies, the governmental ownership is indirect. Financial institutions may also partly own the PXs. When PXs are Private companies, their stakeholders are usually financial institutions or private companies (usually Electric Utilities that participate in the market).

## 4. Regulation

Market regulation consists firstly of defining the rules of the game, and secondly enforcing obligations and monitoring performance. The regulation influences the PXs structure and functions. Depending on regulation PXs can be seen as infrastructure and be a regulated entity or it can be a limited company and seen as a commercial organization:

- In a regulated PX, the regulator is the one who determine the type of market organization and the main rules that manage the PXs work.
- A limited PX, is a private company that decides to organize a market. In this case the participants are the ones who decide to take part in the market, independent to other regulated activities. More than one limited PX can coexist in the same electric area, in competition.

There are quite a few differences in regulation between countries that produce different structures and markets. A better uniform regulation between PXs is desirable to be able to expand the markets and have a better co-operation between neighbouring PXs.

The desegregation of functions and the introduction of competition are reflected in the changing shape of the market and market participants. Under competition the vertically integrated utility gives way to a number of different and more specialised market players including generation, transmission, and distribution and supply companies. The unbundling of the various functions, often mandated or facilitated by regulations, is a key factor in the development of these new markets [10].

An important question in network regulation is to decide whether access conditions and prices need to be regulated. The EU Electricity Directive, for instance, allows for two Third Party Access (TPA) models, respectively known as Regulated and Negotiated TPA. Under Regulated TPA the ultimate responsibility for approving access conditions lies with a regulatory body. Under negotiated TPA, there is no (ex ante) network regulation and network service providers are free to negotiate prices; government and competition authorities can intervene only ex post. With few exceptions, most reforming countries have chosen Regulated TPA. Furthermore, Negotiated TPA has many problems, including high access tariffs that make TPA rights ineffective, that have led the EU Commission to propose Regulated TPA as the only acceptable alternative.

If market liberalisation is to generate sufficient investment to meet demand and to ensure competitive behaviour, it is important that investors perceive the regulatory regime as being open to new investments [11]. And it is also important to have stable and predictable regulatory regime.

## 5. Participants

The different markets accept different kind of participants. In some markets only generators are accepted while in more mature markets there may be generators, large costumers, distribution companies and traders. Initially in a deregulation, it is often only the largest generating companies that are eligible for participation in the market. However, as the market develops more and more system users are candidates to participate in the market. Demand participation is becoming important in many markets. The small end-users are normally participating through larger entities.

The table 1 shows the number of participants in different catagories in the Spanish and the Nordic Day Ahead Electricity Markets. These markets are of the more mature markets with large number of participants.

**Table 1.** Example of type and number of participants

| Type of participants | Spanish Market | Nordic Market |
|---|---|---|
| Producers | 548 | 90 |
| Distributors | 13 | 50 |
| Traders | 64 | 20 |
| External agents | 27 | 35 |
| Qualified consumer/Industry consumer | 4 | 150 |

The huge number of producers in the Spanish Market is caused by a special arrangement where small producers (mainly wind power) officially are agents in the market, but often are acting through other larger entities.

## 6. Summary/Conclusions

The paper has addressed the organization of Power Exchanges, their major responsibilities, owner structure, regulation aspects and the participants. The findings of the differences in PXs organization and responsibilities reflect that a wide variety of market designs are used around the world. The maturity of the markets is different and the chosen solutions very much depend on the structure before the liberalisation. In more mature markets the responsibilities are wider with increasing number of functions. Both financial and physical markets are normally present as well as more complex bidding structures to account for differences in the market participants need. Congestion management is mainly the responsibilities of the TSOs, but in some cases it must be considered in the market design in order to avoid price distortion. However, as the input of the transmission system transfer limits are important for the market clearing processes, the interface between the PX and the TSO is very important for a flexible and efficient market. Very often the PX's are owned by several Transmission System Operators, and as these are quite frequently public owned companies, the governmental ownership is indirect. In any case the responsibilities of PXs must be separate from TSOs.

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# FREQUENCY PERFORMANCE MONITORING AND ANALYSIS IT SUBSYSTEM FOR a TSO's CONTROL CENTRE: ARCHITECTURE AND INITIAL EXPERIENCE WITH ITS USE

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## 1. Introduction

Electric power utilities worldwide are faced by two major challenges now days, namely deregulation and the fast development in information technology (IT). While deregulation and restructuring has brought on structural and numerous operational changes to utilities, causing increased attention regarding power system operation reliability, security and quality of supply, the IT development has provided advanced technical possibilities for utilities to cope with these new challenges.

In parallel, different TSO service users, customers and regulators require more regular and consistent performance monitoring related to these services and products. Between different qualities of supply quantities, performance of frequency behavior over time comes first, due to its relevance for main market parties, generators and consumers, but also for system operators as typical ancillary (balancing) service providers.

On the other hand, modern IT enables utilities to solve effectively numerous operational problems, including the problem of power system operational performance monitoring and tracking.

In this paper, we describe relevant part of the basic SCADA/EMS system, which enables some power system quality of supply parameters related to system frequency and its regulation to be monitored, memorized and analyzed, initially described in [1].

The monitoring and analysis subsystem (PERFMON) was implemented in the National Control Centre (NDC) of Serbia in Belgrade. It is based on the state-of-the-art IT concepts and software tools (like client-server architecture, object-relational databases, standard API's and protocols) and the open-source solutions for operating system and DBMS, described in [2].

Beside the description of the performance parameters monitored within the power system (like frequency, frequency deviation, area and block control error and their related statistics) in the paper, initial 2 year experience with the IT subsystem use is presented too, as well as preliminary conclusions reached, including the frequency regulation quality achieved.

## 2. Overview of Scada/Agc System

Frequency performance monitoring subsystem is implemented as a part of SCADA/EMS system, and is closely tied with its AGC subsystem. The AGC actually provides most of the data used for frequency performance monitoring. The overview of structure of whole system is depicted in fig. 1. As shown, in figure 1. all real-time data from power system are provided through SCADA system. Those, among other, include all measurements necessary for operation of AGC like measurements of tie-line powers, system frequency, etc. Part of input data necessary for Perfmon operation are provided directly from SCADA system, other input are calculated within AGC LFC module and exchanged with Perfmon using direct application to application link. AGC and Perfmon share same (relational) database. It's is used by AGC for storing some historical data (ACE, frequency error, etc), and for retrieving interchange schedules, parametric and configuration data. Perfmon uses same database for storing calculated final performance indices, but also to store temporary results and data. Since the actual system is dual-redundant, where all components of the system (SCADA server, AGC, Perfmon, AGC/Perfmon database, …) are duplicated in hot-swap configuration those temporary data are used for application recovery in case of failure of single (active) server. In redundant system, only one instance of Perfmon, active one, actually performs calculations of performance indices, while other one is dormant. Instances of database are automatically synchronized in order to obtain exact replicas of content, thus enabling previously dormant instance to continue from point where active have stopped (due to crash, failover etc).

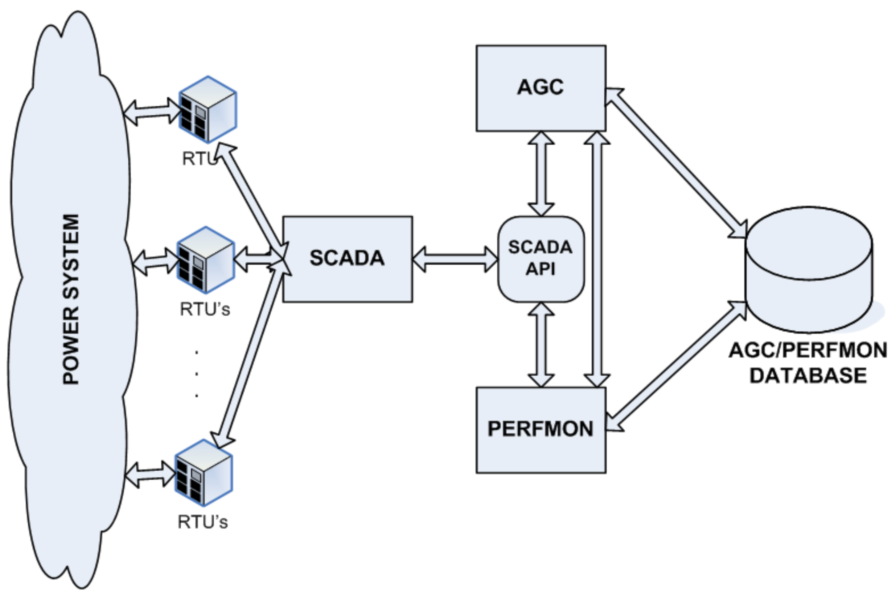


**Figure. 1** System overview

## 3. Frequency Performance Monitoring Within Tso

Briefly, basic functions of Perfmon are:

- Recording of raw historical data related to AGC, including tie-line measurements, history of actual and scheduled interchanges, and active power of units under AGC control.
- Recording of unit control and response statistics like: number of pulses sent, detected unresponsive units, etc.
- Calculating unit control participation factors.
- Tracking of basic AGC/LFC performance indices like standard deviations of ACE, counting and statistics related to ACE zero-crossings, and other data including all data necessary for secondary regulation reports as prescribed by UCTE.
- Calculation of bonification and penalty factors related to interchanges within JIEL block. Based on those factors mutual payments are done.
- Set of calculations and statistics related to frequency, including following:
    - Raw frequency measurements and frequency deviations
    - Average values and standard deviations of frequency and its deviation at 5 min, 15 min, 1 hour, daily and monthly range
    - Statistics related to intervals when frequency deviation was larger than 10 mHz, 50 mHz, 150 mHz and other user selectable limit. Statistics include time outside limit and percentage of total recording time at monthly level.

All statistics are divided in different time horizon's including 5 minute, 15 minute, hourly, daily and yearly indices. Since we have data stored in relational database, additional analyses are possible without excessive effort by using standard software tools and packages, like Microsoft Excel, and/or by using Structured Query Language (SQL). Using mentioned tools it is easy to create queries, which can be used for discovery of relations among events, and to create reports regarding frequency and secondary control quality and performance.

## 4. Software Implementation of the Perfmon at TSO

Software and hardware implementation of system as a whole is based on indigenous platform. The core of the platform is Linux based (Red Hat Linux) VIEW6000 SCADA system. Detailed description of this SCADA system is beyond of scope of this paper. AGC and Perfmon, like SCADA system, operate as Linux applications consisting of multiple components. They are designed as client-server applications where server side applications are coupled with SCADA system by using appropriate SCADA application programming interface (API). Client applications, namely user interfaces, connect to server side using either custom AGC communication protocol over TCP/IP or Open Network Computing RPC. Most applications are platform independent. AGC HMI intended for use by operators (dispatchers) are designed as Tcl/Tk scripts, which may be executed from any authorized Windows or UNIX computer on local network (security restrictions for systems access of course apply). Client applications for analyst interested in analysis of data are designed as .NET framework based applications. Microsoft Visual Basic for Applications (VBA) interface is designed for Microsoft Excel users.

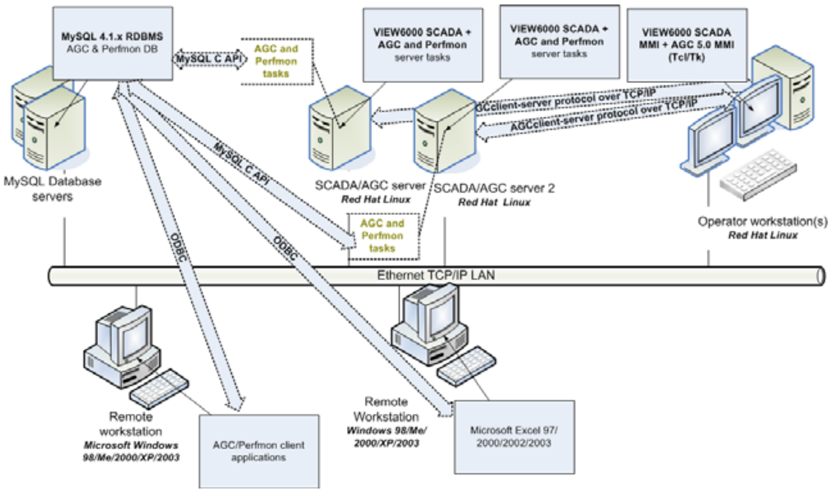


**Figure 2.** Overview of system architecture

As rational database solution we have chosen the MySQL relational database management system (RDBMS). This RDBMS posses many characteristics, which made it, right solution for our purposes:

- MySQL is fast and optimized RDBMS with low resource consumption comparing with some other options like Oracle.
- MySQL is open source database, thus sources are readily available if customizations are necessary. That also means that it is possible to compile executables optimized for exact needs of system and software/hardware platform.
- MySQL is readily available on different platforms, including Linux.
- MySQL is embeddable into other applications.
- Last, but not the least important, the price of client and server licenses are very low comparing to other options.

In order to achieve as fast as possible AGC and Perfmon communication with MySQL RDBMS the native MySQL C API is used as interface of choice. The overview of system architecture is shown in figure 2.

## 5. Frequency Performance Observed

In order to illustrate some of the data collected and processed by Perfmon in this section we will show some frequency related data. Analytical overview of this data will be given in section 6. Recordings are for period from July 2006 to May 2007.
At table 1 average monthly standard deviation is shown together with recordings of periods when frequency deviation was larger than 50 mHz and 150 mHz, respectively.

**Table 1.** Frequency related data.

| Year-month | Average standard deviation of frequency | Recorded time with │Δf│>50 mHz | Percentage of total recorded time with │Δf│>50 mHz | Recorded time with │Δf│>150 mHz | Percentage of total recorded time with │Δf│>150 mHz |
|---|---|---|---|---|---|
| **2006-07** | 0.0166 | 26896 | 1.01 | 3416 | 0.13 |
| **2006-08** | 0.0594 | 22348 | 0.84 | 1408 | 0.05 |
| **2006-09** | 0.0164 | 39376 | 1.53 | 0 | 0.00 |
| **2006-10** | 0.0179 | 57924 | 2.18 | 0 | 0.00 |
| **2006-11** | 0.0183 | 61156 | 2.36 | 1528 | 0.06 |
| **2006-12** | 0.0763 | 52460 | 2.12 | 1564 | 0.06 |
| **2007-01** | 0.0171 | 49264 | 1.87 | 748 | 0.03 |
| **2007-02** | 0.0137 | 27472 | 1.19 | 1272 | 0.06 |
| **2007-03** | 0.0184 | 39352 | 2.62 | 648 | 0.04 |
| **2007-04** | 0.0165 | 11548 | 1.72 | 0 | 0.00 |
| **2007-05** | 0.0124 | 10756 | 0.67 | 848 | 0.05 |

In figure 3 graphical representation of percentage of total recorded time with │Δf│>50 mHz is given:

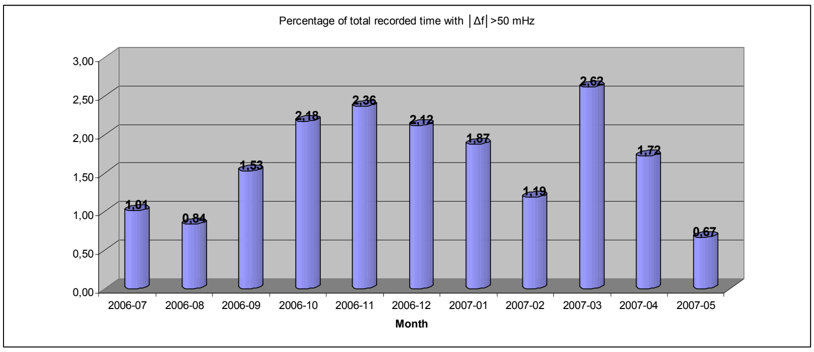


**Figure 3.** Percentage of total recorded time with │Δf│>50 mHz

## 6. Frequency and ACE Performance Analysis Results

There are many different quality indices of performance of secondary control. In US NERC criteria are widely used. In Europe UCTE has defined so called "Trumpet curve" which defines response of secondary control after an outage. However, now, UCTE has no officially defined quality indices of performance of secondary control during normal operation of the power system.

However, a small UCTE ad-hoc group "Balancing Quality Indices" has recently proposed a set of indices covering this topic [3]. This set is now in a process of acceptance in UCTE bodies.

In this paper, a subset of new, still informal, UCTE indices is used to check the performance of AGC in Serbian power system.

According to above mentioned indices allowed mean monthly value of ACE for Serbia is 17 MW. The values calculated during real time operation of Serbian power system are summarized in the following table:

**Table 2. Average ACE**

| Month | May 2006 | June 2006 | July 2006 | Aug. 2006 | Sep. 2006 | Oct. 2006 | Nov. 2006 | Dec. 2006 |
|---|---|---|---|---|---|---|---|---|
| Mean ACE (MW) | 4.38 | 4.98 | 2.20 | 3.33 | 2.95 | 3.61 | 2.78 | 5.37 |

Second criterion concerns Average deviation of ACE calculated on monthly basis according to the formula:

$$AD = \sqrt{\sum_{720} ACE_h^2 / 720} \tag{1}$$

Where $ACE_h$ represents hourly value of ACE and 720 numbers of hours in a month, if necessary adapted to the right number. Allowed value of Average deviation for Serbian power system is 31 MW. The values calculated during real time operation of Serbian power system are summarized in the following table:

**Table 3.** Average standard deviation of ACE

| Month | May 2006 | June 2006 | July 2006 | Aug. 2006 | Sep. 2006 | Oct. 2006 | Nov. 2006 | Dec. 2006 |
|---|---|---|---|---|---|---|---|---|
| AD (MW) | 20.18 | 20.06 | 10.95 | 12.26 | 14.84 | 14.56 | 11.56 | 13.01 |

Another criterion explores fact that any ACE value below zero when frequency is below 50 Hz (or the frequency set point value) is thus “contributing” to the frequency deviation, whereas any ACE value above zero in this case is “helping” the frequency go back to 50 Hz.

Criterion comparing ACE and frequency allows us to check the amount in which each control area participate in frequency deviation, or helps interconnection to restore frequency.

Starting from well-known formula for calculation of Area Control Error:

$$ACE = \Delta P_i + ( K_i \, x \, \Delta f ) \tag{2}$$

relative contribution of one control area to frequency deviation could be calculated as:

$$\Delta P_i / ( K_i \, x \, \Delta f ) < 0 \tag{3}$$

If the value of relative contribution is lower than zero control, area was helping restoration of frequency. If the value of relative contribution is positive control area is a source of frequency deviation.

The values calculated during real time operation of Serbian power system are summarized in the following table. Calculation has been performed on hourly basis, and than summarized for a month:

**Table 4.** Relative contribution of Serbian power system to frequency deviation

| Month | May 2006 | June 2006 | July 2006 | Aug. 2006 | Sep. 2006 | Oct. 2006 | Nov. 2006 | Dec. 2006 |
|---|---|---|---|---|---|---|---|---|
| RC [MW] | -159 | 1817 | -4477 | -3183 | 859 | 2568 | -686 | -4797 |

Table shows that Serbian control area predominantly help restoration of UCTE frequency during five of eight examined months.

## 7. Conclusions

This paper describes relevant part of the basic SCADA/EMS system that enables frequency and regulation performance measures to be monitored, stored and analyzed. The performance monitoring system presented is RDBMS standard based that enables numerous possibilities for analysis, some of them presented in the paper. From the results obtained for the year 2006, quality of frequency and its regulation was generally satisfactory.

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# MARIN POLLUTION AND EFFECTIVE USE OF THE RTV SILICON COATINGS IN CRETAN POWER SYSTEM

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## Abstract
Room Temperature Vulcanized (RTV) silicon rubber coatings have been widely used on high voltage insulators of the power system of the Greek island of Crete. The application of these materials started ten years ago and continued with intensive pace to the present day. Nowadays, the majority of the substation insulators and a considerable portion of transmission line insulators are coated. The coated insulators are in no need of washing after the silicon application and they have shown excellent performance against pollution under the local environmental conditions. Although marine pollution is heavy due to long dry periods and the frequent winds that usually blow from sea towards the coast, the use of silicon coatings has diminished pollution threats against the power system. The performance of these materials has exceeded our most optimistic expectations regarding their effectiveness and their life expectancy. The electric utility has achieved considerable savings due to abolition of the insulator washings while the system reliability has significantly increased.

## 1. Introduction
The transmission system of the Greek island of Crete was upgraded from 66kV to 150kV in the beginning of the 1980's. From the very beginning of its operation under the higher voltage level the problem of marine contamination of the insulators appeared to be a serious threat against system reliability and security. A lot of faults took place on the new Transmission Lines (TL) as well as the Substations (S/S) as a result of the combination of the sea salt on the surface of the insulators and the high humidity in the atmosphere. The most unfavorable conditions dominate mainly by the end of the summer and particularly during the months of August and September when a lot of sea contamination has been accumulated due to the constant winds blowing the whole dry period. Also, the humidity in the atmosphere starts to be higher by the end of the summer while every day it reaches its highest levels early in the morning when it is the most critical time for the secure operation of the system.

The fight against pollution during the first years after the system was upgraded to 150kV, was performed with very simple means. Suitable trucks were used that were equipped with water tanks and high pressure pumps in order to wash the installations. By the end of 90ties, two significant improvements were introduced in the maintenance of high voltage (h.v.) installations: the use of RTV silicon (Si) coatings for the S/S insulators and the live water washing by helicopter of TL insulators.

These two methods have proved to be very efficient and their use has reinforced the reliability of Cretan power system. Especially, the RTV Si-coatings have performed very effectively during the past 10 years although no cleaning work has been done during this time. These materials continue to perform excellently until now with no sign of deterioration.

Although the marine pollution on the island is classified to the one of the worst world wide, there are three characteristics that favor the effectiveness of the RTVs coatings:

- The pollution is mainly sea salt which is soluble making easy the every year cleaning by the rains in the winter and therefore, no solid layer is formed on the surface of the insulators. On the contrary, industrial pollution may be less conductive but it can result in the formation of a solid layer which has a cumulative effect.
- The pollution of the insulators grows gradually during the whole dry period so that there is plenty of time for the low molecular weight molecules of the RTV Si-rubber coating to migrate to its outer surface and make it hydrophobic before the end of the summer when high humidity prevails in the air.
- The temperature of environment is usually high in Crete and particularly during August and September when the contamination problem is severe and this temperature helps to speed up molecular migration and transfer of hydrophobicity into pollution layer.

## 2. Substations

***Use of RTV coatings for the substations***

The use of RTV Si-coatings for the S/S insulators started in 1998 and continued all the following years until now. Three different manufacturer materials have been used. Figure 1 shows the quantity of each material that was used each year. The total quantity of RTVs that has been used during the last nine years comes up to 7600 kg, while the average quantity per year is estimated to be 845 kg.

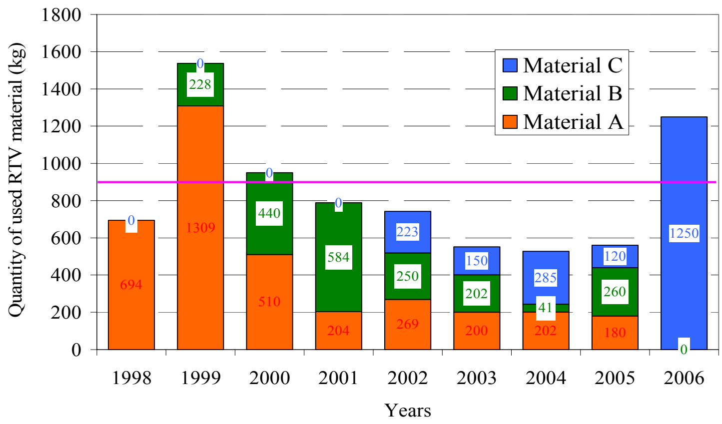


**Figure 1.** RTV materials used in Crete power system each year

**Table 1**. High voltage gates coated with RTV materials

| s/n | Substations | Total h.v. open air gates | Coated gates |
|---|---|---|---|
| 1 | Ag. Nikolaos | 4 | 0 |
| 2 | Agia | 4 | 4 |
| 3 | Linoperamata 66 kV | 11 | 11 |
| 4 | Linoperamata 150 kV | 23 | 23 |
| 5 | Atherinilakos | 5 | 5 |
| 6 | Iraklion I | 5 | 0 |
| 7 | Iraklion II | 7 | 0 |
| 8 | Iraklion III | 4 | 0 |
| 9 | Ierapetra | 7 | 7 |
| 10 | Kasteli | 3 | 2 |
| 11 | Maronia | 2 | 2 |
| 12 | Mires | 4 | 4 |
| 13 | Pretoria | 4 | 4 |
| 14 | Rethimno | 5 | 0 |
| 15 | Sitia | 5 | 5 |
| 16 | Stalida | 4 | 4 |
| 17 | Chania | 15 | 9 |
| 18 | Vrises | 4 | 2 |
| 19 | Ag. Varvara | 2 | 0 |
| Sum | | 118 | 82 |

Table I shows the number of h.v. open air gates per S/S and the respective gates that have been coated. In the Cretan power system, there are 118 h.v. gates in total and 82 of them are coated (percentage equal to 70 %).

***The event of September 18$^{th}$ 2006***

On September 18$^{th}$ 2006, a fault took place on the transmission system due to a flash over of a composite insulator, which resulted in a major disturbance in the system and extensive customer load interruptions. This insulator was made from Teflon and it was used on a tower in the S/S of Linoperamata power plant. The insulator was installed in 2001, when the line was constructed. It was the first time that organic insulation (composite insulators or RTV coating) used for the 150kV installations of Cretan power system collapsed. However, the following factors should be taken in consideration:

- This insulator was a short one (130 cm) and it was used to hold the conductor jumper, as shown in Figure 2. The respective tower is a small one, type Z1, which is usually used for 66 kV TLs and it was selected purposely because of the lack of space. The distance between the cross arms of the upper and down phases is only 265cm. Therefore, the normal type of Si-rubber insulators used in Cretan power system that are 190 cm long could not be used because of the necessary clearance distance.
- Teflon is a cheaper insulator material which has inferior properties compared to the Si-rubber.
- This insulator was exposed to the heaviest pollution conditions that exist in the system as the respective tower is situated next to the chimneys of the power plant and a few meters away from the coast.
- Flash over took place when the relative humidity in the air was 97% according to meteorological station of Linoperamata power plant recordings.

As the fault took place in a very critical position (next to the generating units) and the protection relays did not operate very well, there was a big disturbance in the system. All generating units of the two power plants (Linoperamata and Atherinolakkos) tripped and only the third power plant in Chania was saved. The system generation before the event was 440 MW and the generation that was lost came up to 324MW (percentage 73.6%). This disturbance was the major one that the system experienced since 2001. The diagram of Fig 3 shows the system load demand and the loss of energy on that day.

**Figure 2.** Tower with the flashed-over insulator

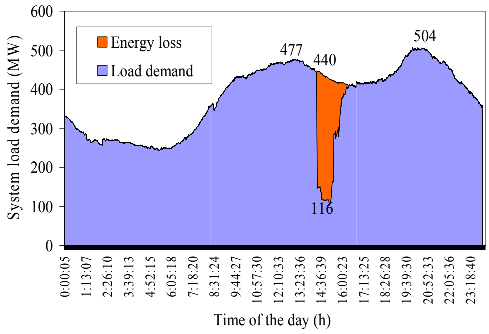


**Figure 3.** Energy loss due to the insulator flash over

## 3. Transmission Lines

### *Faults on the transmission lines*

Fig 4 shows the total number of faults on the TL and the respective faults because of the pollution. It can be noticed that during the last ten years when advanced maintenance methods against insulator pollution were used, the number of faults in the TL was substantially reduced. In the year 1985, 105 faults took place because of the pollution, while in the year 2006 the respective faults were limited to two although the total length of the TL was increased in the mean time.

### *Methods against pollution*

Regarding the TL, three different methods have been adopted to combat marine pollution, namely, the live water washing from helicopter, the use of Si-rubber insulators and the use of the RTV coatings.

### *Live washing*

The live water washing from helicopter is used for all the old TLs which have either glass or porcelain insulators. This method is effective but according to our experience it has the following drawbacks:

- Under strong wind conditions that are frequent in Crete, the helicopter cannot fly to wash the insulators and this can result in long time delays which can be critical for the system security.
- For the TL that are situated in a small distance from each other, the helicopter cannot wash the inner circuits.
- The application of this method needs careful timing of the washing schedule otherwise; there might be increases of risks or costs.

- The cost of this method is rather high as it should be applied twice a year and apart from the helicopter cost an additional significant cost should included which regards to supporting crews, the de-ionized water, the transport trucks, the supervising crews etc.

## 4. Composite Insulators

All TL that are constructed after the year 2000 are equipped with Si-rubber insulators. These insulators are also not washed and their performance against pollution is excellent, so far. Figure 5 shows the insulator pie diagram for the various types of insulators that are used in the Cretan power system. The total number of Si-rubber insulators being installed in Crete come up to 3596 items (percentage 40%).

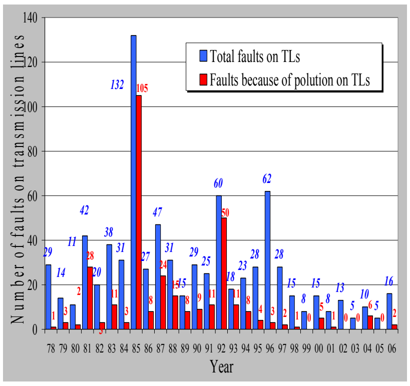


**Figure 4.** Faults on the transmission lines of the Cretan power system

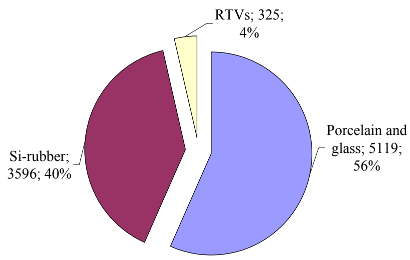


**Figure 5.** Insulator pie diagram for various types of insulators

## 5. Use of RTVs

RTV coatings have also been used for the TL for three cases where their use has offered unique results, namely:

- adequate clearance distance
- transmission line on metal poles
- jumpers holding

## 6. Adequate Clearance Distance

The new, double circuit TL Atherinolakkos-Ierapetra was initially designed to use glass insulators and the type of the tower that was selected is shown in the diagram of Figure 6 (type S4). When the towers had been constructed, the decision about the insulation of TL was revised and the Si-rubber insulators were chosen. However, the type of composite insulator that is used in Crete, of 190 cm long, could not be utilized in the upper phase of TL because of the short distance between the cross arms of the upper and middle phases. Hence, the solution of using glass insulators that should be coated before their installation was adopted. For this reason, the glass insulators were hung on a metal wire in the base of a tower and they were coated, as it can be seen in the Figure 7. These insulators chains which are 154 cm long are energized since 2004 and their behavior is equal to the longer ones (190 cm), composite insulators that are used in the same TL.

The simultaneous operation of both types of insulators that are stressed under the same heavy conditions in the same TL will prove their effectiveness in the future.

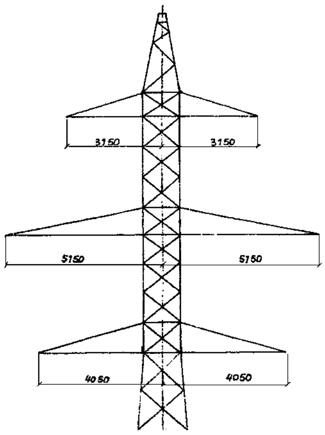


**Figure 6.** Double circuit TL, type S4

**Figure 7.** Coating of the glass insulators with RTV material

## 7. Transmission Line on Metal Poles

Metal poles are often used in residential areas instead of conventional towers because of their reduced base dimensions. In the year 2003, a new double circuit TL was constructed which connected the S/S Iraklion II with the new power plant of Atherinolakos. In order to reduce the annoyance to the nearby houses the last part of this line that enters the city of Iraklion was constructed on metal poles and this type is shown in Figure 8. The conductors are hung up on insulator arrangements (V strings) that consist of a post horizontal, porcelain insulator and an inclined insulator chain that includes twelve glass cap and pin insulators, fog type. This line was situated parallel to an existing double circuit line on conventional towers that was also equipped with the same type of glass insulators.

The performance of this line could not be worse. From the beginning of its operation the line produced a high noise that was very annoying under pollution conditions. This noise was by far higher than the nearby older TL that was situated a few meters away. That was due to the higher leakage current as well as to the sound amplification that was created by the hollow metal post. During the last three years of the line operation, a significant number of units of glass insulators were broken showing a statistical failure rate for this type of insulators that was unusual. Figure 9 shows a chain of glass insulators with three broken units during the maintenance works.

It has been noticed that units of glass insulators were broken mostly under the normal system operation and good weather and not just during a lightning, or a flash over or a transient due to a circuit breaker operation.

**Figure 8.** Double circuit, 150kV, TL that is constructed on metal poles

**Figure 9.** Maintenance work to change the three broken units

On October 28th 2006, a similar event caused the injury of a passing man below the line. After this event, there was a decision to coat the insulators in situ on the metal pole and this job that was done for first time by the Public Power Corporation personnel. The work was performed successfully with the use of a special crane that could lift two technicians up to a height of approximately 30 meters. The time to coat a chain of insulators was about 20min and the quantity of RTV material was about 2Kg. Figs 10 and 11 shows the use of crane and the coating works up on the pole. After the insulators had been coated the noise problem was disappeared.

**Figure 10.** Use of a crane to coat the insulators

**Figure 11.** Coating of insulators up on the pole

## 8. Jumpers Holding

The eastern part of the island is the area that receives the strongest winds in the whole Greece. When a storm happens it has been noticed that the jumpers in the tension towers are raised up and approach the metal parts of the respective cross arm above them resulting in a flash over. In order to stabilize the jumpers and reduce their movement freedom, an insulator chain was hung from the bridge to fasten the jumper. For this purpose, glass insulators were suitable to be used due to their higher weight. However, these insulators could not be utilized in a TL with composite insulators without being coated.

## 9. Conclusions

The insulation of the Cretan power system is exposed to severe marine pollution as the island geography is long and not very wide, most of the cities are built along the coast and the high voltage installations are situated a small distance from the coast. Moreover, there is a long dry period during which frequent winds blow from the sea towards the land. The use of organic insulation has reinforced the system robustness and has reduced the probability of flash over because of the pollution. Particularly, the extensive use of RTVs for the S/S and their lesser use for the TL have proved to be very effective. RTVs have been working for 10 years in Crete and no flash over has occurred although no cleaning work has been performed after the initial application. The excellent performance of the RTVs and their durability all these years has exceeded our most optimistic expectations.

However, the concern about the h.v. insulation continues by using new materials and monitoring the performance of the already operating ones. For this purpose, a test station has been constructed where different types of new and used insulators and materials can be tested. Moreover, the whole power system of Crete can be considered as a test station taking in consideration that it is unique in the world with this extensive use of the organic insulation (70% for the S/Ss and 44% for the TL). Therefore, different RTV materials and composite insulators are tested every day under real operating conditions.

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# MONTE CARLO PROCEDURES FOR SIMULATING REAL TIME CONTINGENCES AND SETTING OPTIMAL REDISPATCHING STRATEGIES IN MULTI-AREA SYSTEMS

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## Abstract
The evaluation of the necessary operating reserve margins in an electric power system has been traditionally carried out by the System Operator (SO) on a deterministic basis, using the so called "first contingency security criterion". According this approach, only few generating units and/or power lines are considered in order to determine the worst operation conditions. As an alternative, this paper presents a simulation method, based on a probabilistic approach using a sequential Montecarlo technique, which takes into account all the generating units and the transmission power lines of the electric system considered. Starting from the production and consumption profiles scheduled by the energy markets, the real time operation is simulated in normal, contingency and emergency conditions, taking into account the availability of generating units and power lines; the redispatching procedures activated after a contingency are carried out minimizing the expenses for the auxiliary services purchase under line power flow limits constraints.
A daily case study, calibrated on an IEEE test grid, is carried out and discussed, focusing how such a technique can be suitably used to evaluate system reliability as a function of reserve margins, load shedding amounts, dispatching rules and emergency procedures.

**Keywords:** Electricity Market, Operating Reserve Margin, Multi-area Systems, Monte Carlo Simulations.

## 1. Introduction
The main task that any System Operator (SO) must always perform is to verify the system reliability and security. For this reason, SO must check the dispatching schedule defined by the market for generating units and loads, in order to satisfy the network security criteria and to avoid line congestions. To ensure the system reliability, SO must guarantee some system services and, primarily, the availability of an adequate amount of power for primary and secondary reserve (spinning reserve) and an adequate level of power and energy for balancing operations (tertiary reserve).

Up to now, the required operating reserve margin is usually set using the first contingency security criterion (N-1 criterion), improved with simple probabilistic reserve correction; such an approach takes into account, separately, only some of the worst conditions that may happen in an electric system. The method is very simple to apply, but the precision obtained depends on a lot of parameters that are difficult to take under control, such as abnormal load conditions and generation dispatching, lines and/or units unavailability, etc.. From the other hand, since making available

* The simulation software has been developed with the support of the Italian TSO, Terna.

operating reserve margins has an obvious economic impact, there is a strong incentive to set the reserve margins in a proper way.

In order to solve the above mentioned problem both considering as the generating park reliability as the power ratings of the transmission grid power lines, a more complete probabilistic approach has to be developed. Such an approach can practically take into account almost all the contingencies that may happen to generators and lines in an electric power system and their combinations, and can allow SO to have a deeper insight on the real time use of the transmission grid lines and on the consequences that their power ratings may have on the system management.

In the present paper, a simulation method based on a sequential Monte Carlo technique is proposed and described. A case study based on a power system model relevant to the IEEE Reliability Test System (RTS96) is shown and discussed; we considered the test grid as subdivided into three areas linked by interconnection lines, but the proposed model is independent on the number of considered areas, because it can take under control all the lines of the grid. The study has been carried out in order to evaluate the system reliability as a function of power margin and balancing reserve amount, also focusing on the impact of possible redispatching rules during contingency and emergency conditions.

## 2. Electric System Model

The aim of the present study is to develop a complex mathematical model of daily operation of a large electric system that will permit to carry out a sensitivity analysis of its reliability, taking into account a large set of parameters and variables, such as the secondary and tertiary reserve margins, the transmission system power flow limits, the management rules of pumped-storage plants, the merit order criteria relevant to the activation of reserve units, the dispatching rules during contingency and emergency conditions, the total amount of interruptible loads and load shedding, and so on.

More in details, starting from the results of the electricity markets (Day-ahead, Adjustment and Ancillary Service Markets) such a tool could be used by the SO:

- to allocate adequate margins of secondary and tertiary reserve, in order to ensure a predefined level for risk indexes (LOLP, EENS, etc.);
- to schedule load shedding procedures for the following day, if the reserve margins selected by the markets are not enough to guarantee an assigned level of reliability;
- to set the power flow limits to be allowed by SO on the transmission lines;
- to optimize the use of particular kinds of reserve units, such as pumped-storage plants;
- to optimize contingency and emergency procedures;
- to define objective criteria for their activation, in particular in case of severe contingencies which require “normal” market rules to be temporarily suspended.

The model refers to a hydro-thermoelectric system, that can be considered as constituted by more areas, linked by interconnection lines. The zoom of the analysis is anyway the single-path detail (interconnection or intrazonal lines). In the model, only active power and energy are taken into account; network power losses are not explicitly considered, being added to the load.

The model takes into account the following main structural data and technical characteristics of:

- each generation plant (conventional steam units, Gas Turbines, hydro units, pumped-storage plants, CCGT);
- the hydro reservoirs connected to power plants;
- all the transmission branches;
- area-load and corresponding forecasting accuracy on a quarter of hour base.

*A. Thermoelectric units model.*

A thermoelectric unit may be a conventional steam plant, a CCGT unit or a GT unit. Each plant is characterized by minimum and maximum power output, increasing/decreasing power ramps, availability indexes (MTTF, MTTR), start up times and the market zone to which the unit belongs.

*B. Hydro plants model.*

Each hydro plant belonging to an assigned market zone is connected to an equivalent zonal reservoir; each generating plant is characterized by minimum and maximum power output, availability indexes (MTTF, MTTR) and geographical position.

*C. Pumped-storage plants model.*

If present, each pumped-storage plant is characterized by a power range, consumption during pumping operations, process efficiency, availability indexes (MTTF, MTTR), geographical position and water capacity of the reservoir which the plant is connected to (each plant has its own basin).

*D. Lines model.*

A DC load flow is operated to evaluate the loading of each line in service. Two different power flow limits are defined; the first refers to the steady-state conditions; the second, higher, is relevant to the overload that the line can support for a maximum of 15 minutes with contingency and emergency conditions.
Lines can be out of order, according to a probabilistic model described by MTTF and MTTR parameters.

*E. Load model.*

In this probabilistic approach the load, expressed in terms of a value for each load buses in each quarter of an hour, is modeled with a probability distribution, whose average value depends both on the load forecasted value and the forecasting errors experienced in the previous time steps; the standard deviation of the probability function is not constant during the 24 hours, due to the higher load uncertainty in particular moments of the day (e.g. sunrise and sunset).

## 3. Simulation of the System Operation

The problem of simulating the daily operation of a large electric system in order to set operating reserve margins is very complex, because system adequacy, reliability and security are influenced by random events, such as the outages of generators and interconnection lines, as well as the errors in load forecasting; moreover the problem solution is affected by different parameters, such as generation dispatching or the management of pumped-storage plants.

This complexity suggests that a simulation method based on a sequential Monte Carlo technique could be more powerful than direct methods.

With regards to the operation of the simulated electric system, the following hypotheses have been assumed:

- the simulation is extended to a single day (24 hours) and the time step is a quarter of an hour (15 minutes);
- the forecasted dispatching of the generating park is known from the Day-Ahead Spot Market, as well as the merit order list of the units selected in the Ancillary Service Market;
- the simulation is carried out considering sequential steady state conditions; this means that all the dynamic behavior of the system from a generic time step to the subsequent is neglected;
- the model takes into account that load can be dropped during emergencies in the following different ways:
    - the use of under-frequency relays, preset to drop pumped-storage units in pumping operation;
    - the disconnection of interruptible loads†, that can be manually carried out by SO control room or automatically activated by a programmable protection system;
    - the application of an automatic load shedding program, designed curtail shares of the loads at predefined under-frequency thresholds;
- the power flows across the lines are evaluated through the DC power flow algorithm;
- the events relevant to units outages, lines faults, unexpected load variations happen at the beginning of the considered time step;
- after a contingency and during emergency conditions, hydro and pumped-storage units are assumed to produce their power without any delay;
- after a contingency and during emergency conditions, thermoelectric units can produce according to their increasing/decreasing power ramp.

The operation of the system is simulated for different values of operating reserve margin (ORM). ORM is considered as independent variable and the following quantities as dependent variables:

- Expected Energy Not Served (EENS);
- Replacement Reserve Energy (RRE), that is the energy produced by units available in 60 minutes;
- Loss of Load Probability (LOLP).

† According to the grid code and to economical agreements stipulated between SO and voluntary customers.

This choice gives the SO a tool to check the influence of the ORM on system reliability and to evaluate its amount, taking into account also the costs deriving from the power for reserve and from the energy for real time balancing (RRE).
The system operation has been divided into three steps:

Step 1: normal operation;
Step 2: contingency or emergency operation;
Step 3: re-dispatching operation.

*Step 1: normal operation.*
At the beginning of each time step (15 minutes) a Monte Carlo drawing, regarding the present state of the generation units and of the interconnection lines, is performed. If there are no generators or lines outages and if the drawn value of load is close to the forecasting within a predefined error, normal operation is performed according to the dispatching of the energy market, otherwise operation with contingency and emergency conditions is activated.

*Step 2: contingency or emergency conditions.*
The operation after a contingency or during emergency conditions is performed according to the following operating rules:

- if at the present time step there is an unexpected failure of a generator, the power not delivered is substituted by the operating reserve of the units in service and, in case, by an adequate number of units able to start up in 15 minutes (non-spinning reserve units); these units are activated by the SO according to the merit order list defined by the Ancillary Service Market;
- if some of the interconnection lines, during the 15 minutes considered, are overloaded due to generators and/or interconnection lines faults, the system is re-dispatched by the SO according to the list of the units selected in the Ancillary Service Market;
- when a severe contingency affects the generation or the transmission system and the demand cannot be fully served in secure conditions, pumped-storage units, interruptible customers or diffuse load can be shed by under-frequency relays or by specific protection systems, activated by exceeding power flows across transmission lines.

*Step 3: re-dispatching operation.*
During this procedure, that can require several time steps, the secondary reserve regulating band is restored. The system is re-dispatched by means of balancing operations which increase the production of the cheaper units and decrease the production of the most expensive ones, possibly turning off the non-spinning reserve units put in service during step 2. All units are re-dispatched according to the merit order of the Ancillary Service Market. This dispatching is valid till the end of the day. This re-dispatching operation is performed also to modify the hourly production produced by the errors between the hourly forecasted load and the correspondent drawn load. All the operations are performed avoiding any possible overload into the interconnection lines.

The simulation is carried out considering sequential steady state conditions. This means that in the considered quarter of hour only the overall effects of the secondary reserve are taken into account, while the primary regulation can be neglected because it is substituted by the secondary reserve as soon as possible, within the current time step (15’). The power produced by the units under secondary regulation is proportional to the band they have been awarded on Ancillary Service Market and it is independent to their zonal location.

About the tertiary reserve, two different types of dispatching procedures are possible:
- dispatching in contingency or emergency conditions, operated at the same time step of the contingency, typically obtained by non-spinning hydro and pumped-storage units; the procedure is carried out in order to eliminate overloads across lines;
- standard reconstitution of secondary reserve margins, operated in the following time steps, generally obtained by non-spinning thermal units (typically gas turbines) or spinning conventional steam plants operating below their rated power.

All the above mentioned operations are carried out at minimum cost, according to the merit order list defined by the Ancillary Service Market, taking into account the technical constraints corresponding to the transmission and generation system, such as the maximum inter-zonal flows, the start-up times and the increasing-decreasing power ramps of production plants.

## 4. Procedures for Contingency and Emergency Operation

The model previously described has been implemented in specific software that simulates the normal, contingency and emergency conditions of the electric system. The structural data, downloaded once only at the start of the program, refer to the technical specifications of the grid and the generation system.

The scheduled daily dispatching derives from the clearing of energy and Ancillary Service Markets. For each quarter of an hour of the simulated day, the following data are available:

- production schedules, secondary and tertiary reserve margins of each generating unit;
- forecasted load for each load bus;
- scheduled state of each transmission branch;
- merit order lists for up and down regulation defined by the Ancillary Service Market, with prices of balancing energy.

According to the Monte Carlo method, for each time step the actual state of the electric system is drawn: actual load, plant outages and line faults. If the lack (or excess) of power consequent to units outages and/or errors in load forecasting exceeds a predefined threshold, the production reserve is activated, following the Contingency and Emergency Procedure. The aim of this procedure is to make secure the state of the electric system in the current quarter of an hour; further procedures will be focused on system security for the following time steps.

Assuming the system primary regulation to have already restored the energy balance between generation and loads, the secondary reserve is automatically activated; the power increase/decrease issued by the units under secondary regulation is proportional to the band they have been awarded on Ancillary Service Market and it is independent of their zonal location. The consequent power flows on inter-zonal and import links are updated; line tripping is possible due to overload. If any remaining line exceeds its steady-state transit limit, the quick tertiary reserve (hydro, pumped-storage and gas turbines plants) of both interested zones is activated for an equal amount but opposite directions, in order to reduce the transit; the activation order depends on economical merit order lists defined by the Ancillary Service Market, taking into account the geographical, rapidity and capability constraints. If this action is not able to restore a secure working condition in the present quart of an hour, in order to avoid line cascading a manual load shedding procedure in the import zone is activated and an equal amount of decreasing quick tertiary reserve in export zone is required.

Even in the absence of a significant difference between production and load (that means no generating unit outages and a small error in load forecasting) the software verifies the grid operating conditions, in order to manage possible grid faults and avoid line cascading.

The state of the electric system being secure for the current quarter of an hour, a specific procedure operates the re-dispatching of production units for the following time steps. Such a procedure aims to restore the secondary reserve regulating band and substitute the quick tertiary reserve (hydro, pumped-storage plants, GTs) with slower but cheaper plants, like spinning conventional steam units. The system is re-dispatched by means of balancing operations which increase the production of the cheaper units and decrease the production of the most expensive ones, possibly turning off the non-spinning reserve units put in service during contingency and emergency procedure. All units are re-dispatched according to the economic merit order set by the Ancillary Service Market.

Before the following daily simulation, the storage of main results is performed, focusing on EENS and most significant occurred contingencies, like outages of big power plants, line cascading and system separation.

At the end of the simulation, the output file will show both the average and the possible extreme behaviors of the electric system during the day under investigation.

## 5. The Case Study

The proposed method has been applied to the IEEE 96-Bus Reliability Test System (RTS-96). The detailed system data can be found in [1]. Such a system is composed by 96 generating units (18 hydro plants and 78 thermoelectric plants), 51 bus-bars and five interconnection lines. The system peak load is about 7200 MW and the total installed generation is 9400 MW. The topology for RTS-96 is shown in Figure 1.

The system is assumed to have a load profile corresponding to the 90% of the yearly peak. The generation dispatching (formally resulting from the Day-Ahead Market and the Adjustment Market) has been calibrated by the authors respecting the first contingency security criterion (N-1). Considering the load, Area C imports energy from Area A and B. In order to stress the transmission system, the original RTS-96 network has been slightly modified; in particular, the MTTF of Line CB-1 has been decreased.

For the simulations, a time step of a quarter of an hour has been adopted. The analyzed day has been simulated 1000 times according to the Monte Carlo procedure (the computational time is about 10 minutes on a 3-GHz Pentium PC), obtaining the following average results: the balancing energy provided by the III reserve is about 1930 GWh and the EENS is around 20 parts per million.

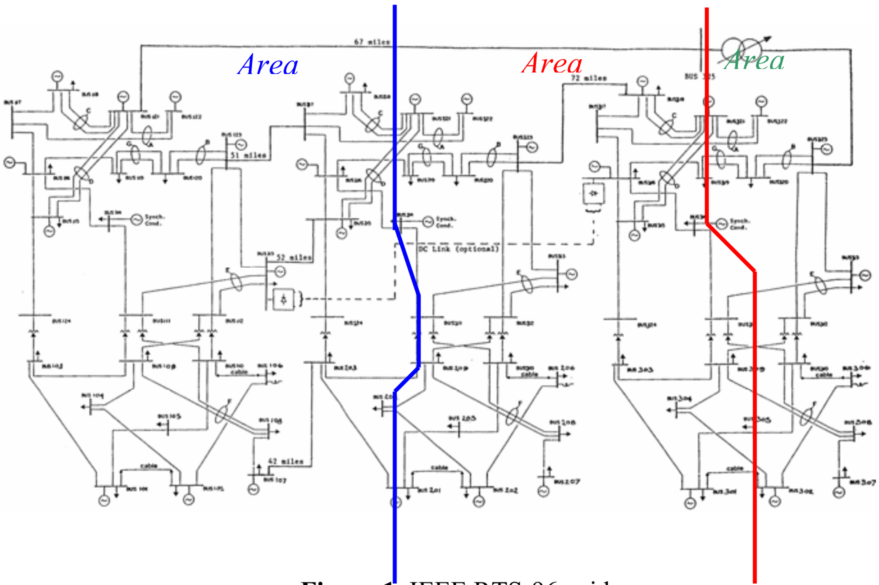


**Figure 1.** IEEE RTS-96-grid

The following considerations refer to the less reliable simulated day, when the following events happen:

04.30 A.M. : unit outage (Area C; loss of 80 MW)
01.30 P.M. : unit outage (Area A; loss of 65 MW)
03.00 P.M. : line outage CB-1 and interzonal congestion ( line CA-1)
09.45 P.M. : unit outage (Area A; loss of 10 MW)
10.15 P.M. : large unit outage (Area C; loss of 300 MW) and interzonal congestion (line CA-1)
11.45 P.M. : unit outage (Area C; loss of 60 MW)
11.45 P.M. : interzonal congestion (line CA-1).

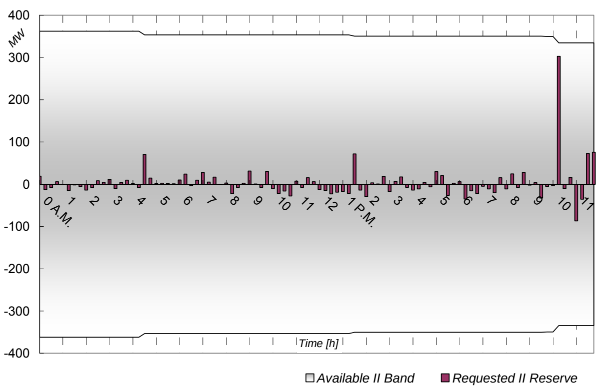


**Figure 2.** Use of II Reserve – Less reliable simulated day

The secondary reserve actually activated by SO (vertical bands), compared to the available amount, is shown in
Figure 2; its trend depends on production units outages and differences between forecasted and actual load.

Figure 3 shows the use of tertiary reserve. It is interesting to remark that, watching at the sign of the three area activated reserve, it is possible to discriminate interzonal congestions from outages of production units. As a matter of fact, after a unit outage or an unexpected load variation, the secondary reserve is activated in the present quarter of an hour; balancing units provide the tertiary reserve in the following time step, up to complete reconstitution of secondary reserve margins; in case of an interzonal congestion (line overloading), tertiary reserve is activated, aimed at eliminating the line overloading within 15 minutes.

Before 4.30 A.M., no unit outage occurs and the error in load forecasting is small. The event at 4.30 causes a lack of production in Area C and a corresponding use of secondary reserve.

Tertiary reserve in Area C is generally more expensive than both Area A and B; therefore, if no specific network constraint is activated, Area C reserve is commonly activated to reduce local generation and Area A/B reserve is activated to increase the production. The secondary reserve is uncharged within 2 quarters of an hour. Similarly, a lack of production at 1.30 P.M. requires secondary reserve; tertiary reserve is activated mainly in Areas A/B.

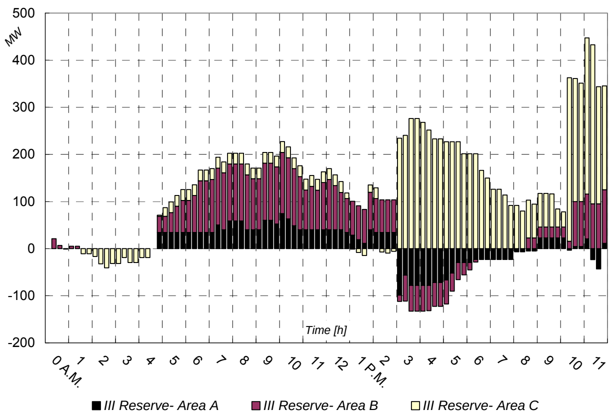


**Figure 3.** Use of III Reserve – Less reliable simulated day

It is interesting to observe in *Figure 4* that after 6.30 A.M. the difference between actual and forecasted load is always positive till 10.45 A.M.. Thus, the requested tertiary reserve increases its value, due to the superposition of error in load forecasting and lack of generation at 4.30 A.M.

At 3.00 P.M., path CB-1 connecting Area C with Area B, goes out of service, causing a congestion (line CA-1). *Figure 5* shows CB-1/CA-1 power flows. The redispatching requires the intervention of tertiary reserve in the present quarter of an hour and all areas are involved in the power shifting (see *Figure 3*). In order to avoid line cascading, even thought cost is high, Area C tertiary reserve is activated up to

≈+230 MW and Areas B/C reserve is decreased to ≈-120 MW.

Due to both merit order list of Ancillary Service Market and the reduced margins in Area C, each production outage ends up by increasing the power flow on lines CA-1/CB-1, up to congestions (*Figure 5*). In fact, at 10.15 P.M. a lack of production of 300 MW occurs in Area C; it causes a line overloading (CA-1) and consequently a load shedding of 20 MW in Area C, due to the lack of quick tertiary reserve in the present quart of an hour.

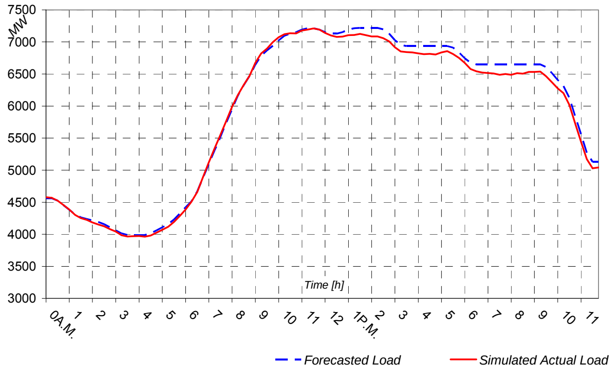


**Figure 4.** Load Profile – Less reliable simulated day

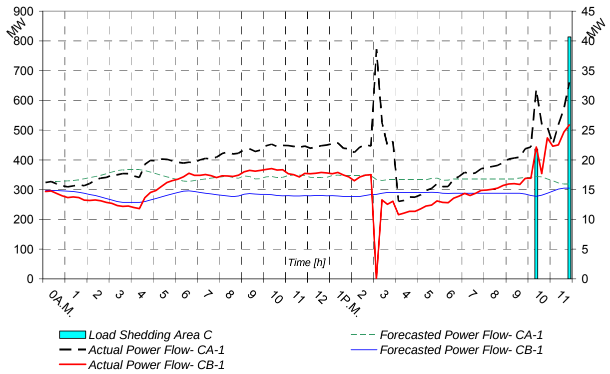


**Figure 5.** Power Flow – Less reliable simulated day

Both in the event at 10.15 P.M. and at 11.45 P.M., it can be remarked that load shedding and interzonal lines power flows are strictly related. As matter of fact, the event at 11.45 P.M. causes an additional lack of production in Area C, with a consequent load shedding in Area C (about 40MW).

## 6. Conclusions

In the present paper a probabilistic steady state approach has been proposed to assess, for given availability parameters of generation and transmission facilities, how the setting of operating reserve power margins affects the amount of Expected Energy Not Served. Assuming the price signals of the Ancillary Service Market, the simulation software operates on emergency OPF, taking into account the generator margins and ramps, as well as the power flow limits of each single lines. This method could be used to set the reserve margins corresponding to an adequate security level, as well as to optimize the operating procedures for real time balancing.

A case study, focused on the IEEE test grid (RTS-96) and relevant to a working day with significantly high load levels, has been simulated and discussed. The results obtained have highlighted a strong correlation between the load shedding procedures and the congestion management, since the load curtailments are often due to transmission constraints, rather than generator adequacy.

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# COMPARING DIFFERENT APPROACHES TO SOLVE THE UNIT COMMITMENT PROBLEM CONSIDERING HYDRO-PUMPED STORAGE STATIONS

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## Abstract
Unit commitment is an important optimization task in the daily operation planning of modern power systems. Due to its complexity, several techniques for the solution of this problem have been proposed. In this paper, three of them are compared: the priority list (PL), the gradient method, and the genetic algorithm (GA). The case studied contains five thermal units and one hydro-pumped storage station (HPSS), and it is based on the Cretan power system characteristics for a 48 hour interval. The performance of the selected approaches is also examined, as well as the need of a HPSS installation in such a system.

**Keywords:** Unit commitment, hydro-pump storage station, optimization techniques, priority list, gradient method, genetic algorithms

## 1. Introduction
The objective of the unit commitment problem (UCP) is to schedule the generation units of a power system in order to serve the load demand at the minimum operating cost, while meeting all plant and system constraints. The UCP is a complex mathematical optimization problem with both integer and continuous variables. The optimal solution to the UCP can be obtained by complete enumeration, which is prohibitive in practice owing to its excessive computational resource requirements [1].

In order to reduce the storage and computation time requirements of the UCP in realistic power systems, a number of suboptimal solution methods have been proposed. The basic methods can be classified into three categories: classical optimization methods, heuristic methods, and artificial intelligence (AI) methods. Classical optimization methods such as Dynamic Programming and Lagrangian Relaxation were used as a direct means for solving this problem. Heuristic methods such as Priority List (PL) provide a suboptimal solution due to incomplete search of the solution space. AI methods such as Neural Networks, Simulated Annealing, Tabu Search and Genetic Algorithms (GA) [2] seem to be very promising in obtaining good results and are still evolving. Moreover, hybrid models that combine two or more of the methods mentioned above have also been presented [3]. For a complete survey of the UCP solution methods, the reader is referenced to [4].

In this paper, a performance comparison of different solution methods for the UCP is performed. The examined system has similar characteristics with the Cretan isolated power system. It contains five thermal units (one steam turbine, one combined cycle (CC), one Diesel and two gas turbines) and one hydro-pumped storage station (HPSS). The compared methods for the solution of the UCP are a) the PL, b) a gradient method that improves the results taken from the PL solution, and c) a GA. The performance criteria for each method are the quality of its solution. Moreover, the need of installing a HPSS is also examined.

The paper is organized as follows: Section 2 formulates the UCP, while Section 3 presents briefly the examined system. Section 4 describes the three examined methods. The provided results are analyzed in Section 5. Section 6 concludes the paper.

## 2. Problem Formulation

The UCP can be formulated as follows:

*Objective function*

For *i* number of units (*i*=1,…N) and *t* time steps (*t*=1,…T) – usually hourly time intervals – minimize operational cost (*OC*) in €:

$$\min(OC) = \sum_{i=1}^{N}\sum_{t=1}^{T}[U_{it} \cdot FC_{it}(P_{it}) + U_{it} \cdot (1 - U_{it-1}) \cdot SUC_i] \tag{1}$$

where $U_{it}$ is a decision variable for the on/off status of unit *i* at time step *t*, $P_{it}$ is the generation output of unit *i* at time step *t* (in MW) and $SUC_i$ is the startup cost of unit *i* (in €).

The fuel cost $FC_{it}(P_{it})$ (in €/h) is described by:

$$FC_{it}(P_{it}) = (a_i + b_i \cdot P_{it} + c_i \cdot P_{it}^{\ 2}) \cdot FP_i \tag{2}$$

where $a_i$, $b_i$, $c_i$ are the cost coefficients (in T/h, T/MWh and T/MWh$^2$, respectively), and *FPi* is the fuel price of unit i (in €/T).

*Constraints*

- Generation output limits:

$$P_{it}\min \le P_{it} \le P_{it}\max \tag{3}$$

- Load balance. For *t*=1,…T:

$$\sum_{i=1}^{N} U_{it} \cdot P_{it} = D_t \tag{4}$$

  where $D_t$ is the system load demand at time step *t*.

- Spinning reserve. For *t*=1,…T:

$$\sum_{i=1}^{N} U_{it} \cdot P_{it}\max \ge D_t + R_t \tag{5}$$

  where $R_t$ is the system reserve at time step *t*.

- Volume limits of a HPSS reservoir. For $k$=1,…,K:

$$volume_k \min \le volume_{kt} \le volume_k \max \quad (6)$$

where $volume_k$min is the minimum water volume of storage reservoir $k$ (in $m^3$), $volume_{kt}$ is the water volume of storage basin $k$ at time step $t$ (in $m^3$), and $volume_k$max is the maximum water volume of storage reservoir $k$ (in $m^3$).

- Begin/end level constraint of a storage reservoir. For $k$=1,…,K:

$$volume_k begin = volume_k end \quad (7)$$

where $volume_k begin$ is the water volume of storage reservoir $k$ at the begin of the optimization period (in $m^3$), and $volume_k end$ is the water volume of storage reservoir $k$ at the end of the optimization period (in $m^3$).

- Turbine and pump operating constraint:
Simultaneous operating of turbines and pumps of storage power stations is not possible.

## 3. Power System Description

The study case system is a realistic model of the power system of Crete, which is the largest autonomous power system in Greece with the highest rate of increase in energy and power demand nationwide. The conventional generation system consists of several types of oil-fired generating units, as it is shown in following Table 1, with a total capacity of 740 MW installed. One characteristic of the load profile is the significant difference between low-load and peak-load recorded values, both within a day and within a year. The low load demand can be assumed to be approximately equal to 25% of the corresponding daily peak loa and occasionally it is reduced in order to correspond to the production of the running units.

Regarding operation strategies, steam and diesel turbines mainly supply the base-load, while gas turbines normally supply the peak load demand at a high running cost that increases significantly the average operational cost of examined power system. Additionally, the required spinning reserve $R_t$ is normally considered as the 10% of load demand $D_t$.

**Table 1.** Characteristics of examined system's thermal units

| Unit | Pmin (MW) | Pmax (MW) | SUC (€) | Fuel |
|---|---|---|---|---|
| Steam | 28 | 50 | 3094 | Mazout |
| Combined Cycle (CC) | 24 | 125 | 422.4 | Diesel |
| Diesel | 12 | 47.2 | 768 | Mazout |
| Gas1 | 2.41 | 58 | 0.1 | Diesel |
| Gas2 | 3 | 15 | 179.1 | Diesel |

Within the previous realistic study case, a hydro-pumped storage station (HPSS) has been considered, with upper limits of 48 MW in both operation conditions and reservoirs capacity (high & low reservoirs) of $5 \cdot 10^6$ $m^3$ each. The water flow $q$ (in $m^3/h$) is equal to $22000 \cdot P$. Taking into account the given capacity of HPSS's reservoirs, the total operation autonomy is estimated less than 5 hours at full power. Furthermore, the overall operating cycle of the HPSS has an efficiency of 75% ($n$=75%), i.e. 4 MWh of pumping are required to replace 3 MWh of generation water use.

# 4. Unit Commitment Problem Modelling

### 4.1 Priority List

The PL method initially arranges the generating units in a predetermined order, which is then used for the UCP such that the system load is satisfied. For the studied power system, the units have been classified as follows: 1) Steam turbine, 2) CC, 3) Diesel, 4) Gas1, 5) Gas2, and 6) HPSS.

### 4.2 Gradient Method

In the gradient method, the equivalent thermal system *FC* curve is first calculated for each hour of the studied time. Then, by calculating the gradient $\lambda$ of the *FC*, the method search for the lowest cost time interval of the period during which to do the pumping [1]. In the decision of whether the pumping operation should occur, the system constraints are taken into account, as well as the efficiency $n$ of the HPSS. In order to search for the possible benefits of the HPSS operation, the on-off status of the thermal units that resulted from the PL approach has been maintained, and the decrease in system's *OC* is examined through the improved scheduling of the HPSS.

### 4.3 Genetic Algorithm

GAs are stochastic global search and optimization methods that mimic the metaphor of natural biological evolution. They operate on a population of potential solutions applying the principle of survival of the fittest to produce successively better approximations to a solution [5], [6]. GAs have also been applied for solving the UCP of hydro-thermal power systems that contain HPSS [7], [8]. The approach followed in this paper is based on [7]. The execution sequence contains the following steps: 1) Use a binary GA to solve the optimal generation schedule for thermal units, 2) Use a binary GA to solve the optimal generation schedule for HPSS, and 3) Check for iteration number.

In the thermal system encoding each chromosome string contains 5 x 48 genes, and each gene is assigned only one bit, where '0' indicates off-line and '1' indicates on-line. For the HPSS encoding each chromosome string contains 7 x 48 genes. The decoding scheme is shown in fig. 1. For each hour, the first bit indicates the HPSS mode ('0' for pumping mode and '1' for generating mode), while the remaining 6 digits are used for the calculation of the HPSS power $P_{HPSS}$ output according to the following equation:

$$P_{HPSS} = \sum_{j=1}^{6} P_{HPSS} \max \cdot (b_j \cdot 2^{-j}) \tag{8}$$

where $P_{HPSS}$max is the maximum power of HPSS (48 MW for the generating mode and -48 MW for the pumping mode) and $b_j$ ($j$=1,…6) is the value of each remaining bit.

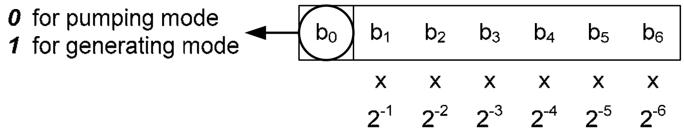


**Figure 1.** HPSS decoding scheme.

The chosen GA parameters were the following:

- Number of individuals: 100
- Number of generations: 120
- Selection method: ranking with survival rate equal to 0.5, elitism
- Recombination method: uniform crossover
- Mutation rate: 0.001 (constant)

The constraints check was implemented with the help of penalty functions. Their values are chosen sufficiently large to discourage the selection of solutions with violated constraints. Due to the discrete nature of the calculated HPSS power (see fig. 1), the begin/end level constraint of storage reservoirs is required to be satisfied within a ±2% tolerance.

## 5. Results Analysis

### 5.1 Priority List

The results extracted from the PL approach are shown in fig. 2. Due to the low priority of the HPSS, its contribution to the load demand is extremely small. The total *OC* for the 48 hour operation of the examined power system is 1,099,308 €.

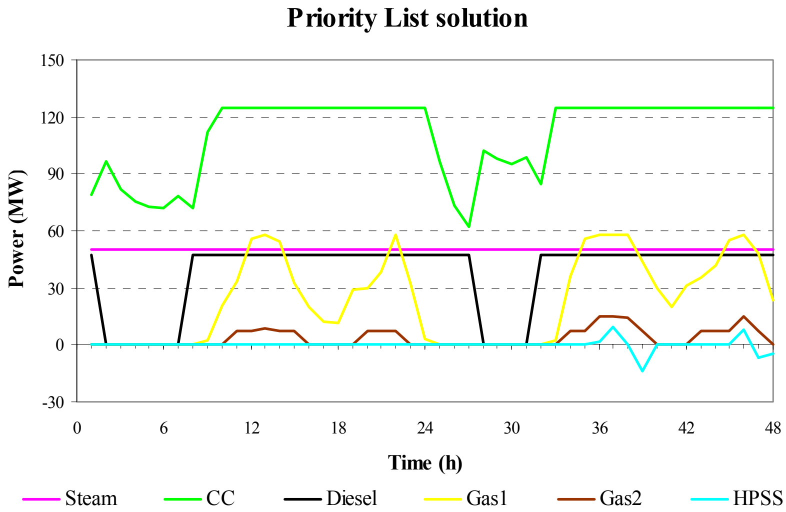


**Figure 2.** Results from the PL approach.

### 5.2 Gradient Method

The use of the gradient method increases significantly the penetration of the HPSS, as fig. 3 depicts. The HPSS generating mode operates when the load demand is greater and all units (including the costly gas turbines) are operating. On the other hand, during the night hours where only the less costly steam, CC and Diesel units are needed to satisfy the load, the HPSS is working on pumping mode. The absence of pumping during the first –low load– hours is explained by the initial reservoirs condition: all available water is in the upper reservoir. The total *OC* is 1,097,532 €, i.e. 0.16% lower than the cost of the PL approach.

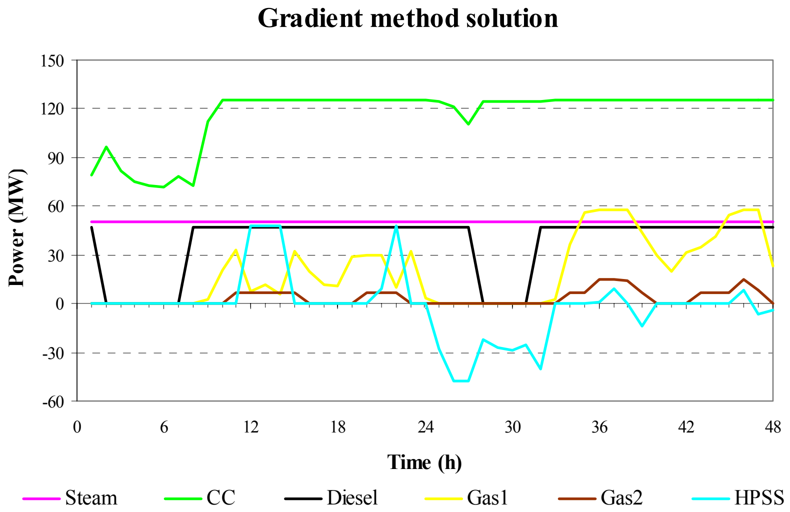


**Figure 3.** Results from the Gradient Method approach.

### 5.3 Genetic Algorithm

The main characteristic of the solution provided by the GA is that at least three units are operating during every hour (see fig. 4). However, the resulted *OC* is 1,074,523 €, i.e. 2.31% lower than the cost of the PL approach. The HPSS operation schedule is almost identical with the obtained by the Gradient Method solution.

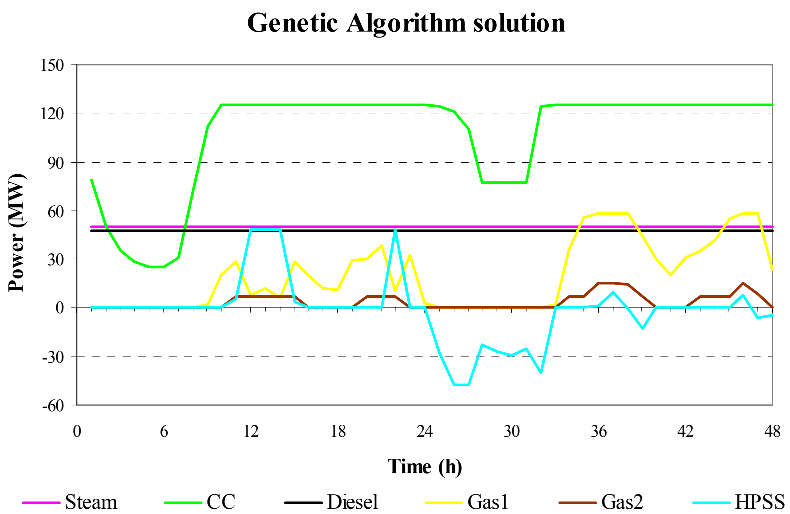


**Figure 4.** Results from the GA approach.

## 6. Conclusions

The performance of several approaches for the solution of the unit commitment problem in a power system that contains thermal units and a hydro-pumped storage station has been examined. It has been shown that the genetic algorithms provide much better results that are based on an improved thermal unit commitment. On the other hand, the need for an installation of a hydro-pumped storage station in a power system of this type is doubtful, as the resulted operation profits are negligible, the installation costs are significant, while the considered hydro-pumped efficiency of 75% represents the upper limit of such systems today. Although, the contribution of such hydro-pumped storage systems in case of significant renewable energy sources penetration in a power system, as the examined Crete's system, looks like a necessity and must be further examined.

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# ROOF INTEGRATED SOLAR PARABOLIC COLLECTORS SIMULATION ANALYSIS

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## Abstract

Concentrating solar collectors systems and especially the mini Parabolic solar reflecting systems have been one of the main research topics due to their ability for integration into the building structure. In the present work the mini parabolic collector was considered in the East – west orientation with such a slope so that the suns vector impinging normal to the parabola during the day. Because of the differences between theoretical and experimental results that observed previously, a new model of calculation of the thermal loses developed. According to this model the behavior of the thermal efficiency for various values of small concentrating ratios and mass flow rate was studied. Data input such as solar radiation (direct and diffuse) and temperature ambient were obtained by the meteorological station of R.E.S. Laboratory of the T.E.I. of Patras.

**Keywords:** Mini parabolic collectors, Simulation, roof integrated, concentration ratio.

## 1. Introduction

Many researchers have investigated the concentrating systems of different sizes, scale [1-3] and application type. Particular interest is shown for roof integrated compound parabolic concentrators (C.P.C.) The research of such systems is under progress and only a few projects are monitored and mentioned [3,4]. In order to increase the system performance roof integrated solar heating systems with glazed collector have been design and investigated [5].

The target of this work is the theoretical analysis of the efficiency of a special design and construction mini parabolic collector (Fig 1.) [6].

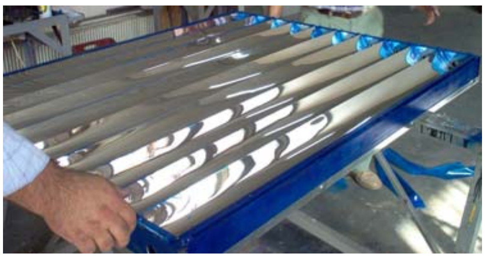

**Figure 1.** Mini parabolic system constructed in the R.E.S. Laboratory

The geometrical parameters, thermal and optical characteristics of the mini parbolic collector system, along with the system configuration (orientation, inclination, and disposition) are taken into account in the determination of the system's efficiency.

## 2. Theoretical Analysis

The numerical code developed used FORTRAN 4.0 and models:

a. The building's roof.
b. The impinging solar radiation.
c. The reflection and absorption of the solar beam and their conversion to heat and finally the storage in a tank.

The geometric dimensions are opted for roof integration. The reflectance, emissivity and the absorptance for the reflecting material and the absorber tube anodized Al and copper painted black respectively are:

- Parabola reflectance : $\rho$= 0.90
- Tube absorptance : $\alpha$= 0.90
- Parabola emissivity : $\varepsilon_q$=0.10
- Tube emissivity : $\varepsilon_c$=0.80

The input data required by the code are: day of the year, ambient temperature $T_\alpha$, building parameters (orientation, roof inclination) collectors positioning and geometric characteristics. Instant incident radiation intense direct and diffuse. The determination of sun's altitude and solar azimuth angle is done by [7].

The program, via an orthogonal transformation, determines the sun's unit vector with reference to a $O(x_1,y_1,z_1)$ system with an axis along the absorber's tube central line $x_1$, the $y_1$ axis normal to $x_1$ and $z_1$ axis normal to the roof's plane.(see Figure 2 )

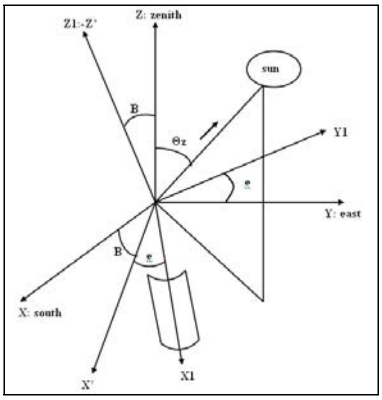


**Figure 2.** Sun's and collector's position with reference to $O(x_1 ,y_1 ,z_1)$ system fixed on the parabola's focal axis which coincides with the absorber's axis.

Figure 2 shows the roof inclination angle $\beta$, the collector's position angle e, the solar altitude $\alpha$, the solar azimuth angle $\gamma_S$. Two rotations, around the y axis and then,around the z axis, transform from O(,x,y,z) system, to the $0( x_1 ,y_1 ,z_1)$ one. The aperture of the parabola is divided into 512 strips (see Figure 3), and examines if the beam strikes directly the absorber or if it does after a reflection. In every case the point and angle of incident on the absorber are determined.

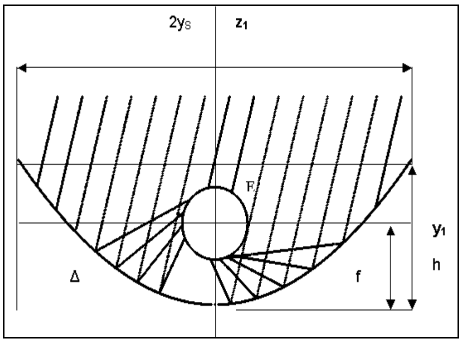


**Figure 3.** A configuration of the reflecting parabola and absorber on the plane $y_1$, $z_1$ with the direct sun beam in three possible cases. f is the focal length, $2y_S$ is the aperture, h is the depth, D is the absorber's diameter.

As it concerns the diffuse isotropic component of the solar insolation Monte–Carlo sampling was used [10] to determine the vector components of a random ray.

The efficiency, $\boldsymbol{\eta}$, of the parabolic reflecting collector was studied by running the simulation package developed for this project.

Concerning the theoretical results, [11,12] a series of runs of the simulation model developed studied the efficiency $\boldsymbol{\eta}$. This study examined the influence of the mass flow rate $\dot{\mathbf{m}}$, the concentration ratios, **C,** the fluid inlet temperature, $\mathbf{T_{fin}}$, and the difference of the fluid inlet temperature, $\mathbf{T_{fin}}$, and the ambient temperature, $\mathbf{T_a}$, over the total solar radiation on the parabolic collectors plane, $\mathbf{\Delta T/I_T}$.

## 3. Results

The theoretical results were obtained for around the solar noon period. That was due to the fact that in the experimental analysis, there appear some observations about the influence of the Concentration ratio, C, on the final output, i.e. efficiency and thermal gain, for time periods far from the solar noon, when the angle of incidence gets high values.

Therefore, this analysis is important in order to investigate the effect of reflected solar beam incident on the absorber and especially its angle of incidence for various P.T.C. systems with various C values.

In fact, for a period around solar noon the angle of incidence of the beam rays is in high majority of low values. On the other hand, as solar time moves away of the solar noon, either before or after, the angle of incidence becomes quite higher and therefore this implies a behavioral change in the PTC energy performance.

To obtain the simulation results, the meteorological data of the $335^{th}$ day of the year 2006 (1/12/2006), were used. In all cases it was considered that the solar radiation strikes the parabolic collector at normal, the system was facing south and has the right **β** angle. The package was executed for various Concentration ratios, **C**, and different absorber tube diameters, fitted in the parabolic collector's focal axis. The total collector system consisted of 6 troughs in series as shown in Figure 1.

The shape of the curve of thermal efficiency **η** versus **$\Delta T/I_T$** as constructed by fitting the simulation results, is of second order. This shape is clear when large ($T_{fin}$ –$T_a$) values were used; the same is discussed in [7,13]. In our cases as the ($T_{fin}$ –$T_a$) values weren't high enough, the curves obtained seems to have linear behavior, see Figs. 4 and 5.

The input data are analytically presented in Table1.

**Table 1.** Simulation procedure input data.

| | |
|---|---|
| Site | Patra, Greece |
| Day/year | 335/2006 |
| Latitude **φ** | 38.25 $^o$ |
| Longitude **l** | 21.73 $^o$ |
| Collector Type | 6 – trough parabolic collector |
| Absorber tube diameter **D** | 3 mm, 5 mm, 8 mm, 15 mm |
| Collectors Inclination **β** | 60.35 $^o$ |
| Collectors Orientation **γ** | $0^o$ |
| Collectors Disposition | East – West |
| **Measured Quantities** | |
| Total Solar radiation impinging normal to the collector's plane **$I_T$** | 936 $W/m^2$ |
| Diffuse Solar radiation on the collector's plane **$I_d$** | 220 $W/m^2$ |
| Ambient Temperature **$T_a$** | 16.3 $^oC$ |

In Figure 4 the variation of the thermal efficiency **η** versus **$\Delta T/I_T$** for four different Concentration ratios **C**, (3.395, 6.369, 10.185, 16.976) for the same mass flow rate 72 [l/h] are presented.

As it was expected, from theoretical analysis [7, 9, 13] better behavior was obtained from the parabolic collector with the higher Concentration ratio. It can be seen that as the Concentration ratio increases the rate of decrease of the efficiency versus **$\Delta T/I_T$** is smaller. This means the energy losses gets smaller, as the slope decreases. This implies that the parabolic collector systems with high concentration ratio **C** perform better when the generating point of the P.T.C. is in high **$\Delta T/I_T$** values.

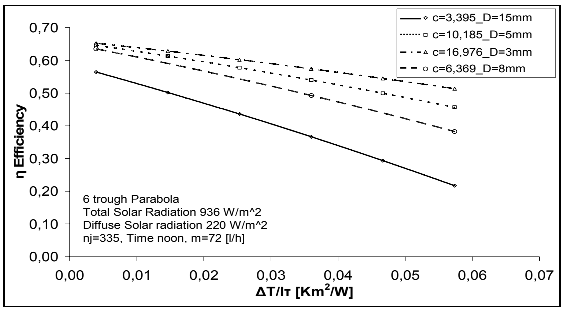


**Figure 4.** Theoretical thermal efficiency versus $\Delta T/I_T$ for the four different Concentration ratios, obtained by the simulation package.

In Figure 5 the variation of the thermal efficiency, **η**, versus **$\Delta T/I_T$**, keeping **C** constant is shown. The parameter in this study is the mass flow rate, $\dot{m}$ .As it was expected higher thermal performance is obtained with bigger mass flow rates, $\dot{m}$ . The rate of decrease of the efficiency **η** versus **$\Delta T/I_T$** , is almost the same for high mass flow rate. However, this rate of change depends also on the generating point, **$\Delta T/I_T$, $(T_{fin} - T_a)/I_T$**. In general taking, low $\dot{m}$ values into consideration, as the **$\Delta T/I_T$** increases the divergence between the curves at various $\dot{m}$ decreases. This is in contrast with the analysis of **(η, $\Delta T/I_T$)** with **C** as parameter (see Figure 5).

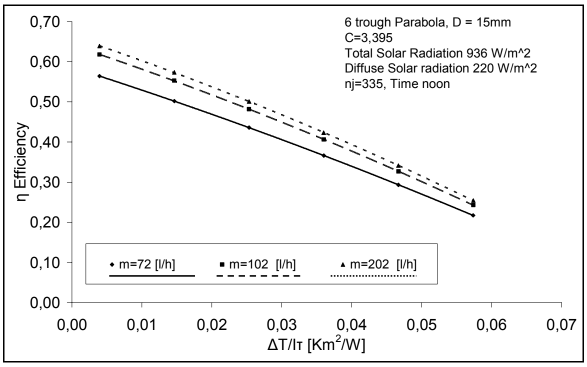


**Figure 5.** Theoretical thermal efficiency versus $\Delta T/I_T$ for three different mass flow rates

A further analysis investigates the dependence of **η** on $\dot{m}$ . In Figs. 6 and 7, the thermal efficiency, η, versus mass flow rate, $\dot{m}$ , at various Concentration ratios, C, is shown, for inlet fluid temperatures, $T_{fin}$ 20°C and 50 °C, respectively.

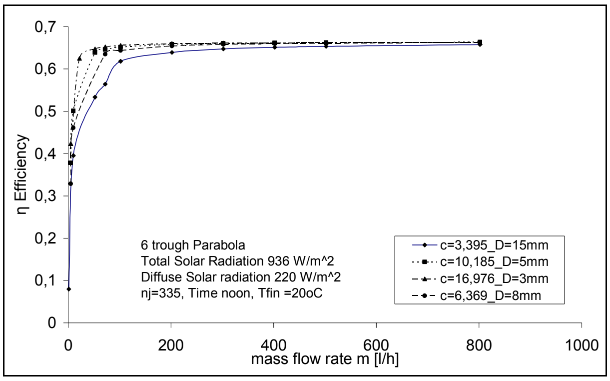


**Figure 6.** Theoretical thermal efficiency η, versus mass flow rate, $\dot{\mathbf{m}}$ for various Concentration ratios, C for a small fluid inlet temperature $T_{fin} = 20\ ^oC$

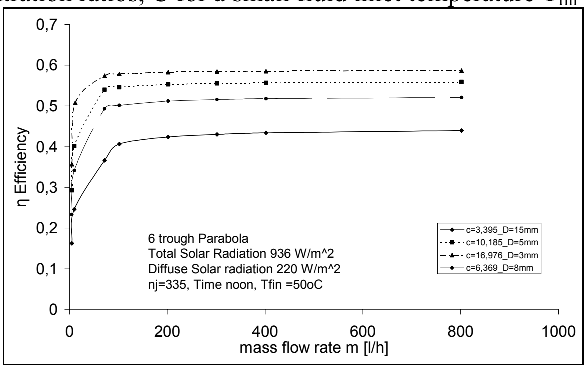


**Figure 7.** Theoretical thermal efficiency, η versus mass flow rate, $\dot{\mathbf{m}}$ for various Concentration ratios, C for a fluid inlet temperature of $T_{fin} = 50\ ^oC$

In the above Figs. 6 and 7, it is evident that the thermal efficiency, **η**, saturates after some $\dot{\mathbf{m}}$ value. This value is lower for lower $T_{fin}$ value. This saturation occurs for all **C** ratios. However, the saturation $\dot{\mathbf{m}}$ rate is lower for high C, values when $T_{fin}$ takes low values. For small mass flow rates, the thermal efficiency presents a very big rate of increase and this happens independently to fluid inlet temperatures.

Small fluid inlet temperature $T_{fin}$ (Figure 6) gives better results for a big concentration ratio only for small values of mass flow rate. Such values are lower than the optimum $\dot{\mathbf{m}}$ value to be 52 [l/h]. Such values are of no use. However, for big fluid inlet temperatures (Figure 7), the efficiency sets better for all values of mass flow rate, $\dot{\mathbf{m}}$ , as the **C** increases.

## 4. Conclusions

The conclusions may be listed as follows:

- As the concentration ratio increases the thermal efficiency increases, with mass flow rate constant, for periods around solar noon.
- As the mass flow rate increases the thermal efficiency increases around solar noon periods, for the same concentration ratios.

- The thermal efficiency increases as a function of mass flow rate but this increase reach a saturation for all concentration ratios. However, the saturation $\dot{m}$ rate is lower for high C, values when $T_{fin}$ takes low values. For small mass flow rates, the thermal efficiency presents a very big rate of increase and this happens independently to fluid inlet temperatures.

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# THE ROLE OF A POWER EXCHANGE FOR ENERGY TRADING AND POWER GENERATION INVESTMENT

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## Abstract
After the liberalization process began, European electricity industry has undergone a transformation led by a combination of technical innovations, economic forces, and legal changes. Market liberalisation is about establishing a framework for efficient trading. Economic signals provide accurate information on which investment decisions can be made. The economic signals for investors are mainly reference prices of electricity.

This paper examines the role of a power exchange for energy trading and power generation investment to provide reference prices of electricity. First, electricity trading arrangements are summarized. Second, reference price setting in an independent, neutral power exchange is examined. Finally, the role of a power exchange for facilitating efficient energy trading and thereby influencing decision making in power generation investment is discussed.

## 1. Introduction
Electricity trading can be arranged through bilateral contracts and/or power exchanges. Since electricity cannot be stored, long term (one year and more), mid term (monthly to yearly) and short term (daily to monthly) contracts are necessary to keep supply and demand in balance. Due to difficulties in forecasting demand in advance exactly, market participants need hourly contracts to balance their consumptions and contracts. Spot markets where hourly contracts are traded are usually organized by a power exchange.

Bilateral contracts by definition are signed by two parties and prices are only known by the parties involved. In addition, bilateral contracts are tailor made, so not standardized. Therefore, reference price for market is difficult to set from bilateral contracts. An electricity power exchange, which is absolutely neutral toward the market, provides a spot market (mainly day-ahead) for electricity, which like any other market matches demand and supply for each hour, while providing a reference price.

Consequently, economic signals for investors in liberalized market are provided by a power exchange and efficient energy trading can be facilitated.

## 2. Electricity Trading Arrangements
The last decade has witnessed radical changes in the structure of the power markets in Europe. While the process of regulation and liberalization in some countries is still subject to current debate and legislation, market integration in the European Union requires harmonizing electricity markets. The first to start liberalizing their electricity markets in Europe, were England and Wales in 1990. Thereby, power

exchanges (PX) play an increasingly important role, since electricity has transformed from a primarily technical business, to one in which the product is treated in much the same way as any other commodity [1].

Effective wholesale markets are critical to the successful development of the SEE electricity market as well.

The development of electricity trading and the creation of electricity power exchanges are one of the most visible results of the liberalization of the electricity industry in Europe [2]. Power exchanges are market places that facilitate wholesale trade in electric energy.

Market players (generators, traders and suppliers) come to a market place to trade electricity and make contracts. Market players have needs and obligations to generate or consume a specific amount of electricity at a specific time in the future. These needs and obligations are covered by contracts with committing partners. Contract negotiations will determine the contract conditions like time, place, volume etc. and price. If contracts are standardized and well defined as products, only price is left for market players to agree on. Such a market is said to be effective; it keeps transaction costs at a minimum and price becomes the signal that directs all actions. Thus, the standardisation of electricity as a tradable product becomes the critical challenge for successful electricity market liberalisation, enabling the creation of a framework for transparent prices that signal real cost and the willingness to pay those costs. If the prices reflect the real values at stake and if incentives are right, the resulting actions will lead to efficient outcomes [3].

The liberalization in the European Union (EU) is a top down process driven by the Directives of the European Parliament and of the Council (Directive 96/92/EC, 1996; Directive 2003/54/EC, 2003). The Directives lay down the general conditions that should be in place to assure the creation of a single internal electricity market (IEM) in Europe, but refrain from designing a concrete market. Given this freedom, most European countries have chosen to keep centralized components to a minimum and to leave market organization to the dynamics of private initiative.

In a liberalized electricity market, participants can trade on a variety of markets. According to Eurelectric [4], trading is critical in a liberalised market, and is one of the key drivers of liberalisation. Firstly, trading supports economic efficiency, drives out inefficiencies in the marketplace, and contributes to lower prices for customers. Secondly, trading offers the necessary products and instruments in order to manage the more volatile market conditions, which occur in a liberalised market. Risk management is a more and more vital function that trading brings into a liberalised market.

Depending on the delivery period, bulk electricity can be traded on spot or forward markets. Spot markets are mainly day-ahead markets on which electricity is traded one day before physical delivery takes place. On forward markets, power is traded for delivery further ahead in time.

Products in electricity trading can be classified broadly into physical products, financial products and combination of the two. Physical products are traded for real physical delivery between parties. For example, in physical day-ahead markets the traded amount of electricity is actually delivered by the seller to the buyer the following day, and, in this case, is done for each hour the day, although hours can also be grouped in blocks. Financial products include different power derivatives, such as options, contracts for differences, and futures, which are based on the underlying spot market price, and which are widely used to manage the risks of price fluctuations. Financial products do not necessarily lead to physical delivery of electricity, as they are mostly settled financially between the involved parties. There are also products which combine both physical and financial elements [4].

Figure 1 provides overview of the basic product types in European electricity markets.

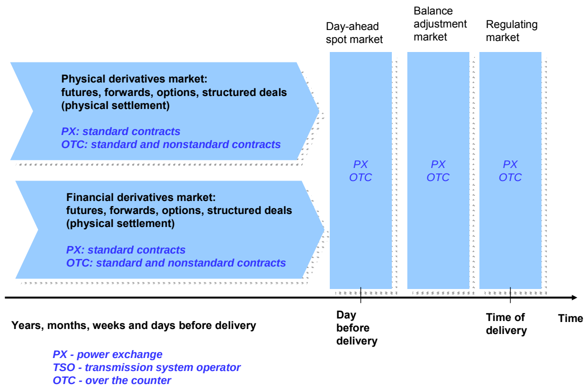


**Figure 6.** Electricity trading market structure in Europe (Source: Eurelectric[4])

Bilateral forward and over-the-counter (OTC) trades constitute most wholesale trade volume in the internal electricity market (IEM). In this way, suppliers buy in advance to cover their consumption portfolio with long-term and forward contracts. Electricity is not storable and real consumption is not completely predictable in advance. Hence, there is also need for additional daily and hourly contracts in spot markets to cover at least prediction errors.

Transaction costs of fine tuning a portfolio via OTC type of spot markets are high because of the search costs of finding an adequate counter party, the bargaining costs and the problem of non-anonymity as the confidentiality of each company's position is valuable close to real time. Therefore, a mixture of private and public initiatives of generators, suppliers and transmission system operators has lead to the creation of power exchanges in most Member States. Power exchanges are trading platforms operating day-ahead (one day before delivery) and facilitating anonymous trade in hourly and multi-hourly contracts called block orders. Even though power exchanges only attract a relative small fraction of total trade, their public hourly price index serves as a reference for the contracts negotiated in forward markets [5]. Power exchanges are organised and standardised marketplaces. Market participants transact anonymously using the exchange as central counter party. Trades are cleared by the power exchange or its appointed clearing house, thereby greatly reducing counter party risk, i.e. the risk that a party defaults on its contractual obligations. Power exchanges that have gained some significance include Nord Pool, EEX in Germany, APX in Holland, Powernext in France, OMEL in Spain and GME in Italy.

Over the last years and in the face of the ongoing liberalisation of the electricity sector in Europe and many other parts of the world, a number of electricity exchanges have been put into operation, and the development is far from completed. By centralising transactions, guaranteeing transparency and disseminating relevant information, the Power Exchange will enhance the competitiveness of the market.
A strong underlying spot market is crucial for the development of a successful wholesale market, by helping to develop a credible price for power.

## 3. Reference Price Setting in PX

An electricity power exchange provides a spot market (mainly day-ahead) for electricity, which like any other market matches demand and supply for each hour, while providing a public price index.

In absence of generation capacity constraints economic theory would suggest that prices on spot markets generally reflect the short run marginal cost (SRMC) of the generation unit producing the last unit of electricity to meet demand (i.e. where supply and demand curve meet). This is illustrated in Figure 2 as a merit order which refers to the sequence of generating units according to their SRMC. SRMC are mainly the fuel costs and some other, less substantial, variable production costs.

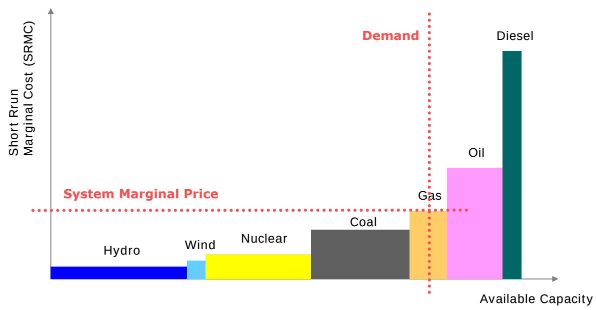


**Figure 7.** Merit order and short run marginal cost

The primary function of an organised spot market for electricity is to maximise cost efficiency by supplying the demand for power from the most economic source available. It is difficult to achieve such optimisation without a continuous price setting mechanism producing a transparent equilibrium price. The large differences in production costs for the different generating units entail a high risk for losses of efficiency stemming from a poorly functioning pricing system. In addition, a much greater reserve capacity would be necessary in order to guarantee supply in a system without a successful spot market.

The primary role of a market price is to establish equilibrium between supply and demand. Spot prices on power exchanges are usually set in auctions, separately for 24 individual hours. Each market participant hands in price-quantity pairs for its selling and purchasing plans, from which the exchange derives aggregate supply and demand curves. The market price and the corresponding clearing quantity are then set as a result of the matching process. Prices and volumes for the individual hours are publicised and made available by the power exchange.

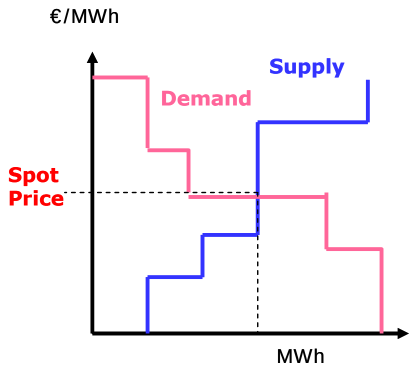


**Figure 3.** Price setting in a power exchange

The prices on the spot markets reflect the actual fundamental situation, which is the ratio of demand and offer, mainly determined by available capacities and the weather. The daily spot price serves as a reference price for the future contracts when it comes to physical delivery or financial settlement of these contracts.

The total trading volumes in power exchanges are seven to ten times higher than the total generation. Most of these volumes are traded on the future markets. This long-term trading is mostly done for hedging purposes. The prices seen on these markets indicate the expectations of market participants and serve as important signals for future investments.

## 4. The Role of PX for Power Generation Investment

The main goal of exchange-based spot markets lies in the facilitation of the trading of short-term standardized products and the promotion of market information, competition, and liquidity. Power exchanges (ideally) also provide other benefits, such as a neutral marketplace, a neutral price reference, easy access, low transaction costs, a safe counterpart, and clearing and settlement service. Besides, spot market prices are an important reference both for over-the-counter (bilateral) trading, and for the trading of forward, future and option contracts. Forward prices express the market's aggregate expectation of future electricity prices.

Investments in the electricity generation are very capital intensive with long lead times and payback times. Decisions by private or state owned companies to invest on purely economic grounds are typically based on an expectation of sufficient cash flows based on the market price.

In traditional regulatory regimes, investment costs are passed through to customers directly so that investors are guaranteed return on their investments. In a liberalized electricity market, electricity prices are the key driver of investment decisions for power generation [6].

Investment decisions for power generation are based on expected spot prices, i.e. forward/futures prices. In other words, economic and financial viability of investments are based not only spot market prices, but also on the mid- and long-term expectations of price development. These expectations are market signals for making well-founded estimations of investment returns.

When there is enough reserve capacity, for example during off-peak period, prices of electricity in perfectly competitive markets reflect SRMC. Market prices tend to rise above SRMC when reserve margins are low, for example during peak period, and in oligoplistic markets. In case of market prices rising above SRMC, generators are able to recover fixed costs and provide a return on investment. In the long run, average prices should be sufficient to sustain ongoing investment by covering fixed costs and providing a return on investment as well as covering variable costs [6].

Whereas forward prices are or should be primarily influenced by supply-demand fundamentals that are expected to prevail in the future, spot prices are determined by the out-turn of these fundamentals. In this way forward prices can give an indication of the overall market expectation about future spot prices.

It can be seen from Figure 4, investment decision of a generation company is based on expected market price which is above 40€/MWh [7]. Spot and futures prices from Nordpool are shown on the left-hand side and average generation cost for different technologies are shown on the right-hand side of Figure 4.

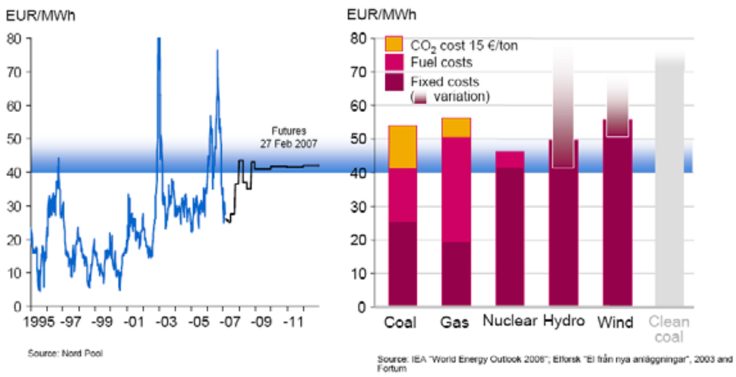


**Figure 4.** Expected market price and electricity generation cost (Source: Fortum[7])

By entering into a futures contract, an electricity generator can purchase a given quantity of electricity, at an agreed price, for a future period of whatever duration. Futures hedge the risk of future price volatility, whether the contract is a financial future or a future with physical delivery. In the first option, upon the expiry of the contract, the generator will only pay the possible monetary difference between the set price and the price in the reference period. In the second option, at maturity, there will also be physical delivery of electricity. Such an "insurance" against the risk of price volatility is offered by forwards, whose only difference with respect to futures is the time of payment of the monetary differences (in the futures, settlement is made on a daily basis, whereas in the forwards it is only made at the end). Finally, options offer an ad-hoc insurance, which is paid through a premium; this protection does not limit the gains on the underlying transaction (e.g. in case of an increase or decrease in the electricity price, to the benefit of the producer or of the consumer, respectively), but it does mitigate losses.

The role that is played by financial derivatives based on the prices of commodities, and in particular of electricity, may be outlined as follows: i) transfer of the risk between market players for various purposes; and ii) price discovery, i.e. disseminating informed market players' expectations about the future trend of prices. In effect, the new expectations (that arbitrage mechanisms transmit to the spot market) rapidly spread to the derivatives market.

## 5. Conclusion

The last decade has witnessed radical changes in the structure of the power markets in Europe. Trading is critical in a liberalised market, and is one of the key drivers of liberalisation. Depending on the delivery period, bulk electricity can be traded on spot or forward markets. Spot markets are mainly day-ahead markets on which electricity is traded one day before physical delivery takes place. On forward markets, power is traded for delivery further ahead in time.

Products in electricity trading can be classified broadly into physical products, financial products and combination of the two.

The primary role of a market price is to establish equilibrium between supply and demand. Spot prices on power exchanges are usually set in auctions, separately for 24 individual hours. Each market participant hands in price-quantity pairs for its selling and purchasing plans, from which the exchange derives aggregate supply and demand curves. The market price and the corresponding clearing quantity are then set as a result of the matching process. Prices and volumes for the individual hours are publicised and made available by the power exchange.

The prices on the spot markets reflect the actual fundamental situation, which is the ratio of demand and offer, mainly determined by available capacities and the weather. The daily spot price serves as a reference price for the future contracts when it comes to physical delivery or financial settlement of these contracts.

Investments in the electricity generation are very capital intensive with long lead times and payback times. Decisions by private or state owned companies to invest on purely economic grounds are typically based on an expectation of sufficient cash flows based on the market price, which is the key driver of investment decisions.

Whereas forward prices are or should be primarily influenced by supply-demand fundamentals that are expected to prevail in the future, spot prices are determined by the out-turn of these fundamentals. In this way forward prices can give an indication of the overall market expectation about future spot prices.

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# HEURISTIC BASED SYNCHRONOUS GENERATOR EXCITATION CONTROL FOR USE IN A DEREGULATED ENVIRONMENT OF ISLAND POWER SYSTEMS

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## Abstract

The proposed work aims at the systematical design, development and implementation of an overall intelligent control system applied in the excitation part of a practical synchronous machine system, for real time operation either as stand alone or in remote mode. It is widely known that there is an emerging need for fast and also reliable excitation systems especially in island systems with diesel engine generators or even in hybrid wind-diesel systems especially in a deregulated environment. In order to achieve this goal, the design of a laboratory prototype is designed first, which completely simulates the operational behavior of a real system and, at the same time, provides the ability for studying and investigating the overall system in a laboratory environment under several operating conditions. The systematical design of the proposed approach illustrate that there are potential capabilities of such an excitation system and is believed that -from a practical point of view- due to its inherent flexibility, will offer better damping effects on the generator oscillations over a wider range of operating conditions, than the associated ones of conventional excitation controller designs currently used in industrial environments.

## 1. Structure of the Proposed Full Electrical Drive System

According to Fig.1, the basic structure of the proposed electrical drive overall system comprises of seven separate sub-systems, namely: a) the synchronous generator, b) the exciter, c) the 3-phase load (symmetrical or not), d) the 3-phase circuit breaker, e) the 1-phase circuit breaker (for the 3-phase load's common point grounding), f) the prime mover of the synchronous generator, g) the heuristic real time excitation control system (for stand-alone or remote operation). It is evident from the above that the main research topic relates with sub-system “g”, while the rest are compulsory for testing, control and authentication of the overall system. The proposed hardware structure comprises of nine different circuits (modules), each of them performing a different function. In particular, these modules are also described in Fig.1. Due to space limitations, the analytical description of the aforementioned modules is not shown here. Instead, here we focus on the control technique which is presented next. It should be noted however that especially for the power electronics module, the topology that was selected among others is a bridge type DC-DC converter with a transformer with two secondary windings (Figure 2), while the control technique adopted is based on pulse width modulation (PWM) with unipolar voltage.

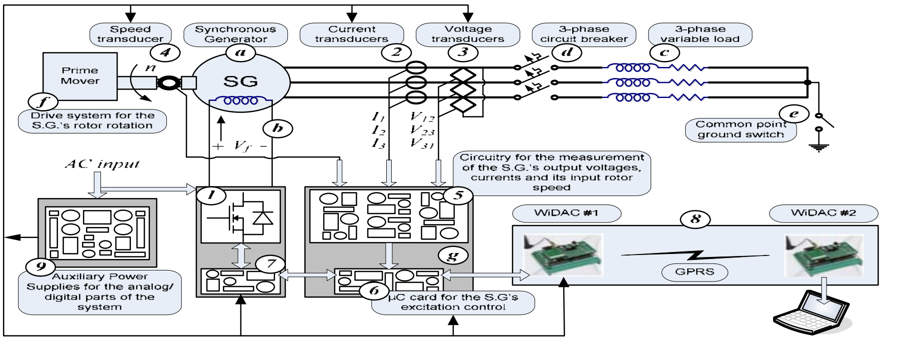



**Figure 1.** Basic structure of the electrical drive system under construction and study.

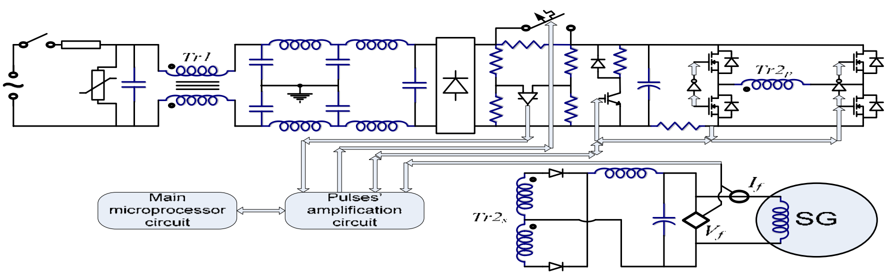



**Figure 2.** Full schematic diagram of the developed power electronics module.

## 2. Description of the Proposed Overall System's Control Technique

The main feature of the proposed excitation system is the software developed. The implemented algorithm should face up effectively several things during the system's operation such as, the instant and secure fault detection at the generator's output, the way of calculating the desired excitation voltage through non linear equations in order to correct the generator's output voltage, the system's response time along with its response behavior, the way of controlling the power circuit and the correct data transfer and synchronization with the remote control centre. Some of the above requirements are described next.

***Philosophy of the Voltage Measurement Technique at the Generator's Output***

One major problem for the reliable operation of our system is the fast and correct measurement of the generator's output voltage. In general, the measurements needed for the calculation of the RMS value of this voltage constitute a relative slow process (it takes 2-3 periods -40ms to 60ms- to calculate securely). Furthermore, some short duration disturbances may be missed and also a long time delay may be a fact in the voltage control loop due to the delay in the error measurement, which is undesirable. In order to overcome all the above problems the following logic has been adopted, which is shown in Figure 3.

- It is known that from the generator's speed and the number of poles, the output voltage frequency can be derived. It is known also that the waveform is sinusoidal. Since, speed is actually a mechanical measure, that is not changing fast, it can be assumed that its measurement through the speed measurement module, will give the output voltage's frequency at least for the next 30ms, time quite larger that the relevant period.
- By knowing the generator's output voltage frequency, we can calculate the time interval that corresponds to a voltage's angle change by $5^o$ ($t_5^o$), so as the time interval that corresponds between 2 values in the microprocessor's pre-stored sine array. This is also the time interval between two voltage measurements.

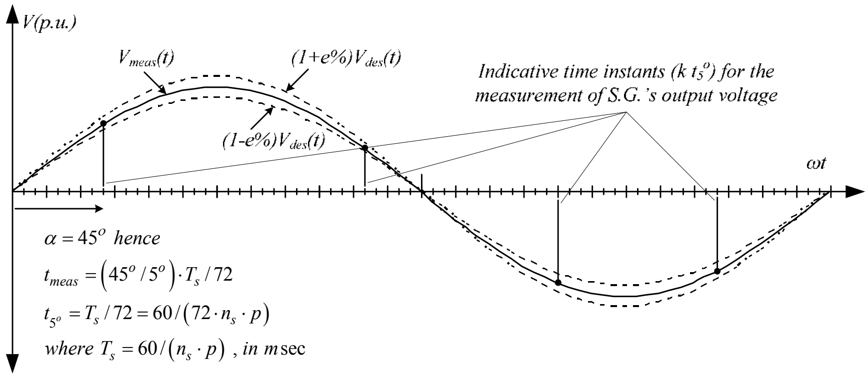



**Figure 3.** Proposed measure technique for the fault detection on the generator's output voltage.

- Through the voltage measurements module we can detect, each time, the zero crossing point of the voltage waveform thus the time instant that corresponds to $0^o$ and thereafter a proper initialization for the safe operation of the output voltage measurement circuit is conducted.
- Each measured voltage value lies between acceptable (permissible) limits which can be preset (i.e. ±10%) for the desired voltage value corresponding to the specific angle.

***Philosophy of the Control Technique of the Power Circuit Unit***

The developed control technique's logic to be applied to sub-system (b) of the system under study comprises on PWM with unipolar output voltage. In this technique each semiconductor pair (same "leg") of the bridge is controlled independently, which results to a better output voltage waveform production in terms of ripple reduction due to the doubling of the output voltage frequency and also the sub-doubling of the voltage ripple (Figure 4). This also leads to the minimization of the required output filters. The transition signals of the semiconductor elements are defined from the comparison between a triangular waveform ($V_{tri}$) and two control voltages a) $U_{control}$ for the semiconductor switches of leg "A" and b) -$U_{control}$ for the semiconductor switches of leg "B". The "pulse giving" logic is described next: while the control voltage value is greater than the triangular voltage value, we activate the upper switch of the respective leg and we activate the lower switch of the respective leg otherwise. It can be proofed that if $\delta_1$ is the duty cycle of the semiconductor devices of leg “A” and $\delta_2$ the respective duty cycle ratio of those of leg “B”, then:

$$\delta_1 = \frac{1}{2}\left(\frac{U_{control}}{V_{tri,\max}} + 1\right), \ \delta_2 = 1 - \delta_1 \tag{1}$$

It is observed from the above equations that in a bridge type DC-DC converter that is controlled by a PWM technique with unipolar output voltage, the average value of the output voltage $V_o$ is varying linearly with the variation of the $U_{control}$ control voltage. In the specific application, due to the existence of the transformer (with transformation ratio $n_1/n_2$), this ratio should be taken into account into the equation that gives the excitation voltage of the synchronous generator. The above analysis is valid by assuming that we are in steady state operation and also that every converter’s elements are ideal. Furthermore, the non-linearity that is introduced in the above operation due to the “dead time” (that is the time delay that is necessary between the shut-off time instant of one semiconductor element and the start-up time instant of the other semiconductor element of the same leg, in order for a possible DC input voltage short-circuit to be avoided) has been taken into account implicitly.

***Philosophy of the Calculation of the Desired Excitation Current***

In order for a synchronous generator to have certain output voltage, then the respective excitation current needed is possible to be obtained algebraically by using the equivalent circuit, the no-load characteristic curve (magnetizing curve) as well as the generator’s technical characteristics. By implementing into the microprocessor’s software (in array format) the generator’s magnetizing curve and by measuring its output current, the excitation current and consequently the desired value of the control voltage $U_{control}$ for the power circuit can be calculated as,

$$U_{control} = \frac{V_{tri}^{max}}{V_{in}} \frac{n_1}{n_2} V_F^{calc} a \tag{2}$$

where, $V_{tri}^{max}$ is the maximum voltage value of triangular control waveform, $V_{in}$ is the power circuit’s bridge type converter’s input voltage of the synchronous generator’s excitation control module, $V_F^{calc}$ is the calculated desired excitation voltage and α is a constant (greater than unity) that is involved into the equation in order for the losses as well as the non-linearity due to “dead time” to be taken into account.

***Communication with the Control Centre***

It is evident that the communication of the remote system with the control center is quite crucial especially with reference to the remote control ability and also the system’s training ability in order for it to respond faster in prospective disturbances. For this communication to be established, twelve (12) digital signals will be involved where eight (8) of them are input signals for the remote system and the rest are output ones.

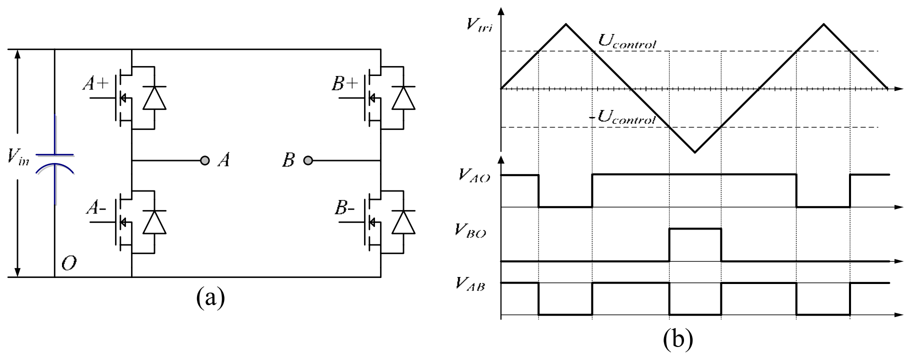


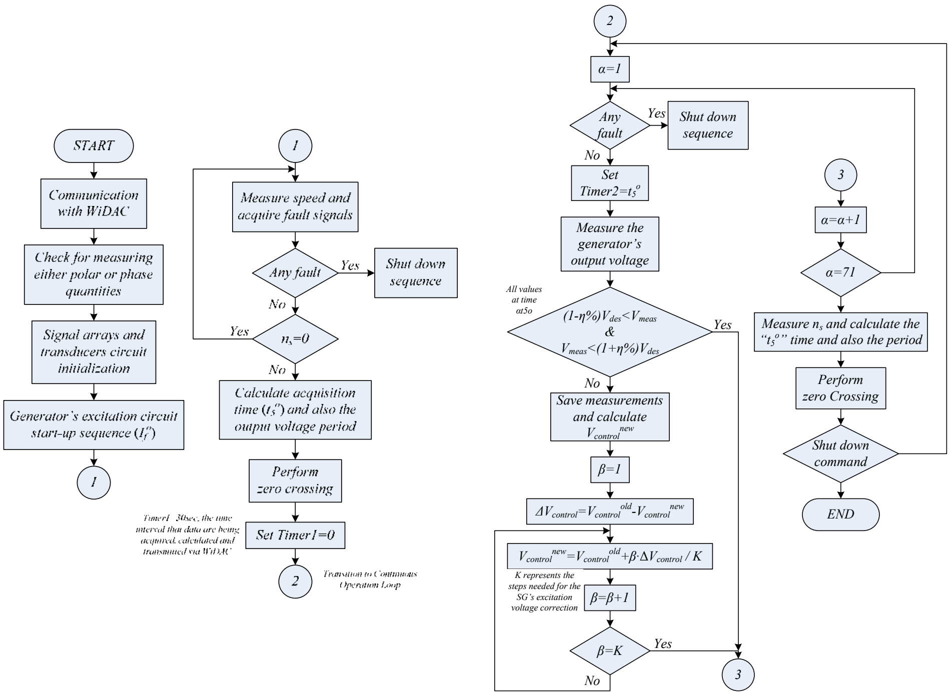

**Figure 4.** a) Structure of the full bridge converter, b) Adopted unipolar output voltage PWM with the relevant waveforms.

During the initial communication phase, data are transferred from the control centre which determine the way that the system will start its operation, how the phase or the polar generator's output voltages will be measured -in order for initial vectors into the microprocessor's memory to be created-, the activation of the appropriate hardware and also the way that the system should react in case of any kind of fault (the latter needs six digital signals). Additional data are transferred from the control centre that give information about the output voltage permissible fluctuation limit ($\pm\eta\%$) using a 4-bit signal. Information are transferred also by a 2-bit signal, regarding the number of "steps" ($k$) that should be followed in the excitation control sub-system when a disturbance greater than that defined by $\eta$, appears on the generator's output voltage.

Conversely, data are transferred from the remote system to the control centre, that relate to the system's status, i.e. "on-off" indication, fault existence, symmetrical or asymmetrical loading etc. Additionally, during normal operation conditions, data are being transferred (in a serial way) to the control centre every 30 seconds, regarding the r.m.s. values of the generator's output voltages (phase or polar), the r.m.s. of the load currents, the phase differences, the output voltage's frequency, the excitation voltage and the excitation current. In case of a disturbance, data related to the detection of the specific disturbance are send and after the new system's equilibrium, new set of data are also send concerning the final system's state. In the same case, data related to the system's behavior during the disturbance are also send to the control centre. These data include the amount of changes of the generator's output voltage until the new stability state is reached and the total system's response time. All the above mentioned data are transferred wirelessly to a terminal of the control centre, in order for a full data base to be created for the system's normal operation behavior and also for its response characteristics in every previous disturbance. The data base records are then necessary to be processed by the control centre developed software, if it desirable for new (sub-optimal to optimal) values of the parameters "$\eta$" and "$k$" to be found. In that way, for future load disturbances, a faster and more reliable response of the system will be possible.

***Overall Flow Chart of the Proposed Control Technique***

The simplified flowchart of the proposed control technique developed in order to be implemented in the practical excitation system of a synchronous generator for remote operation in real-time, is shown in the Figure 5. All the relevant requirements that were discussed in previous Sections are fully satisfied i.e. the instant and correct fault and/or disturbance detection at the generator's output voltage, the way of calculation -at any time- of the desirable excitation current needed for this voltage to be corrected, the system's response time, the system's desirable behavior, the power circuitry control technique, the communication with the control centre along with the relevant software and hardware techniques adopted etc.




(a) (b)

**Figure 5.** Flowchart of the proposed control technique a) Initialization phase, b) Continuous operation loop phase.

## 3. Conclusion

The paper developed and proposed a novel heuristic control technique as well as an overall design of a practical excitation system for a synchronous generator. From the design of such a system it is evident that special attention should be paid on the selection of the appropriate hardware and also to the control technique to be adopted and developed as software. Moreover, a crucial part is the technique that is to be used as the communication protocol between the system and the control centre along with the appropriate selected data to be transferred. The system is designed in such a way, so it can be studied exhaustively in a laboratory environment while in the same time provides the capability to investigate the proposed topologies and control techniques when these are to be transferred in an industrial environment. Concerning the proposed control technique, the main points (i.e. the immediate and correct disturbance/fault detection at the generator's output voltage, the response time as well as the behavior of the system) that guarantee smooth and proper operation were pointed out and solutions were proposed. Finally, the importance of the proper communication between the system and the control centre was shown up along with the necessary capability to be trained continuously so that it can handle future disturbances.

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*This work is part of a research project (sub-project no. 13), which in turn is part of ΕΠΕΑΕΚ II, Action «ARCHIMEDES II – Support of Research Groups at the Technological and Educational Institutions», Action Category 2.2.3.στ.*
*The Project is co-funded by the European Social Fund and National Resources.*

# INNOVATIVE EDUCATION, TRAINING AND DEVELOPMENT PRACTICES AT THE ELECTRICITY AUTHORITY OF CYPRUS

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Deregulation of the Electricity Sector brought a totally new state of affairs to the structure and operation of Electricity Companies throughout Europe. The overall effect of liberalization is **the increase in efficiency and lower energy prices**. A **threefold increase in employee output and price reduction by 24% was reported since 1990 in the UK** producing savings to the customers. Liberalization creates **drive for innovation**, which gives **new products**/and services and **choices to suit individual needs**. Also focusing on the needs and expectations of the customer **brings better service**. A chance is given to employees to own part of the company through **share ownership schemes.**

But the effects of Deregulation/Liberalization on Employment sound an alarm when referring to the loss of 250 000 jobs in less than 10 years in Europe. The experience of Deregulation/Liberalization in the UK showed a loss of 50.000 jobs in the UK in the electricity sector alone.

Social Implications are anticipated reflecting to all Social Partners but in a different way to each one. Naturally, each Social Partner is primarily concerned in solving its own anticipated problems, e.g

- Workers are concerned for job loses and their well-being
- Employers are concerned about their competitiveness
- Governments are concerned with transposing the "Acquis" into State Law and other soft factors such as security & quality of supply, social obligations, etc.

Solving the problems of one Social Partner will not resolve the issue. A solution will have **to balance economic Vs Social Objectives** through a **constructive Social Dialogue** between the Social Partners, thus building a strategy for sustainable development for the future.

In parallel to the development of the social dialogue **the European Commission** is also trying to reduce the consequences of deregulation on employees by **promoting a number of policies** such as **Life-long learning, Equal opportunities, Retraining/redeployment and Social Responsibility.** The **qualitative aspect** of the situation **must also be taken into account** and in particular:

- Redundant People who do not wish to leave have to be **retrained and redeployed in other parts of the business**. When transferred to jobs that they like they can be happier and more productive.
- The **need for new skills** eg in Information Technology, Customer Service, Project Management, Business Development and Consulting give people **more chances and new jobs**.

- **Innovations** can be introduced such as the offering of **vocational training and preparing people who sign to terminate their employment** for a career outside the company.
- It is a well known fact that organizational skill requirements are constantly changing. As the shift from the industrial revolution to the services and the knowledge age, the future will be characterized by changing technology, increasing competitive pressures and the fragmentation and globalization of product markets.

The US superiority in economic performance is the result of Life Long Learning Commitment. It is thus not a surprise that the chosen method to achieve the EU Lisbon strategy i.e. to make Europe the N$^{o}$ 1 economy in the world by 2010, is through Research and Life Long Learning.

Before attempting to give an account of what we do in Training and Development it is useful to say a few words about relevant aspects of the **European Social and Employment Policy**.

Employment issues within the EU are expressed in the form of the Community Charter of Fundamental Social Rights. A Key aspect of the Social Chapter is the development of human resources for lasting employment. The EU tries to combat unemployment by introducing policies, such as the "**white paper**" which sets the strategy for boosting the **competitiveness of the European businesses**, through **investing in human resources training and education.** The EU recognises the need for setting up a system of **continuous, for life, education and training of its human resources**, helping employees to constantly adjust to the radical technological and other changes happening in the work environment. As I mentioned earlier the Lisbon Strategy set as primary target **to make EU the world's most competitive and dynamic knowledge-based economy** by 2010 and this can only be achieved through continuous Training of its Human Resources.

EAC, in view of the liberalized environment and free competition that were coming due to the accession of Cyprus to the EU, performed a number of studies and entered into a dialogue with the employee Unions for agreeing the necessary changes. Two years of discussions with the Unions resulted in a "**Framework Agreement"** concerning the future of the Organisation having four targets:

- A policy for no compulsory redundancies
- Continued cooperation in bringing changes for increased flexibility, productivity and efficiency
- The undertaking that everyone must undergo **training/retraining** as part of the commitment to competitiveness and development.
- **Redeployment** to other jobs within the Organisation.

The agreement included:

- The development of new businesses in related fields for utilising our infrastructure and knowledge
- Decision to pursue Changes for rendering the Organisation flexible and competitive
- **Introduction of new technology and new work methods**
- **Introduction of culture change activities for customer orientation**
- **Introduction of modern Human Resource Policies**

- **Development of education and training of the staff**
- Restructuring the Organisation with a view to enhance productivity and effectiveness.

It is obvious that a good number of the above changes require **substantial training** efforts.

In addition and following an agreement with the Greek Public Power Corporation (ΔΕΗ), for the preparation of analytical training programs and delivering vocational training to our Technicians in specialized professions, revealed a lack of training facilities and a lack of theoretical knowledge and uniformity of the followed practices. In order to place the Training onto a more systematic basis, EAC conducted a Study, resulting in the decision for a new training system and the establishment of an in-house Training School with suitable buildings and workshop facilities.

Thus in accordance with the EU continuous **life-long learning policy,** EAC has recently established and is developing a **Training School** and embarked on an ambitious Certified Training Programme for all its employees. This programme aims at establishing an integrated Educational System that would

- Provide support to the Corporate Strategy through the development of its Human Resources
- Create a competitive advantage through its Human Resource and
- Secure efficient and effective work execution

Each of the 3 main staff categories, Professional-Technical-Clerical, is allocated an integrated stream of training so as to correspond to the skills, knowledge and behaviour required by each 'profession': **basic training**, **specialised training** and **personal development training (Figure 1).**

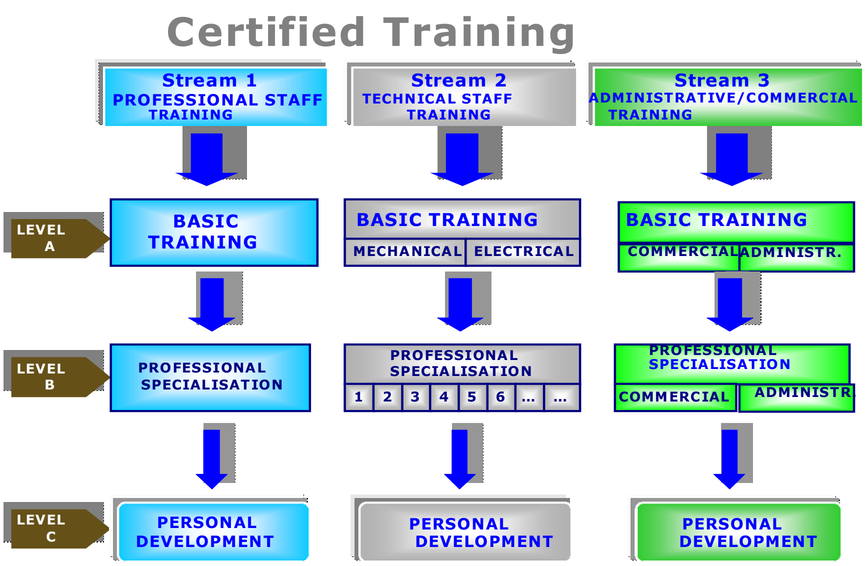


**Figure 1**

| ANALYTICAL DESCRIPTION OF TRAINING SYSTEMS | | | |
|---|---|---|---|
| LEVEL III – Administrative & Financial Staff Development | | | |
| **Management Development** | **Technical Staff Development** | **Administrative and Financial Staff Development** | **Commercial Staff Development** |
| 1. Strategic Analysis of the Energy Market<br>2. Strategic Management<br>3. Strategic Planning<br>4. Strategic Marketing<br>5. Organisational Development & Management of Change<br>6. Business Process Reengineering<br>7. Decision making systems<br>8. Creativity & Technology Management<br>9. Management Information Systems (MIS)<br>10. Financial Management<br>11. Business Strategy Game (Simulation)<br>12. Leadership skills Development<br>13. Performance Measurement Systems<br>14. Strategic Human Resource Management | 1. General Management Principles<br>2. Principles of business Administration<br>3. Financial Management<br>4. Management & Budgetary Control<br>5. Product & Services Marketing – EAC Products<br>6. Statistics<br>7. Strategic & Business Planning | 1. Financial Analysis of Accounting Statements<br>2. Principles of Business Administration<br>3. Financial Management<br>4. Management & Budgetary control<br>5. Products & Services Marketing<br>6. Quantitative methods<br>7. Strategic & business Planning | 1. Development & Controlling Marketing Plans<br>2. Principles of Business Administration<br>3. Financial Management<br>4. Management & Budgetary Control<br>5. Customer Accounts Management<br>6. Quantitative Methods<br>7. Strategic & Business Planning |
| LEVEL II – SPECIALISED TRAINING | | | |
| 1. Project Management for Technical Projects<br>2. Quality Control Systems<br>3. Business Process Reengineering<br>4. Supply Chain – Logistics<br>5. Electrical Economy – Planning<br>6. Sales – Marketing<br>7. Management Accounting & Costing | **Theoretical Part**<br>1. Electrical Technology<br>2. Electrical Drawings<br>3. Electrical Machines<br>4. Generation-Transmission-Distribution of Electricity<br>5. Work Safety<br>6. Communication-Team work<br>**Practical Part**<br>Laboratories | 1. Customer Service (Internal – External)<br>2. Problem Management & Communication Techniques<br>3. Development & Management of Human Resources<br>4. General Accounting – EAC Accounting System<br>5. Statistics<br>6. MS Office | 1. Products & Services Marketing<br>2. Organisation & Management of Sales<br>3. Customer Service Quality<br>4. The Art and Techniques of Sales<br>5. Statistics<br>6. Commercial Information Systems |
| LEVEL I – BASIC TRAINING | | | |
| **Professional Staff**<br>1. External Environment – Energy Market<br>2. Introduction to General Management Principles<br>3. Organisation & EAC Production Systems – Products<br>4. Human Resource Management (EAC Personnel Regulations)<br>5. Introduction to Financial Management<br>6. EAC Safety & Health<br>7. EAC Information Systems | **Technical Staff**<br>(Depending on the Profession * e.g. Linesmen)<br>**Theoretical Part**<br>1. Electrical Technology<br>2. Electrical Drawing<br>3. Electrical Machines<br>4. Generation-Transmission-Distribution of Electricity<br>5. Work Safety<br>**Practical Part**<br>Laboratories | **Administrative & Commercial Staff**<br>1. External Environment – Energy Market<br>2. Introduction to General Management Principles<br>3. Organisation & EAC Production Systems – Products<br>4. Human Resource Management (EAC Personnel Regulations)<br>5. Office Organisation – Personal Organisation<br>6. EAC Safety & Health<br>7. Office Information Systems | 1. External Environment – Energy Market<br>2. Introduction to General Management Principles<br>3. Organisation & EAC Production Systems – Products<br>4. Human Resource Management (EAC Personnel Regulations)<br>5 Marketing & Sales General Principles<br>6. EAC Safety & Health<br>7. Office Information Systems |
| **STREAM 1**<br>**PROFESSIONAL STAFF TRAINING** | **STREAM 2**<br>**TECHNICAL STAFF TRAINING** | **STREAM 3a**<br>**ADMINISTRATIVE & FINANCIAL STAFF TRAINING** | **STREAM 3b**<br>**COMMERCIAL STAFF TRAINING** |

*For every Technical profession and specialisation there is a different training programme for the Basic and Specialised Training (Levels I and II)

**Figure 2.**

This gives a matrix of nine combinations of training modules, each consisting of a series of courses, 63 in all (Fig.2). This Certified Training comprises integrated training programs fully covering the breath and depth of each professional field. It also ensures that the trainees acquire the skills to handle successfully the systems, methods and technologies used in the EAC. The Certified Training programs are professionally oriented ensuring at the same time the necessary theoretical knowledge.

The programs are concluded in different streams and levels according to the depth of specialisation determined by each field and EAC needs. For each completed level of training a corresponding certificate is awarded after passing the necessary exams. Attendance of the next hierarchical level of training requires successful completion of the lower level. We have started including this requirement in the revised Schemes of Service so that employees can only apply for promotion only if they have succeeded to pass the exams of the Training School for the appropriate level. The objective of the Certified Training is the development of high calibre staff and the diffusion of knowledge, skills and behaviour for effectively supporting the productive, commercial and administrative functions. The staff will not only be able to handle successfully current issues but will be able to shape the developments in their sector and ensure EAC's leading role and sustainable success in the future.

It is a main objective of the Training School that part of the training is delivered by specialized EAC personnel. In this way training costs are minimized and the benefit is substantial.

Apart from 7 lecture rooms, two computer training rooms and a number of specialised workshops for technical training, an outdoor practical training area has been prepared by erecting electricity HV and LV poles, lines and underground cables and sustation, comprising a small electrical network.

In addition to the Certified Training, EAC offers opportunities for Continuous (Life-long Learning) for its employees. Continuous learning comprises programs such as:

- ♦ **Specialised Education for Professional staff.**
- ♦ **Specialised Training for Technical and Commercial / Administrative staff**.
- ♦ **Trainers Training**
- ♦ **On the Job Training**
- ♦ **Distance Learning and e-learning programmes**

**Determination of training needs** is another associated project that we have in progress. The staff was grouped into a number of professions and interviews were conducted with representative samples of the profession so as to determine the profile for each profession. The profiles are being used for identifying individual skill gaps to be closed through the Training School. Profiles include, apart from the mission of the profession and its main activities, their required behaviour, skills and knowledge, which are very useful in determining the training needs of their occupants.

For speeding up implementation of the programmes we sought alternative ways to the conventional training which takes a long time to implement. Thus e-learning was considered. A study was carried out as part of an MBA course to determine the suitability of e-learning for use at our Training School.

A number of parameters / **Key Success Factors** were considered:
Positive attitude, computer literacy, computer availability, and English language knowledge were investigated through a survey questionnaire. The computer network availability was investigated by examining our infrastructure. The suitability of e-courses in closing the skills gap was investigated by tabulating the required courses against a number of suitability criteria for e-learning.

Also an EU Power Industry analysis of learning practices was conducted with the following findings:

(a) EAC provides 2.4 days/trainee/year against the EU Power industry average of 4.1 days/year.
(b) There are **skill gaps in teamwork, problem-solving, management capacity, customer service and communication** due to the working methods, changes in progress and new services.
(c) **Policies** in the EU electricity sector are based on the **development of training for adaptable employees**, who can be retrained for other duties.
(d) EU States show an interest in:
    - Improving the States' **quality and recognition of learning**
    - **Innovating** in the methods and recognition of training and
    - Developing high quality **IT-based methods** accessible to all learners.

(e) There is need to **introduce new learning methods** around cross-disciplinary areas of knowledge and skills, which would enable learners to develop into diversified areas.
(f) **Learning** is an interactive group activity which takes place in the workplace rather than in conventional classrooms. This type of learning demands fluid and dynamic **environments** such as in the liberalised electricity sector and unified European Market with intense competition, and **a lifelong learning cycle** so as to build and maintain new skills.
(g) EU States should implement policies introducing **recognised qualifications, training chances** and **career perspectives** based on the concept of lifelong education and training.
(h) EAC training needs focus around Induction Training, Retraining to increase productivity, Multiskilling and Training in new fields

As EAC is in the process of developing a new training system there is a good opportunity to build the core of its system on off-the-shelf e-learning courses and supplement it with conventional training.
To determine the suitability of e-learning a Survey was conducted among EAC employees and to test a number of hypotheses to enable the understanding of the perceptions, preferences and expectations of employees and management on the provided training. The key areas investigated were:

(1) The **timing** of **present training.**
(2) **Access** of personnel **to a PC** and the Internet.
(3) **Attitudes** of both **Management and employees**.
(4) The need for **customisation of courses**.
(5) The **Standard of Training**.

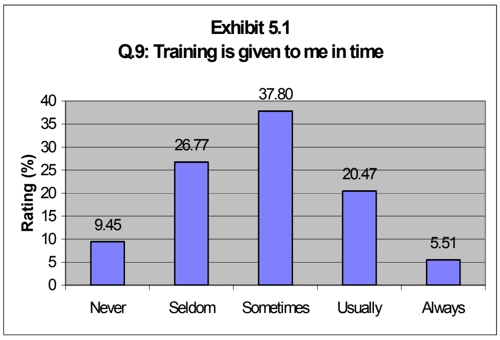


**Figure 3**

Responses revealed the following:
- Training is **not given** at the right time (Figure 3).
- There is access to a PC and Internet, so people **will** be able to attend e-learning (Figure 4 and 5).
- **Flexibility** for learning anytime, anywhere can be increased (Figure 6).
- Managers **are** willing to send their people to training courses (Figure 7).
- **Not all** people in each category can follow the same course (Figure 8).
- People do not have the chance to follow customised courses to their level of proficiency (Figure 8).
- **Professional** employees can/are willing to follow courses in English (Figure 9).

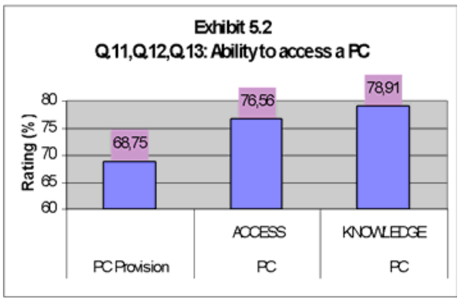


Figure 4

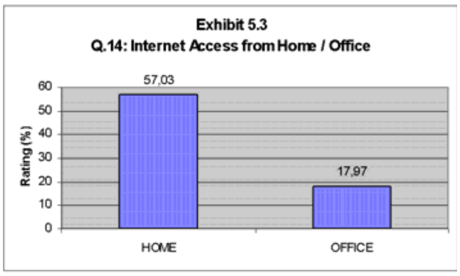


Figure 5

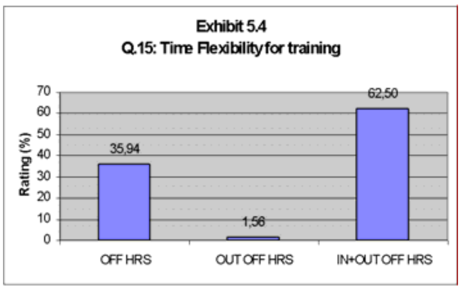


Figure 6

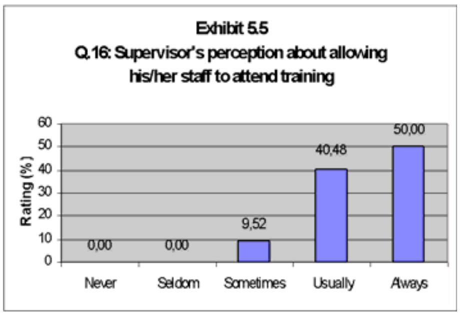


Figure 7

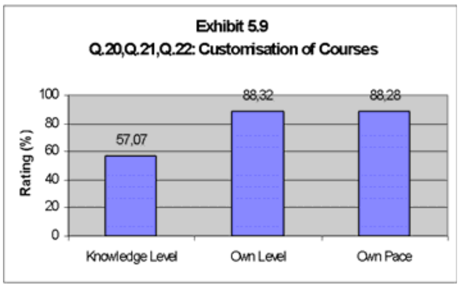


Figure 8

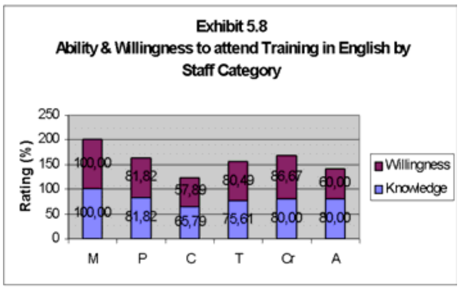


Figure 9

E-learning in energy companies in Europe and America was also investigated including the advantages of electronic technology in blending e-learning with conventional training. **It was shown that:**

- Realisation time for training is significantly lower with e-learning.
- E-learning can bring fast introduction of new courses.
- E-learning facilitates the completion of the certified training in reasonable timescales.
- E-learning reduces training cost per person.
- Blending combines innovative e-learning with traditional workshops. Employees, especially managers are pressed for time, so taking them off-site for extra class-time would be prohibitive.

After analyzing the results and findings of all the Surveys/investigations three scenarios were devised and examined for effecting a blended e-learning system:
**Scenario I,** providing **faster access** to the course content due to its presence **on local EAC Servers**.

**Scenario II**, **providing the course content** through the provider's platform, thus slower **accessibility**.

**Scenario III,** including Scenario I plus providing for the **Development of** Customised e-learning Courses.

Based on **Scenario III**, which provides everything for implementing 37 e-courses plus all the essential software / hardware for subsequent in-house customisation of e-learning courses, blending will offset initial capital expenses right from the first year of implementation and gains of €100.000 in subsequent years. The tangible benefits over a five-year period are expected to exceed €4**00.000**. In addition, the cost of implementing e-learning, as it is among the EU primary aims (e-Europe 2002, e-Europe 2005 and i2010 Programs), may be paid through the European Social Fund, with higher tangible benefits.

An **action plan** was produced for implementing the blending of e-learning with conventional learning. I shall **highlight** the proposed action:
By introducing at a first stage e-learning mainly for managers and other Professional staff who are **able and willing** to attend courses in English, and making available 37 e-learning courses on EAC servers and blended with conventional teaching, a substantial number of benefits are expected. Comparative evaluation of courses and pre-course tests and post-test assessments will be performed using specially developed forms for measuring the relative improvement and the true effectiveness of a course and making the necessary adjustments.
At a second stage and provided satisfaction for e-courses is high, customisation of required courses will be developed in house. A Safety & Health course has already been introduced in the conventional way for evaluating Health & Safety course effectiveness. In this way implementation of customised courses would be gradual and effective thus leading to a smooth transition to customised e-learning courses. Evaluation of course effectiveness will be continuous and ongoing and in this way the best blending combination will be continuously achieved.

Benefits from e-learning include:

- Covering more information
- Self-paced approach to learning
- Flexibility to learn anytime, anywhere
- Careful monitoring
- An effective blend of learning methods
- Significant cost savings
- An opportunity to accommodate new learners

As a conclusion, I would like to quote the words of John Chambers, CEO, Cisco Systems:**"The next big killer application for the internet is going to be education. Education over the internet is going to be so big it is going to make e-mail look like a rounding error."**

Furthermore I would like to stress out that education and training is an investment and not an expense and it always pays back. It may be slow to reveal its benefits but given enough time it does.

**Like a bamboo shoot during the first 4 years of planting there is nothing visible above the ground but in the 5th year and in only 6 weeks the shoots grow 25-30 meters high. How long did it take for the bamboo to grow: 4 years or 6 weeks?**

# WIND FARMS EXPERIENCE IN CRETE ISLAND

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## Abstract

A relatively large number of WF have been installed on the island of Crete in Greece. Due to the weak islanded system Voltage Drops occur. Wind Turbines are sensitive and make things harder. Some Wind Turbines sustain Voltage Drops and contribute to the System Recovery. In the Power Dispatching Center a package of programs and a protocol have been developed from 1996. Nineteen Wind Farms have been connected to the SCADA system. Orders for curtailment are given from the main server taking into account the current system load, the allowed penetration according to the conditions, and the operation of conventional units. The programs operate successfully and the Wind farms operate without problems for the system. Momentarily Wind Penetration reaches 30% because of curtailments and Daily Energy penetration >20%

**Keywords:** *Voltage drops, Communication protocol, Wind Farm management, Dispatching Center, Islanded system, Wind Power penetration.*

**1.** A relatively large number of WF has been installed on the island of Crete in Greece.10-13 % of the Energy every year from 1996 is provided from the Wind Farms. In the end of 2006 125 MW of Wind Farms are installed. The installed conventional capacity of the island is 741 MW. The ‘Public Power Corporation’ (PPC) debated the effects of high wind power penetration in a small island power system like Crete. The load factor in Crete is low, around 55%. The daily max-min ratio of load can exceed 200 %.

This pattern requires a large installed capacity to meet the daily peaks. Night valleys are difficult to schedule to ensure efficiency and security. PPC concerns were focused on the scheduling issues during the night and security during thunderstorms, or bad weather. There was also concern about voltage fluctuations. In the Power Dispatching Center a package of programs and a protocol have been developed from 1996. Nineteen Wind Farms have been connected on-line to the Dispatching Center. Orders for curtailment are given from the main server taking into account the current system load, the allowed penetration according to the conditions, and the operation of conventional units. The programs operate successfully and the Wind farms operate without problems for the system.

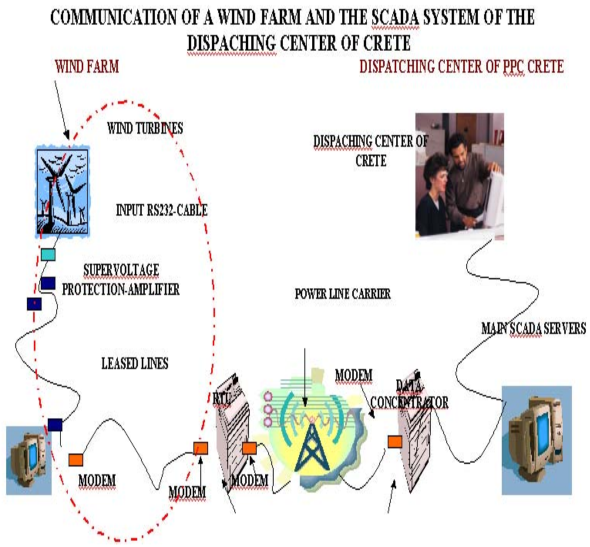



**Figure 1.** Communication of a WF with the Crete Dispatching Center

**2.** Due to the weak islanded system, high drops of the voltage occur some times. The Wind Turbines cannot afford the droops and stop. The results are aggravating for the Production and Transmission System of Crete. Some Wind Farms in Crete have installed an Advanced System to sustain voltage drops. Wind turbines with the enhanced grid support option are specially designed to tolerate short time voltage reductions due to grid faults. The grid support option limits the time before the turbine resume pre-fault power production and it limits the risk for a voltage collapse due to a very low reactive power draw after the clearance of the grid fault. Incidents showing the behavior of the Wind Farms with and without the enhanced grid support option in Crete are presented.


**Figure 2.** Fault in the 150kV transmission line Atherinolakkos-Heraklion

For example on the 26 of December 2006 due to thunderstorms 3 times during the day faults occurred on the High Voltage (150 kV) line between Atherinalakkos and Heraklion substation at 10:03, 10:52 and 14:58 and the second and third time was isolated by the circuit breakers. The fault lasted more than 400 msec each. The frequency dropped to 49,46 Hz, 49,86 Hz and 48,95 Hz and recovered due to load shedding Voltage drops occurred in the whole System.

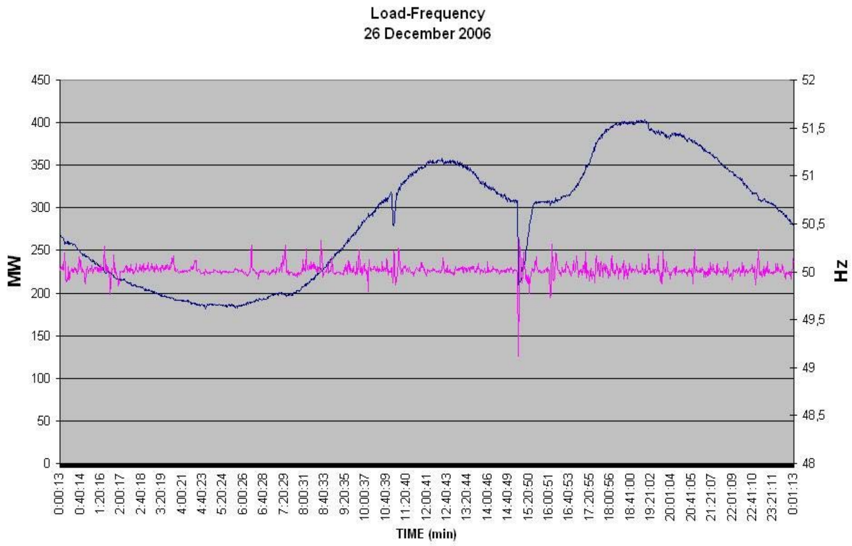



**Figure 3.** Load-Frequency and disturbances 26 Dec 2006 10:03, 10:52, 14:58 1 min sampling

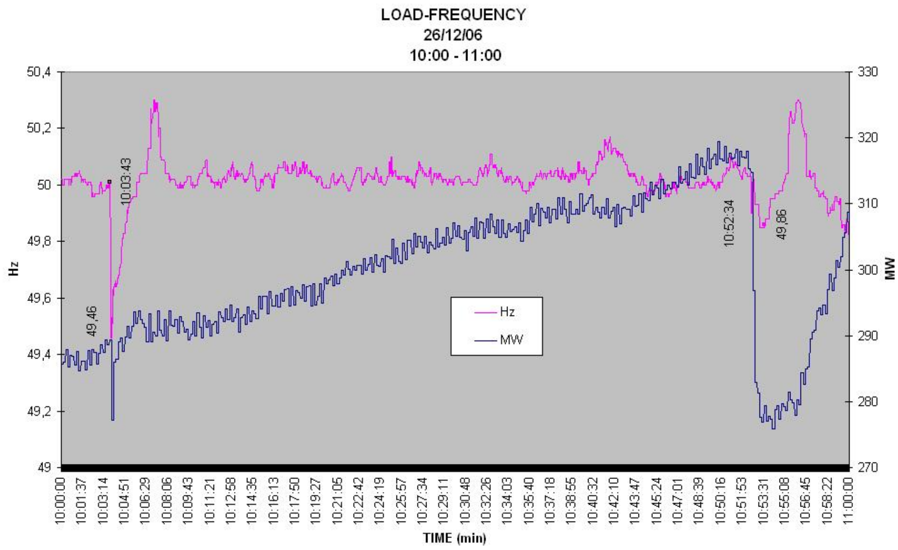



**Figure 4.** Load-Frequency and disturbances 26 Dec 2006 10:00-11:00 1 sec sampling

Due to these drops all the Wind Farms stopped because of the low voltage protection except three Wind Farms ('Plastika Kritis', 'Domiki Kritis', and 'Ydroeoliki').
The above Wind Farms have installed the 'VESTAS Enhanced grid support' option.

**Table 1.** Wind Turbines Protection Settings

| CRETE POWER SYSTEM<br>PROTECTION SETTINGS OF THE WIND TURBINES | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | WIND TURBINES | | | | | | |
| | PRODUCER | BONUS | ZOND-40 | ENERCON E-40 | WIND MASTER, TACKE, NORDTANK | MICON | VESTAS | VESTAS ADVANCED GRID OPTION |
| SETTINGS | NAME OF THE WIND PARK | ROKAS | AEOLOS &IWECO | MARONIA (AXLADIA,KRIA,ANEMOESSA) | TOPLOU | XIROLIMNI | PLASTIKA,DOMIKI, YDROEOLIKI | PLASTIKA,DOMIKI, YDROEOLIKI |
| TOLERANCE IN VOLTAGE DEVIATIONS FROM THE NOMINAL VALUE %/sec | Maximum Overvoltage | > 8,5 / 0,5 | > 10 / 0,25 | | > +10 / 0,2 | > +12,5 / 0,1 | > +20 /0,08 | |
| | Overvoltage threshold | +6...+8,5 / 60 | | | | +10...+12,5 / 60 | +10...+20 / 60 ...0,2 | |
| | Nominal operation | -10...+6 / oo | -10...+10 / oo | -22,72...+27,27 / oo | -10...+10 / oo | -12...+10 /oo | -10...+10 / oo | |
| | Untervoltage threshold | -10...-20,5 / 60 | | -22,72...-36,36 / 1,5 | | -12...-20 / 60 | -13,5...-20 / 0,2 | |
| | Minimum Untervoltage | < -20,5 / 0,5 | < -10 / 0,25 | < -36,36 / 0,3 | < -10 / 0,2 | < -20 / 0,1 | < -25 / 0,08 | -100 / 10 |
| TOLERANCE IN FREQUENCY DEVIATIONS FROM THE NOMINAL VALUE %/sec | Overfrequency | > 51 / 2 | > 51 / 3 | > 56 / 0 | > 51 / 1,5 | > 51 / 0,1 | > 51 / 0,2 | |
| | Nominal operation | 47...51 / oo | 48...51 / oo | 46...56 / oo | 49...51 / oo | 47...51 / oo | 47...51 / oo | |
| | Unterfrequency | < 47 / 2 | < 48 / 3 | < 46 / 0 | < 49 / 0,2 | < 47 / 0,2 | < 47 / 0,2 | |

In Table 1 the Producer's Wind Turbines Protection Settings are presented. The tolerance in undervoltage of the Wind turbines increases from 0.8 sec to 10 sec The time of 10 sec is big enough for the grid to recover . If Wind Turbines sustain the voltage drop they help the whole system sustain the faults otherwise bigger problems may occur like further frequency drop (because of power lack) and more load shedding.

In Figure 5 the faults are recorded by the Atherinalakkos substation protection relays. The Wind Power penetration was big during this day: 15-25% It's clear that after the faults Wind Farms who stopped due to undervoltage, started producing in some minutes.

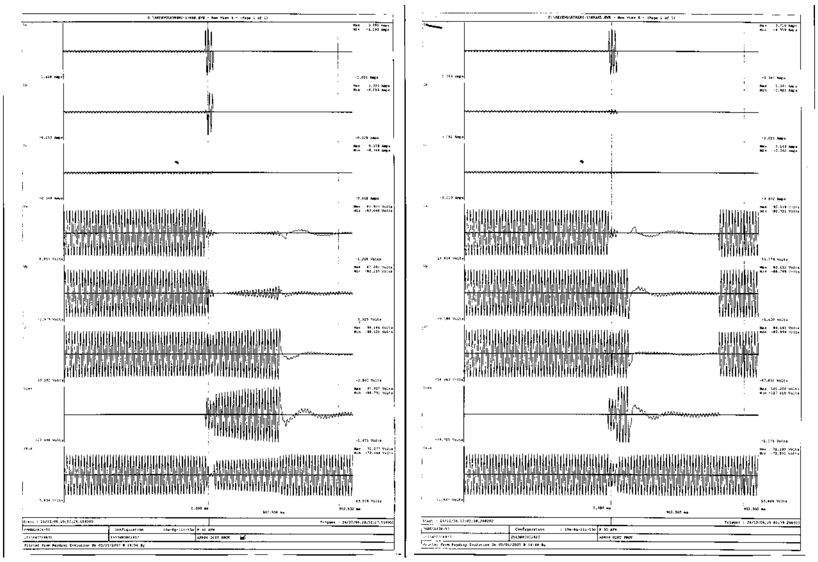


**Figure 5.** Voltage and Current recordings in Atherinolakkos Substation 26 Dec 2006 10:03 a.m. and 10:52 a.m. 0,6 sec and 0,45 sec.

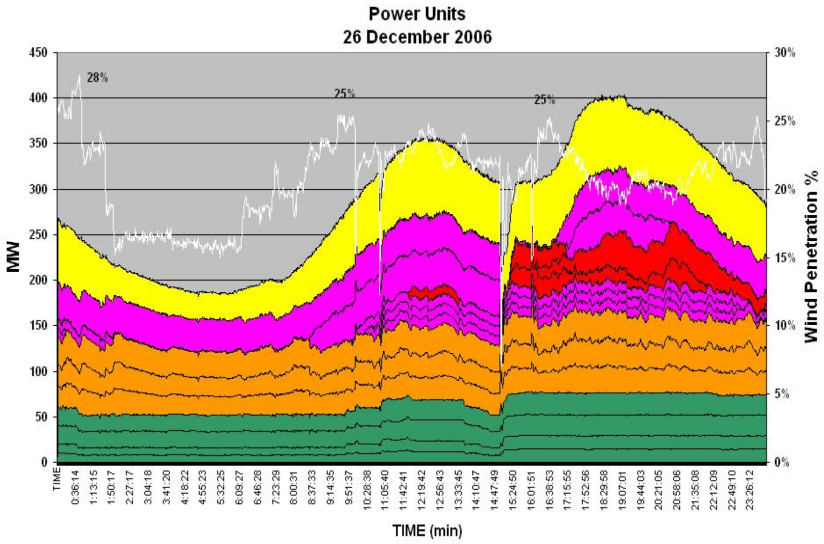



**Figure 6.** Power Units and Wind Farms (yellow) during 26 Dec 2006

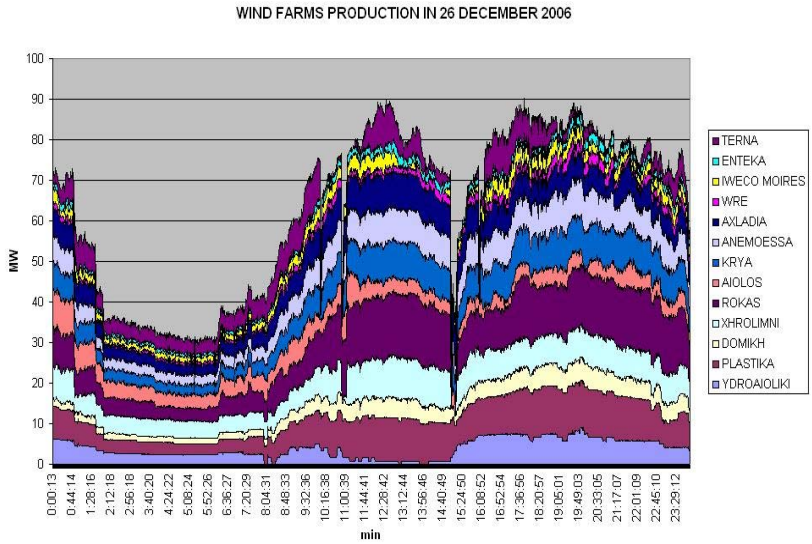
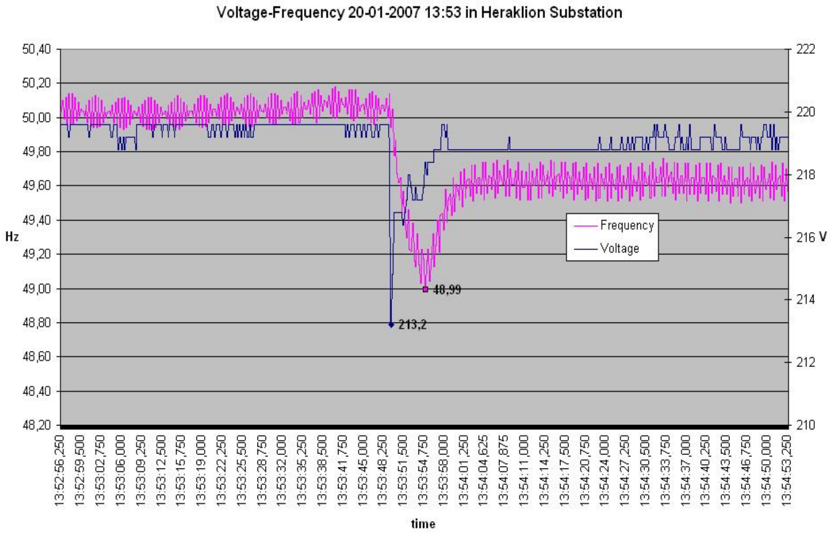



**Figure 7.** Wind Farms during 26 Dec 2006

**3.** Another similar incident (high voltage fault in the same line) on the 20th of January 2007 shows that the undervoltage wasn't big enough to stop the Wind Turbines so there was no problem for the system.



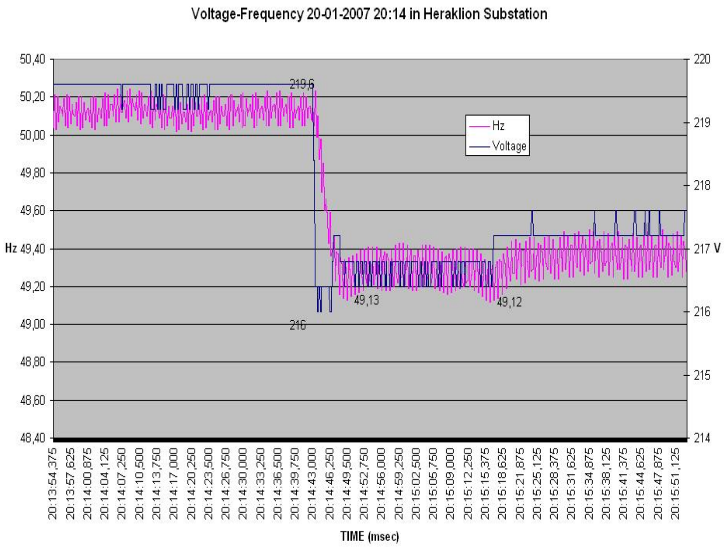




**Figure 8, 9.** Voltage-Frequency in msec in Heraklion Substation on 20 January 2007 13:54 and 20:14 (Undervoltage without problems for the Wind Farms)

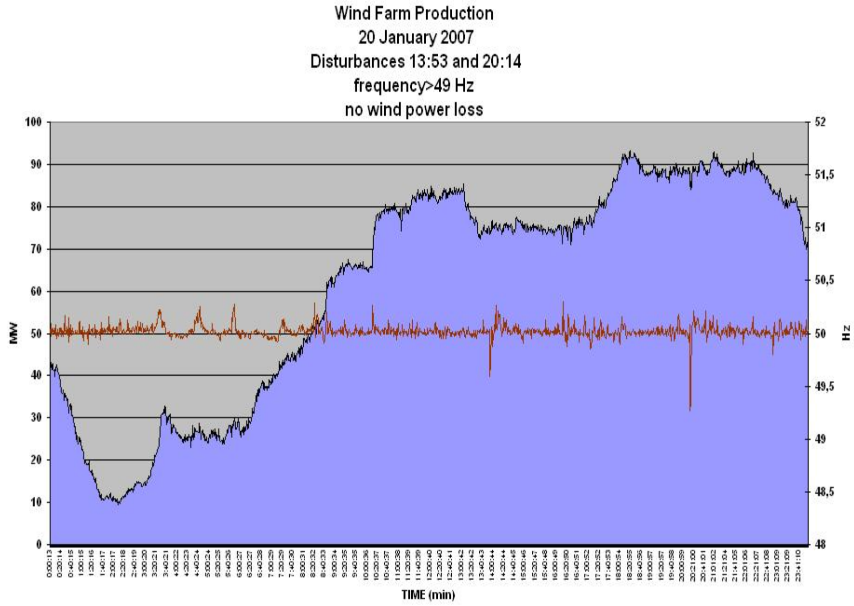



**Figure 10.** Wind power during the day of the 20th of January 2007

**4.** Big fluctuations of the Wind Farms Production of the whole island occur some times during the year. Examples of this fluctuation are given in the Fig.11,12 below. During the days with fluctuations gas turbines should be ready to get started as soon as the frequency drops, because of the lack of Wind power.

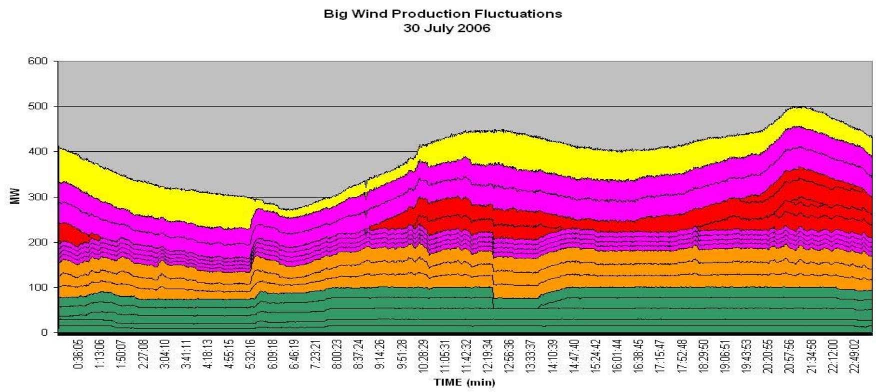



**Figure 11.** Big Wind Production Fluctuations during the 30th of July 2006 (yellow)

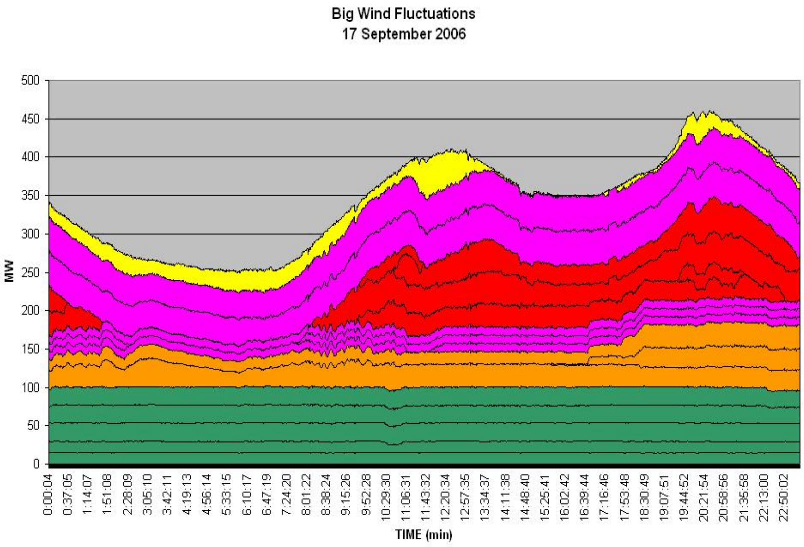



**Figure 12.** Big Wind Production Fluctuations during the 17th of September 2006 (yellow)

A 5 days ahead Wind Power Prediction model is created by PPC SA during the European Process 'ANEMOS' and 'SKYRON' predictions.

The aim of the project is to develop accurate models that outperform considerably actual state-of-the art, for onshore and off-shore wind resource forecasting (statistical and physical). Emphasis is given on integrating high resolution weather predictions. For the offshore case, marine meteorology is considered as well as information by satellite-radar images. An integrated software, ANEMOS, is developed to host the various models. This system is installed for on-line operation at onshore wind farms by PPC for local/regional wind prediction. The applications are characterized by different terrains, on-/near-/off-shore farms, climatic conditions, interconnected or island grids. The on-line operation by the utility will permits to validate the model and to analyze how predictions can contribute to a competitive integration of wind energy in the developing liberalized electricity market.

The power penetration during the day is limited to 30% of the load for stability and security of the system. During the night it's limited because of the technical minimal of the conventional Units. So days with high penetration are shown in the Figure 13 and Fig.14

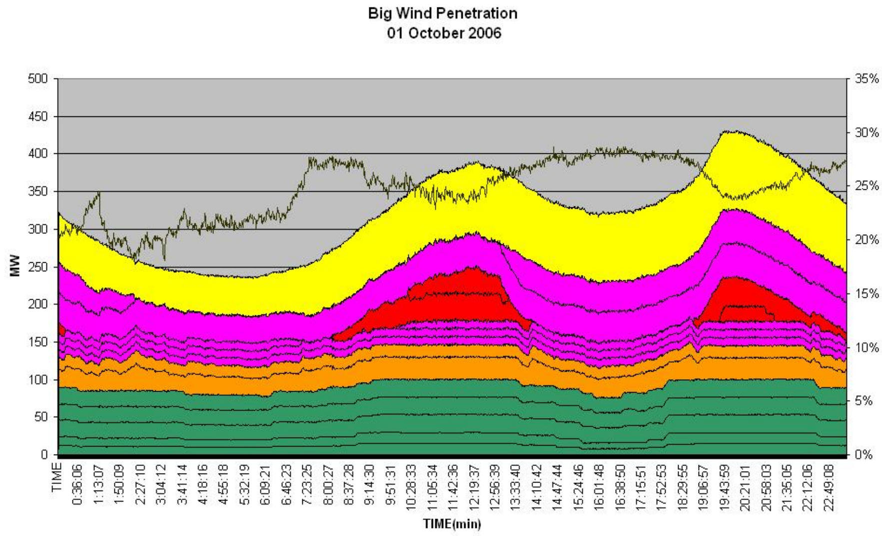



**Figure 13.** Big Wind Penetration during the 01th of October 2006 (yellow)

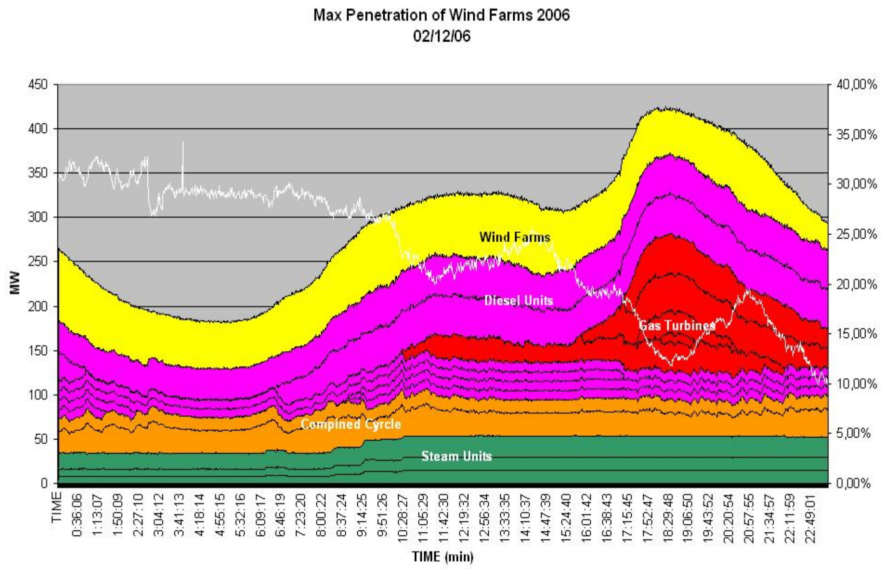



**Figure 14.** Maximum Wind Penetration during the 02th of December 2006 (yellow)

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# PUBLIC KEY INFRASTRUCTURE AS A NEW TECHNOLOGY ENABLING ELECTRONIC AUCTIONS USED IN THE CONTEXT OF ELECTRICITY MARKET RESTRUCTURING: AN ASPECT OF THE COMPLEX GLOBAL ECONOMY

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## Abstract
In this paper it is attempted to analyze the importance of Public Key Infrastructure as a new technology enabling electronic auctions used in the context of electricity market restructuring. According to recent surveys, one of the most severe restraining factors for the proliferation of E-commerce is the (lack of) security measures required to assure both businesses and customers that their business relationship and transactions will be carried out in privacy, correctly, and timely. Several aspects of these requirements can be secured by means of cryptography, in particular public key cryptography. This paper first considers security requirements for E-commerce applications, then discusses the workings of the Public Key Infrastructure and, finally, highlights its role in developing secure, hence trustworthy, E-commerce applications.

## 1. Introduction
The aim of this paper is to promote awareness of the role of Public Key Infrastructure in the complex global economy. The Internet is changing every aspect of our lives, but no area is undergoing as rapid and significant a change as the way businesses operate. Today, companies large, medium and small are using the Internet to communicate with their customers, suppliers and partners, to facilitate the communication among their employees and among their branches, to connect with their back-end data-systems, and to transact commerce, i.e. they do e-business. In this environment, where almost every organization is increasing its reliance on information and computer -processing facilities, e-commerce is bringing with it new dependencies and new risks.

## 2. The Public Key Infrastructure (PKI)
A comprehensive list of PKI services that satisfy the above requirements follows [1-2]; this list includes all services specified in [3]. The functions required to perform each of these services can subsequently be defined.

The specified PKI services are as follows:

1. *Registration.* In order for a user to join the PKI environments s/he must register with a RA belonging to the PKI. The primary goal of this service is to establish the reliable unique binding between a user and her/his public key. Functions supporting this service include: Initial request submission, Registration form's format validity checks on behalf of the RA, end entity authentication and identification, and anonymity assurance.

2. *Digital Signatures.* In order to satisfy the message authentication, message integrity and non-repudiation of origin user requirements, the PKI should offer digital signature services. Functions supporting this service include message hash generation and message hash encryption/decryption.

3. *Encryption.* Encryption is a basic service providing the cryptographic functions for protection of message confidentiality in a computer network. Functions supporting this service include encryption and decryption of the message.

4. *Time stamping.* Time stamping is described as the process of attaching data and time to a document in order to prove that it existed at a particular moment of time.
   Functions supporting this service include acceptance of a request for a time-stamp, retrieval of the time/date data for the time-stamp, appendage of time-stamps to a message and submission to the requesting entity, verification of the validity of the time-stamp certificate, selection and distribution to the public of the set of hash functions for producing message digests, selection of a digital signature scheme for signing time-stamp certificates, maintenance of a database of time-stamp certificates, generation and delivery of error messages to the requesting entity, maintenance of a log of time -stamping authority (TSA) activity, having the TSA log time-stamped, provision of secure communication channels, maintenance of procedural security controls, distribution of information to the public.

5. *Non-repudiation.* Non-repudiation involves the generation, accumulation, retrieval, and interpretation of evidence that a particular party processed a particular data item. The evidence must be capable of convincing an independent third party, potentially at a much later time, as to the validity of a claim. Functions supporting this service include initialization, revocation and dispute resolution and notary.

6. *Key Management.* Key management is a principal service within a PKI architecture. This service deals primarily with the handling of cryptographic keys in a proper, efficient, scaleable and secure way. It includes key generation, random number generation, key personalization, distribution of keys, key storage, key retrieval, key recovery, backup and restore, key update, key compromise related functions, validation of requests for key accessing functions, determination of the rights of the personnel on key management functions.

7. *Certificate Management.* A digital certificate is an electronic token ensuring the binding between an entity and its public key. The functions supporting this service include generation, distribution, storage, retrieval, and revocation of digital certificates.

8. *Information Repository.* This service maintains the collection of data critical for the operation of the PKI system. It states the general means and fashion for storing, archiving and maintaining several types of data ranging from organization’s legal requirements, to system recovery needs. The functions supporting this service include determination of the items to be archived, determination of the retention period, authorization, authentication, update of the archive, retrieval of information, retrieval of authorization and consignment details of archived documents, distribution of information, deletion.

9. *Directory Services.* In order to interact, a member of a PKI must have access to information about other PKI members. This is achieved by the use of Directory Services which are supported by the following functions: update with new certificates, update with revoked certificates, distribution, replication, caching, searching, retrieval (for certification purposes), retrieval (for cross-certification purposes), returning of information.

10. *Camouflaging communications.* Camouflaging communications not only provides data confidentiality, but also hides the very fact of communication. This is achieved by adding dummy messages into the data stream enabling CSPs and users to hide real data transfers, both in terms of their occurrence and frequency.
Functions supporting this service are responsible for camouflaging on-line as well off-line communications.

11. *Authorization.* The PKI should enable requesting entities to delegate access rights at will to other PKI entities. This means that a PKI user who possesses a resource may grant the right to another PKI user to access this resource. CSPs should ensure the granting of rights, including the ability to access specific information or resources. Supporting functions include authentication, group definition, rights update, group update, enrolment of a user into a group, resolving of rights, determining administrative authorities.

12. *Audit.* In order to ensure that certain operational, procedural, legal, qualitative and several other requirements are complied with, so that trust is enhanced, an auditing service is required. The functions supporting this service fall into two categories: Initial preparatory phase functions and Main operation of the audit plan phase functions.

13. *Quality assurance and trust enhancement services.* It is expected that the potential users of PKI services would require products and services of a given quality to be delivered or be available by a given time and to be priced so that best value for money is achieved. In order to achieve this level of quality, PKI services must be quality assured. Functions supporting this service include organization operations manual specification, organization operations maintenance and improvement.

14. *Customer oriented services.* This group of PKI services includes services which directly involve users or that require some contact, or some kind of dealing or bargaining with the end user. Examples of such services are legal aspects and payment negotiations between a user and a CSP. This group of services is implemented by the following functions: Liability and insurability, underwriting, accounting management, ordinary operations assistance and support provision.

15. *CSP to CSP interoperability.* It is unlikely that in a large scale PKI all users will be connected to a unique CSP. Interoperability services are concerned with the issues necessary for establishing a network of CSPs, possibly operating by different companies with different policies and different domain specialization.

A schematic representation of the Public Key Infrastructure functions follows (Figure 1)

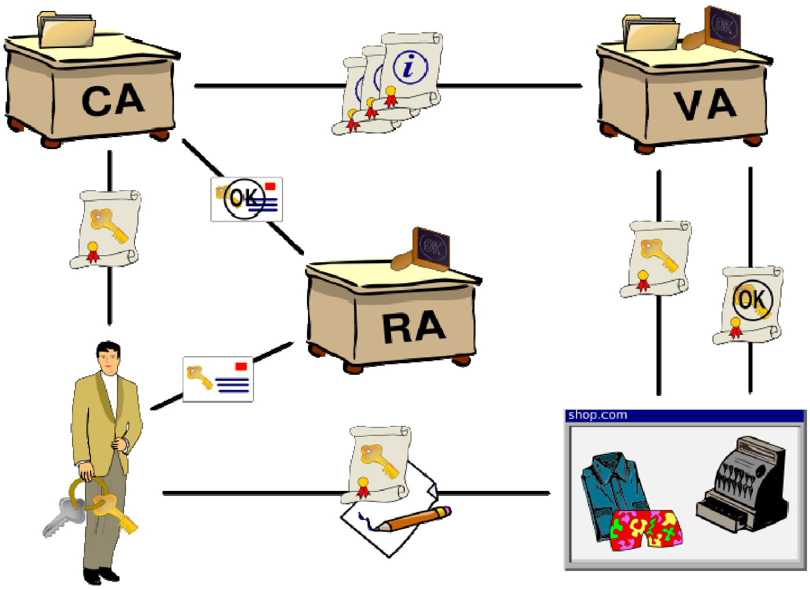


**Figure 1.** Schematic representation of the Public Key Infrastructure functions

## 3. Electronic Auctions

A special aspect of the electronic commerce is the electronic auctions. A **reverse auction** (also called **procurement auction**, **e-auction**, **sourcing event**, **e-sourcing** or **eRA**) is a tool used in industrial business-to-business procurement. It is a type of auction in which the role of the buyer and seller are reversed, with the primary objective to drive purchase prices downward. In an ordinary auction (or also known as forward auction), buyers compete to obtain a good or service. In a reverse auction, sellers compete to obtain business.

Reverse auctions gained popularity in the late 1990s as a result of the emergence of Internet-based online auction tools. FreeMarkets Online Inc., later FreeMarkets Inc. which has been acquired by Ariba in 2004, was the pioneer of online reverse auctions. FreeMarkets was founded in 1995 by former McKinsey consultant and General Electric executive Glen Meakam after he failed to find internal backing for the idea of a reverse auction division at GE. Meakem hired Mc Kinsey colleague Sam Kinney who developed much of the intellectual property behind FreeMarkets. Headquartered in Pittsburgh, PA, FreeMarkets built teams of "market makers" and "commodity managers" to manage to the process of running the online tender process and set up market operations to manage auctions on a global basis.

The company's growth was aided greatly by the hype of the dot-com boom era. FreeMarkets customers included BP plc, United Technologies, Visteon, H.J. Heinz, Phelps Dodge, Exxon Mobil, and Royal-Dutch Shell, to name a few. Dozens of competing start-up reverse auction service providers such as EU- Supply, Procuri and CommerceOne, and established companies such as General Motors (an early FreeMarkets customer) and SAP, rushed join the reverse auction marketspace.

Although FreeMarkets survived the winding down of the dot-com boom, by the early 2000s it was apparent that its business model was really like an old-economy consulting firm with some sophisticated proprietary software. Online reverse auctions started to become mainstream and the prices that FreeMarkets had commanded for its services dropped significantly. This led to a consolidation of the reverse auction service marketplace. FreeMarkets was acquired by its former competitor, California-based Ariba Inc., in 2004.

Reverse auction is a tool used by many purchasing and supply management organizations for spend management, as part of strategic sourcing and overall supply management activities.

In a typical auction, the seller puts an item up for sale. Multiple buyers bid for the item and depending on the nature of the auction (English or Dutch), and one or more of the highest bidders buy the goods at a price determined at the conclusion of the bidding.

In a reverse auction, a buyer contracts with a market maker to help make the necessary preparations to conduct the reverse auction. This includes: finding new suppliers, training new and incumbent suppliers, organizing the auction, managing the auction event, and providing auction data to buyers to facilitate decision making. The market maker, on behalf of the buyer, issues a request for quotation (RFQ) to purchase a particular item or group of items (called a "lot"). At the designated day and time, several suppliers, typically 5-20, log on to the auction site and will input several quotes over a 30-90 minute period. These quotes reflect the prices at which they are willing to supply the requested good or service.

Quoting performed in real-time via the Internet results in dynamic bidding. This helps achieve rapid downward price pressure that is not normally attainable using traditional static 3-quote paper-based bidding processes.

The prices that buyers obtain in the reverse auction reflect the narrow market which it created at the moment in time when the auction is held. Thus, it is possible that better value - i.e. lower prices, as well as better quality, delivery performance, technical capabilities, etc. - could be obtained from suppliers not engaged in the bidding or by other means such as collaborative cost management and joint process improvement.

The buyer may award contracts to the supplier who bid the lowest price. Or, a buyer could award contracts to suppliers who bid higher prices depending upon the buyer's specific needs with regards to quality, lead-time, capacity, or other value-adding capabilities. However, buyers frequently award contracts to incumbent (i.e. current) suppliers, even if prices are higher than the lowest bids, because the switching costs to move work to a new supplier are higher than the potential savings that can be realized. This outcome, while very attractive to buyers, is often strongly criticized by both new and incumbent suppliers.

The use of Optimization software has become popular since about 2002 to help buyers determine which supplier to source the work to. It includes relevant buyer and seller business data, including constrains.

Reverse auctions are used to fill both large and small value contracts for public and private commercial organizations. In addition to items traditionally thought of as commodities, reverse auctions are also used to source buyer-designed goods and services, and has even been used to source reverse auction providers. The first time this occurred was in August of 2001, by America West Airlines (now US Airways) using FreeMarkets software.

The majority of purchasing spend subject to reverse auctions over the years has been in the category of buyer-designed goods, followed by services, and then commodity items. Today, an average of 5% of total corporate spend is sourced using reverse auctions. This figure was higher in past years, indicating the goods and services to which reverse auctions can be successfully applied is limited.

Buyers, sellers, and market makers should adhere to auction rules and industry codes of conduct for the use of reverse auctions, if they exist. Problems arise when one or more parties fail to conform to auction rules. This can range from simple cries of "foul" to litigation.

Buyers should not assume that reverse auctions will, in every case, deliver savings - either on a unit price or total cost basis. Reverse auction savings can range from negative (i.e. it costs the buyer money) to neutral (i.e. no savings) to positive savings (average gross of 10-20%, but net savings is typically half or less).

A true representation of savings can not be achieved if unit price-focused purchasing metrics such as "purchase price variance," "purchase order variance," or "material price variance" are used. Instead, total cost savings must be calculated, inclusive of direct and indirect losses associated with using reverse actions, implementing reverse auction results, subsequent procurement activity, and related activities such as customer returns, defective goods or services, warranty expense, litigation, etc.

Suppliers are advised to determine if a value proposition exists for them that would warrant their participation.

Some have characterized reverse auctions as a technologically-assisted form of zero-sum power-based bargaining, or as "going in reverse" with respect to developing buyer-seller relationships, collaboration, and purchasing process improvement. Reverse auctions have also been criticized as "bid-shopping" - when a buyer uses a supplier's bid to obtain lower prices from other suppliers.

Suppliers seeking to avoid reverse auctions can create unique intellectual property, expand the value propositions for its customers by creating new products and services, or seek to extend or improve collaborative activities with their customers.

Reverse auctions used in industrial business-to-business procurement and spend management activities remains controversial, both within buying organizations, among suppliers, and among the academics who study them. As such, buyers considering the use reverse auctions should carefully evaluate all available information, both favorable and unfavorable, to ensure that informed business decisions are made.

## 4. Electricity Market Restructuring

Inherent characteristic of the deregulation process in the electric energy sector of economy is the negotiation of the commodity price between producer and buyer, obtained by reverse auctions. The electricity sector of the European Union undergoes considerable change as a result of the application of the EC Electricity Directive of 1996 about electricity market liberalisation. All member-states have implemented the directive in their national legislation and electricity market opening has begun showing multiple implications. The changes introduce gradual restructuring of the industry and sharper competition. Public utility orientations change into a view under private interests, increasing market and investment risks. Liberalisation of the electricity sector is also changing the industry's relationships with policy makers, regulators and consumers to a profound degree. The EU Electricity Directive, reinforced by Member States' policy decisions on market liberalisation (and, in some, privatisation), will increase competition in the European electricity and wider energy market. These new market circumstances are accompanied in some countries by structural rationalisation and consolidation via vertical and horizontal integration, mergers, take-overs and/or strategic alliances. The industry's structure will evolve over time: perhaps leading to a few world-scale integrated companies (as in oil); some multi-utility companies (e.g. electricity, gas, heat, water and telecommunications); some regional players in the EU; and numerous small- and medium-sized companies with strong local or national affiliations with their customer base, or serving niche markets. Many new players, such as bankers, financial analysts, brokers and traders, will play important intermediate roles. In sum, the industry's structure is changing rapidly. It will be less homogeneous than in the past, and motivated by different incentives, leading to new regulatory and policy requirements.

## 5. Conclusion

In this paper it was attempted to analyze the importance of Public Key Infrastructure as a new technology enabling electronic auctions used in the context of electricity market restructuring. E-commerce is now a reality. Businesses must start considering how to plan and deploy secure e-commerce applications, so that they retain their competitive advantages over their competitors or gain new ones. PKI is one of the major items in the arsenal of security measures that can be brought to bear against the increasing risks and threats on doing business electronically. However, this should not detain either businesses or consumers; what is needed is a careful examination of the risks involved in the process, a comprehensive plan for managing them and the acceptance or mitigation of the remaining ones.

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# THE LIBERALIZATION OF THE ELECTRIC POWER MARKET IN SOUTH – EASTERN MEDITERRANEAN

**Dimitris SARRIS**

Following the alarming oil crises during the **'70s** and the resulting shift of interest in other sources of energy – from conventional to alternative – the generation of electric power from biomass presented a most viable option.

During the '**80s** a large number of such power units had already been established in northern Europe. As their name denotes, these power units utilize biomass to generate power and heat. The total of power generated by biomass in the European Union was increased by 4%, with the prospect of reaching 8% by the year 2010.

Biomass, as a fuel, is friendly to the environment and clean enough to replace solid fuel on a larger scale.

Currently, the main renewable source of energy in the Region of Crete is biomass, mainly oil-cake and firewood residues. Also, other sources of biomass – less known – are agricultural wastes, farm byproducts and **residues**, etc. Other sources of energy are: the olive oil and the olive stones, the vineyard cultivation remains, banana peels and carobs.

The current practice with biomass is limited to simply burning the total living mass, which creates residues and problems with their disposal.

It would be quite interesting to examine and analyze a new potential which was identified a few years ago, namely the generation of electric power from the oil cake. This potential did not stay long on the drawing board; it was put into the pipeline and is currently applied successfully in Andalusia of Spain by one of the largest olive oil cooperatives of that country – **Oleicola El Tejar**. This company cooperated with **Cornello Centrifughe**, an Italian supplier of olive oil processing equipment, to manufacture a DECANTER [**centrifugal** separator] for the dry processing of the olive paste. This process separates the waste [or vegetable] waters from the settled sludge known as "sansa" or pulp.

More specifically, the centrifugal operation of this DECANTER, which is an environmental friendly device, separates the oil waste waters from the waste pulp to give the olive cake.

From combustion experiments performed it was proved that the olive cake is an interesting source of energy that can be obtained from biomass to meet energy demands.

These results encouraged El Tejar to establish in Cordoba of Spain a 12.6 MW unit to generate power from biomass. This unit has been in operation since June 1995.

The interesting thing about this device, as an investment, is that in addition to energy, it also produces lower quality olive oil (LAMPANTE) which can be marketed.
From a total of 260.000 tons of olive waste pulp **accumulated** in artificial ponds, the Cordoba unit can process 2.000 tons daily. The electricity produced is sold at lower prices in relation to electricity from solid fuel (10,8 pesetas against 8 pesetas per KW). The cost of the investment was 12 million UK pounds (1995 prices) while amortization took place in approximately 4 years.

I have just provided a short summary of a power unit which makes use of biomass to generate electricity. The El Tejar example provides satisfactory answers to our energy concerns and, at the same time, **tackles** successfully the problem of environmental pollution.

I will not digress further, but ought to admit – and most of my fellow country men will agree with me – that a similar unit can be established on Crete. This unit will provide a solution to the power deficit on the island, on the one hand, and mitigate the problem of environmental pollution, on the other hand.

The prospect of energy production from biomass is quite viable on Crete, because: a) our region is a major olive oil producer, b) the "raw materials" for such a unit are available in abundance, c) the local environment is facing serious threats from the operation of olive oil mills, d) the economic and technological advantages to result from such an investment will benefit not only Crete but also other regions of the country.

However, this prospect cannot be realized unless certain conditions are met first, namely: a) the total of olive oil mills on the island adopt eco-friendly DECANTERS to secure the production of "pulp", b) sound organization is required to lead to the selection of the most suitable entities to realize the project (e.g. local governments, producers' associations, etc.), c) if not all, at least the bulk of the biomass must be suitable for processing, d) acquire the funds needed for the investment, e) provide incentives to mill owners to replace their **outdated** equipment, f) be able to solve any technical or social issues in relation to the contemplated investment (e.g. infrastructure requirements, site of the investment, sale price of energy produced, etc.).

Following an analysis of the economic information as regards a similar project which will be realized in the Region of Crete, we concluded that an investment in a biomass power unit is economically and operationally feasible on the island.

Having regard to practices of careless disposal of oil mill waste waters ('katsigaros') in streams and canals, which degrade the environment and poison the local flora and **fauna** – as was the case with the irrigation canals by the Faneromenis dam – and in view of the above mentioned feasibility considerations, the council of the Prefecture of Heraklion unanimously resolved (decision no. 230) in its sitting on 27-October-2003, to proceed with the contemplated investment with an open call for tenders. The aim is to organize an investment entity to include the Prefecture of Heraklion, development organizations, private bodies, etc.

Furthermore, this investment entity shall remain open to include other interested parties in future, for example Agricultural Unions, Municipalities, Olive Oil Associations, private initiatives, etc., on condition that they meet specific criteria.

The object of this investment, with an estimated budget of 24 million Euros, is the construction of a plant for the production of power from biomass (pulp from 2-phase oil mills, vineyard and olive grove **trimmings**, carpentry and woodcraft shavings, etc.)

This investment qualifies for state subsidy as it comes under energy **conservation** programs and substitution of oil by renewable sources of energy.
Also, it is a feasible investment because, according to legal provisions, the generated electricity can be sold to the Public Power Corporation at the price of 0,085 Euros per **KWH**.

However, a key to the success of this project is that local oil mills change their technology from 3-phase to 2-phase processing equipment [olive decanters], given that the **latter** produce oil and "pulp" and no waste waters.

The pulp produced by oil mills which operate 2-phase oil decanters will provide our contemplated investment with the raw material required [biomass] to generate electricity. Since the plant must be in operation all year round, it will utilize the pulp from 2-phase decanters during the winter period and the stored pulp plus the vineyard and olive grove trimmings during the summer period.

This investment on Crete is the only way to minimize – even **obliterate** – the degradation of the environment (conditional upon the change from 3- to 2-phase decanters technology) which is caused by the careless disposal of the vegetable water ('katsigaros') by oil mills. At the same time it will provide economic benefits to cover the costs **incurred**, and also do justice to the fame of the Cretan olive oil whose quality, although internationally recognised, is often **marred** by comments about the condition of the local environment.

# DETERMINATION OF COST STAGES OF TRANSMISSION LINE PRODUCTS FROM LONDON METAL EXCHANGE TO FINAL CONSUMER

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## Abstract
In appreciation stage of the huge project planned for performing of infrastructure of a country, it is required to have some reliable information to learn cost structure for the products collected from national and international manufacturers. Moreover, their offers do not indicate real costs of the goods. It includes several production and capital risk factors and considerable profits. Therefore this article has been intended to give some ideas to authorities about cost appreciating in evaluation of the projects related to the transmission and distribution lines.

In the analysis, a medium scale factory has been considered with 80-100 workers and 10 technical and business persons. Manufacturing stages of the conductors have been described step by step by making a manufacturing flow chart. Thus, their possible cost loads after passing described processing stages have been explained clearly without adding profit. In cost calculation, LME has been considered as 1500 $/ton and premium 60 $/ton as an indication. These values can be corrected by reading current market prices of the aluminum T-bar EC-Grade 99.7% Al and premiums.

**Keywords**: Transmission line conductors, LME, Continuous casting line, Wire drawing line, Wire stranding line.

## 1. Introduction
Main aim of this article is to help to the developing countries interested in application of electrification projects and authority persons related to evaluation of long range infrastructure projects. Developing countries perform their infrastructure projects depending on increasing population and demands. Electrical energy usage is increased due to social needs coming with education, modernization and industrializations of societies.

In these stages, they separate big percentage of their budget to infrastructures and pay back of the money takes several years. However, their limited budget should be invested to construction of new plants and new other investments to get the capital in very short time to continue developing.

Therefore, electrification investments must be controlled strictly by having some information of the aerial conductor prices and forcing the manufacturers in decreasing of the profit percent by offering long range business possibilities or similar trade conditions in the other infrastructure investments.

Each country in the world must install electrical energy transmission lines with aluminum or aluminum alloys. Because, there is not available any alternative materials for transmitting of the electrical energy from power plants to the consuming areas. Therefore, authorities who are responsible management of the electrification of a country must know or must learn some trade or technical information roughly aluminum conductor market, conductor producer in the world and trade conditions of power plants in supplying of electrical energy.

In the transmission of electrical energy, bare aluminum and aluminum alloy conductors are used. These conductors have been categorized according to composition of the composite structures. Composite conductors have been designed to resist heavy climatic conditions used several parts of the world. If the climatic condition of the region is very heavy especially in winter time, high strength type conductors with low corrosion abilities are preferred because of icing loads and wind forces and corrosion activities.

In the Middle East region, there is not available icing load but excessive heating and elongation of the lines under sun and contraction in the evening time reasons fretting problem in the surfaces of the stranded wires.

Therefore, designers and manufactures have produced various types conductors to satisfy all requirements changing respect to regulations of country by country.

However, in the aspect of the manufacturer, all conductors are similar to each other in performing of the main functionality such as: transmitting of the electrical energy and manufacturing stages in the factory.
In manufacturing of a conductor, available stages are as follows;

a) Supplying of ingot or feedstock to plant
b) Checking of the raw materials in entering to the manufacturing plan according to specifications prepared from related international standards,
c) Melting of the T- ingots if the plant has a continuous casting line. If not, use supplied feedstock,
d) Drawing of the feedstock to the required wire diameters,
e) Supplying of the steel wires and checking according to steel, or clad wire specifications,
f) Manufacturing of the conductors by stranding on the purchased drums

This procedure is mainly used for the classic ACSR type conductors, which are used all the countries in the world.

In this industry, aluminum is supplied from the international traders who make business with respect to LME (London Metal Exchange) prices.

They sell several aluminum types. But in conductor manufacturing industry, 99.7% Al-EC grade must be used. If it is not used you have to modify aluminum content with addition of the some additives with reasoning extra cost.

Recently, usage of the aluminums alloy type conductors AAAC (All Aluminum Alloy Conductors), which are stranded with the wires drawn from the alloys AA-6101 or AA-6201 are preferred due to corrosion problems occurred in the ACSR type conductors. International traders do not sell in ingot form of these alloys AA-

6101 or AA-6201 but they sell as billet for the metal extrusion process. You can also supply aluminum "alloy feedstock" from the manufacturers directly.

The price of the any product offered to the electricity market is not determined by the manufacturers. Their prices are determined by international market makers. Therefore, you have to check each step of the manufacturing cost in your plant such as fixed and variable costs regularly. Internet and globalization are also very helpful for the consumers because they can send their specifications by E-mail and collect offered prices for the goods immediately. So every conductor manufacturer should compete with other national or international companies working for same activities. Therefore, manufacturing with high quality with low prices by controlling fixed, variable cost strictly will reason win the possible bids in the future [1, 2 and 3].

## 2. Analysis a Conductor Manufacturing Plant and Cost Stages

A conductor manufacturing plant has been considered to analyse cost structure of the aerial conductors. Its sections have been defined as below;

a) Continuous casting line and 8-head rolling machine to produce 9.5 mm aluminium feedstock, capacity 45 tons/day.
b) Drawing of the feedstock to required conductor wire diameter, capacity 75 tons/day.
c) Stranding of the drawn wires according to conductor construction layers and number of the wires available in the each layers, capacity 50 tons/ day.

The aluminium plant consists of 80-100 workers which can be increased and decreased according to orders. Number of staffers of the factory for engineering, quality control management, sales and purchasing functions is 10 persons.

Fixed cost of the plant, which can manufacture 25.000 tons/year ACSR AAC conductor combinations was determined as 156,000 $ by indicating related items as direct labour, staff, management expenses and illumination costs with data collected from accounting department.

In the analysis, three type conductors have been considered. Big ACSR type conductor such as Cardinal is used as transmission line conductor from power plants and dams to the consuming areas. Pansy (AAC-All aluminum conductor) and Pigeon (ACSR) type 7 wires conductors are used as distribution lines in construction of a country's electrification infrastructure.

**Table 1.** Case analysis of the considered an aluminium conductor manufacturing plant (Medium Scale "25. 000 Tons/Year") with fixed cost data collected from accounting department

| | | |
|---|---|---|
| - Direct Labour | : | 86.314 $ |
| - Staff | : | 36.551 $ |
| - Management Expenses | : | 30.344 $ |
| - Illumination cost of factory | : | 2.758 $ |
| **Total** | : | **155.970 $** |

The total fixed value of same scale companies, which have similar production activities, can be simulated roughly by increasing or decreasing percentage of the above value.

**Table 2.** Possible manufacturing quantities of the medium scale company with the proposed conductors used in transmission and distribution lines. Maximum capacity usage plan for the chosen combination for calculation of working capital requirements

| *Conductor Combination*<br><br>*to use full capacity* | *Quantity*<br><br><br>*ton/month* | *EC Al. Needs*<br><br>*ton/month* | *Steel wire needs*<br><br>*ton/month* | *Drum Needs Type TA per month* | *Drum Needs*<br><br>*Type GR per month* |
|---|---|---|---|---|---|
| *ACSR CARDINAL (54/7)* | 1500 | 1050 | 450 | 0 | 410 |
| *ACSR PIGEON (6/1)* | 300 | 213 | 87 | 437 | 0 |
| *AAC PANSY (1+6)* | 90 | 90 | 0 | 155 | 0 |
| *Total* | 1890 | 1353 | 537 | 592 | 410 |

***Note**: In calculation of the costs of the stages **LME**:* **1500 $/ton** + **Premium: 60 $/ton** has been accepted to show processing cost loads.

**Table 3.** Total working capital requirements in usage of the whole capacity per month of the plant considered

| *Working Capital Requirement in one month period for Raw Materials [*]* | | | |
|---|---|---|---|
| *Al*<br>*$* | *Steel wire*<br>*$* | *Drum TA*<br>*$* | *Drum GR*<br>*$* |
| 2.110.680 | 402.750 | 23.680 | 90.200 |
| *Total* | **2.627.310** $ | | |

* ***Note**: In calculation of the costs of the items **LME**:* **1500 $/ton** + **Premium: 60 $/ton** has been accepted

Working capital level of the considered conductor manufacturing plant according to requirement of the raw materials has been given with Table 2 and Table 3 with respect to quantity planned with Cardinal, Pigeon and Pansy type conductor combinations.

These tables can be used for comparing of the fixed cost and monthly working capital requirements.

Manufacturers must know that working capital requirement is changed when current prices of aluminium are changed in LME market. Therefore, conductor offers should be prepared and presented to customers with an escalation formula.

After an agreement between manufacturer and customer is signed, required quantity of aluminium material is fixed on the base of current LME or mean value of weekly fluctuation of the prices according to capital level of the manufacturer by triple communication” international trader-manufacturer and consumer”.

## 3. Cost Calculation of Conductors

Separation of the conductor costs in the processing stages in a medium scale plant can be arranged by the flow chart described in Fig.1. The figure also demonstrates processing stages of aluminum T-ingot for manufacturing of typical aluminum conductors. Premium concept indicated in the flow chart in Fig.1 is related to cost added to LME base due to purification grade of the material. When the quality of the ingots is increased, premium ratio is increased. For example, in this area EC–Grade ingots are used. “EC” means Electrical Conductor grade and available percents of inclusions in the raw material related to the Ti, V and Cr should be limited below the 0.005%. Producer and international metal trader should guarantee these limitations. Because, premium level is defined according to purification grade of the proposed material. When the purification level is decreased premium to be paid will be also decreased. Quantity of aluminum in unit length for the conductors AAAC and AAC is very high so, their prices in the market will be higher than ACSR type conductors.

In performing of the cost calculation of the conductors, initially unit weight of the conductor is determined from a catalogue or calculated. If it is composite type ACSR, aluminium and steel weights are determined and separated by appreciating process scraps quantities. Some of the customer requires the product as $/ton and others as $/km. After completed calculation of the cost loads due to processing stages of the products, overhead costs are loaded to the final cost. The final cost represents a cost without profit. Then a determined percentage profit is added. This indicates selling price of the conductor. Manufacturer can decrease or increase profit percentage according to the conditions agreed between customer and payment plan or delivery plan presented by the customer and manufacturer respectively [4, 5].

## 4. Conclusion

The article summarised here will contributes in bargain stages to developing countries in supplying of electrification products for infrastructure projects. Because, electrification projects comprises all people living in a country. It is well known that consuming of electrical energy is an indicator in measurement of the civilisation of the populations. Therefore, we hope that the article will help to the electrical authorities of the poor countries in making decision of the long-range projects. Companies must get profit from their manufactured products but level should be in the range of acceptable limits for two sides. Electrification infrastructures of the countries will contribute improving living conditions of human beings. Therefore, manufacturers and traders of electrification products should evaluate those types projects as opportunity for long-range business on condition with low profits.

Additionally, in management of the budgets for electrification infrastructures, authorities should know market structures and cost calculation of the products in evaluation of the projects.

Moreover, each country should have some plants in home market to supply required products immediately. So, medium scale plant capacity and its working capital level and possible production combination and final cost of products and cost loads for different processing have been analysed to give some business ideas to possible investors.

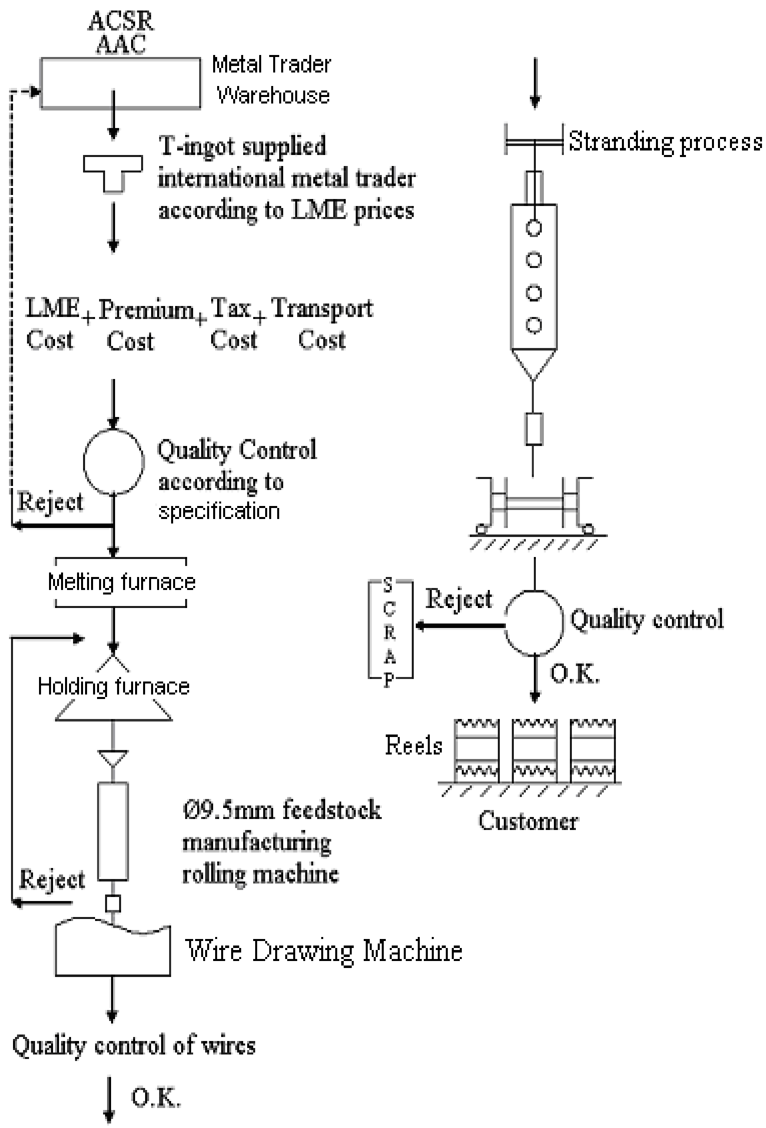


**Figure 1.** Processing and cost adding stages of transmission line conductor

**Table 4.** Cost distribution example of typical conductors with respect to processing stages in the plant

| *Product Stages and Cost loads* | *Cardinal 54/7 ACSR [$/kg]* Transmission Line Conductor* | *Pigeon (7-wires) [$/kg]* Distribution line conductor* | *Pansy (7-wires) [$/kg]* Distribution line conductor* |
|---|---|---|---|
| *Raw material cost Cost of Aluminium weight of the conductor is calculated by multiplying supplying cost of raw material to the plant* | 1.40059 | 1.34795 | 1.6281 |
| *Process scraps Process scraps are calculated by considering scrap-market prices* | 0.01659 | 0.01636 | 0.01696 |
| *Auxiliary material cost* | 0.00148 | 0.00148 | 0.00148 |
| *Continuous casting stage* | | | |
| *-Natural gas cost* | 0.02342 | 0.02174 | 0.032 |
| *-Electrical cost* | 0.01291 | 0.01291 | 0.014192 |
| *-Maintenance cost* | 0.01085 | 0.01006 | 0.0148 |
| *Wire drawing line* | | | |
| *-Electrical cost* | 0.005 | 0.005 | 0.005494 |
| *-Maintenance cost* | 0.006 | 0.00604 | 0.00888 |
| *Wire stranding line* | | | |
| *-Electrical cost* | 0.00292 | 0.00292 | 0.003205 |
| *-Maintenance_cost* | 0.00402 | 0.00402 | 0.00594 |
| | | | |
| Total | 1.4846 $/kg | 1.42848 $/kg | 1.73105 $/kg |

* ***Note***: *In calculation of the costs of the stages* ***LME*: 1500 $/ton** + **Premium: 60 $/ton** has been accepted to show processing cost loads.

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# NON-INTRUSIVE, ON-LINE RESIDENTAL METERING BASED ON BROADBAND COMMUNICATION

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## Abstract
Frequent philosophy changes characterise the evolution of the automated metering of residential customers over the last fifteen years, beginning with AMR, AMM and these days AMS, i.e. Automated Meter Services. The crucial issues concerning the large-scale deployment of "*smart meters"* in residential premises are still the availability of non-intrusive and low-cost communication means and the adaptability of meters to new functionalities.

Through the rapid expansion of high-speed broadband carriers today, any proprietary or dedicated communication infrastructure is no alternative anymore for the automated metering of residential customers. Therefore, we have put the focus on creating smart residential meters that connect instantaneously to the WEB via commercial high-speed broadband carrier networks, establishing an online link with energy suppliers and consumers at any time. The meter provides digitally signed secure data, while time-of-use programs are controlled online. The design of the meter is such that an attachment incorporates the communication and high-level added functionality without affecting the base meter. The attachment is automatically updated with metering data every second. It also passes remote commands to the base meter in this resolution.

This new approach of online residential metering reduces not only the efforts in mass deployment dramatically by connecting instantly to the WEB through highly available carrier networks, but it also permits the consumers to follow up their energy usage patterns online by different WEB devices. That gives them an efficient energy saving tool.

## 1. Introduction
The evolving intelligent use of energy and communication means are connecting the needs of residential consumers with those of suppliers and system operators that serve them. Beyond price and quality of supply, residential mass consumers are increasingly interested in online information on actual consumption and demand for adapting their usage patterns to upcoming challenges in the global energy environment.

Achieving energy efficiency is today's prime goal in both developed and developing countries. The key to that is the actual knowledge of energy use in each customer's site, which can only be provided by efficient information delivery. The new age of the energy will thus be irrevocably knowledge based. One can postulate that energy efficiency goes side-by-side with information efficiency.

Just giving a two-way communication with time and volume optimised data streams, as most of currently available AMR/AMM systems do is not appropriate for broad online information transactions, which are prerequisite establishing and maintaining dynamic and flexible market-based relations between consumers and suppliers, as well as controlling the supply and demand side in a responsive fashion.

Smart Metering implies smart customers and go-ahead, alert suppliers, linked together by means of adaptive, i.e. future proof metering equipment and state-of-the-art but non-dedicated carrier networks.

## 2. Smart Residential Metering

The true Smart Metering is the one that manages geographically dispersed mass consumers through the Internet in real-time via commercial, high-speed broadband carrier networks. Any proprietary system between must be avoided in order to prevent infrastructure related additional investment. By taking advantage of today's highly penetrated public broadband communication infrastructures in customer's premises, the metering information can be handled at virtually zero operational cost.

The most favourable approach implementing Smart Metering has to satisfy in summary ten fundamental criteria:

- Online, real-time information delivery and passing for both consumers and suppliers
- Non-intrusive communication between involved parties
- Non-dedicated, vendor-independent infrastructures
- Adaptable, future proof meter architecture
- Capability of adding new functions during run-time
- Dissemination of digitally signed, authentic metrological data complying with legal requirements
- Secured investment
- Easy-to-install, easy-to-maintain equipment
- Provision of energy saving tools
- Multi-utility capability

## 3. Adaptive Meter Architecture

Changing market rules, evolving legal directives and diversified customers' behaviour are demanding intelligent meters that are easily adaptable both to existing assets and installations, and to added functionalities without affecting the legal metrology requirements.

The novel solid-state residential meter combines a robust, reliable and cost efficient base product with built-in proof of measurement and two-way communication capability for real-time data transactions. Its adaptive design guarantees easy functional expansion and gradual migration towards full scheme Smart Metering features in a customised way. By simple addition of the appropriate attachment unit, the base meter provides standard and customer specific Smart Metering applications.

With regard to online communication in real-time the base meter transmits its data record cyclically <u>every second</u> via the interface. The data record contains all values of consumption and instantaneous power. To guarantee data security and legal validity across the entire value chain, the base meters signs any transmitted information digitally before forwarding them to the attachment unit.

The base meter accommodates the attachment unit as a detachable pack. The attachment is connectable plug & play, both in terms of the real-time information interface and the power supply from the mains.

The standard functionality of the attachment unit comprises:

- Capture of meter data record every second
- Time-of-use management and tariff control
- Upload of meter data record via TCP/IP-stack and embedded WEB-server
- Direct link to broadband carrier network access point
- "Home Plug" compliant broadband PLC-tunnelling

The unit is also suitable for additional applications, such as multi-utility metering gateway, digital living, and further customer management applications, which are provided depending on the business case.

## 4. Non-Intrusive Communication

The mass deployment of Smart Metering depends primarily upon the investment level and investment security in the communication infrastructure since large-scale communication at affordable costs is prerequisite to establish automated residential metering. Today, the rapid expansion of commercial high-speed broadband carriers as commodity good in households presents the long expected breakthrough for online metering services.

Unlike dedicated communication infrastructures, commercial high-speed broadband carriers and Internet access via them are non-intrusive for end-consumers. Energy suppliers whether they are independent or system operators will take advantage of this opportunity to perform and leverage online metering services. The meters can so fit into utilities' operational processes seamlessly making their usage efficient as assets, enabling streamlined operational processes, and providing an online link to the entire customer basis.

The pervasiveness, economy and scalability of the Internet make it prime networking choice for the automated residential metering. Linking adaptive meters at consumer's premises with the high-speed carrier network in their living environment is the only additional effort to perform except the routine meter replacement. To overcome the short distance to the carrier access point with no additional wiring the meter uses the home mains network as a vehicle, and communicates via broadband PLC-tunnel, which fully complies with the "Home Plug Standard".

The meter is able to communicate via any broadband, high-speed wired and wireless carrier networks, preferably based on DSL or GPRS/UMTS technologies.

## 5. Securing Investments by Smart Asset Management

The installed base of residential meters represents an important part of utilities' assets, which are subject to legal directives. The usage period of meters is so correlating with the certification period granted by metrological authorities. The replacement cycle, as a result, influences directly the asset costs.

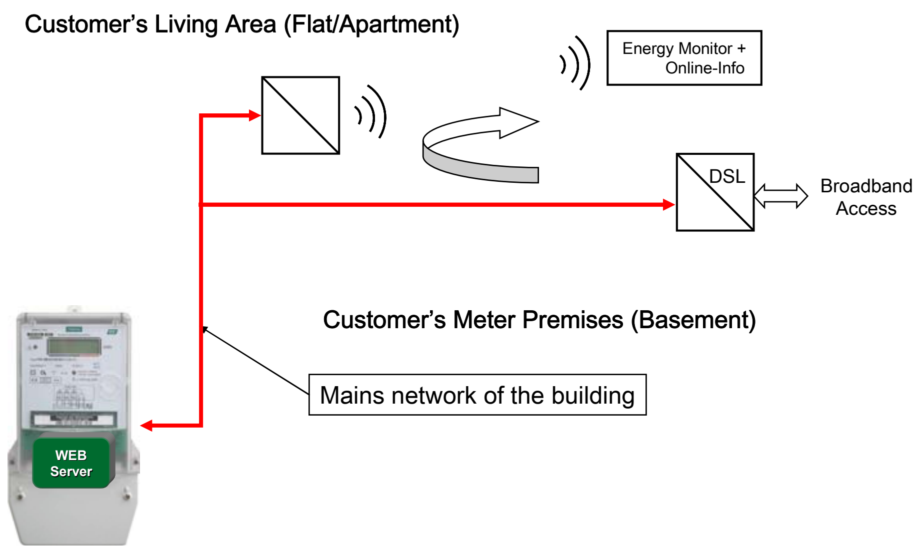
Beyond the real-time communication, the new meter concept also includes new ways to reduce overall asset costs:

Achieving a virtually unlimited certification period by continuous self-verification of the proof of measurement
Separating all active elements from the passive ones

The complete meter consists of a core incorporating the mechanics all passive elements, and in the *solid-state module* containing the entire electronics, i.e. all active elements in one *pack*. Since the base is assumed to provide only passive building elements, including the sensors, it can be anticipated that once installed this part can be freed from any certification, and thus it can remain in operation with virtually no limitation. At least 50% of the assets value can be expected as potential saving by reducing the meter replacement to the solely change of the solid-state module.

The proof of measurement means to permanent control the plausibility of measured values by the meter detecting and indicating any possible deviations from actual values. Via online communication, the meter is able to transfer any implausibility information to the operator automatically. Thus, the legal sampling procedure can also be automated with 100% coverage of the whole meter population. The periodical delivery of the proof of measurement information from every single meter provides consistent, continuous quality assurance from manufacturing to end of lifetime.

Sample configuration of online metering for residential consumers:



## 6. Conclusion

Adaptive Meters for residential consumers provide online real-time communication via high-speed carrier networks making their usage affordable at virtually zero operational costs by just exploiting existing commercial infrastructures. The smart architecture of adaptive meters on the one side, and their built-in proof of measurement ability on the other side increase the product lifespan, and contribute to streamline operational business process. The online real-time metering information is however, the key giving all participants the best benefits in functional and commercial terms.

# CONTRIBUTION OF LANDFILL GAS ELECTRICITY GENERATION TO ENERGY BALANCE OF CRETE ISLAND: AN ECONOMIC, ENVIRONMENTAL AND SUSTAINABLE ASSESSMENT USING LEAP MODEL

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## Abstract:
The aim of this paper is to estimate the energy demand of Crete's building sector for thirty year long and thus the electric generation that is required in order to satisfy the energy needs. A future energy planning for Crete Island with the contribution of renewable energy technologies and especially Landfill Gas (LFG) plants is implemented using the Long-Range Energy Alternatives Planning (LEAP) simulation model.

**Keywords:** Energy Demand, Landfill Gas Plants, Leap Model

## 1. Introduction
Nowadays, energy use in buildings accounts for about 40% of the final energy demand in the European Union (EU) and is responsible for more than 30% of the $CO_2$ emissions.

Under the Kyoto protocol and forthcoming commitments, the European Union has committed itself to reduce the emissions of greenhouse gases (GHGs) by 8 % in the period 2008 to 2012 compared to the level in the year 1990, [1]. The emission of carbon dioxide ($CO_2$), the prevailing greenhouse gas, is for the larger part linked to the combustion of fossil energy carriers.

Furthermore, a worldwide interest in the use of renewable energies has increased as a consequence to the resource limitations of fossil fuels and environmental impact.

The utilization of landfill gas as fuel for electrical energy production can be an important way not only to reduce the landfill impact on the environment but represents an easy way to use a renewable energy source as well. Anaerobic digestion has been one of the most effective processes not only for treating organic wastes, but providing at the same time a significant amount of electric power, [2].

Landfill gas (LFG) consists mainly of $CH_4$ and $CO_2$, both greenhouse gases (GHGs) that contribute to the global warning. In particular $CH_4$ is about 20 times more dangerous than $CO_2$ for the greenhouse effect. Therefore, energy demand is managed to cope not only with energy but environmental problems as well, [3, 4].

Two scenarios, a reference and an energy policy scenario were implemented in order to make an assessment of energy demand and electricity generation in Crete Island for thirty year long. The reference scenario is defined to represent the expected future development without any new planning, based on the existing state in the energy sector. In contrast with this, energy policy scenario represents a suggested future plan in order to counterbalance the energy demand with the energy generation.

## 2. Reference Scenario

According to the reference scenario, Crete's building sector is estimated to be 287.268 thousand buildings and the energy demand raises up to 1.85 GWh in the year 2000 (defined as base year), [5, 6]. The total installed capacity of the electric power generation units is 668 MW and is divided in the following different generation units with dispatch priority, depicted in Figure 1.

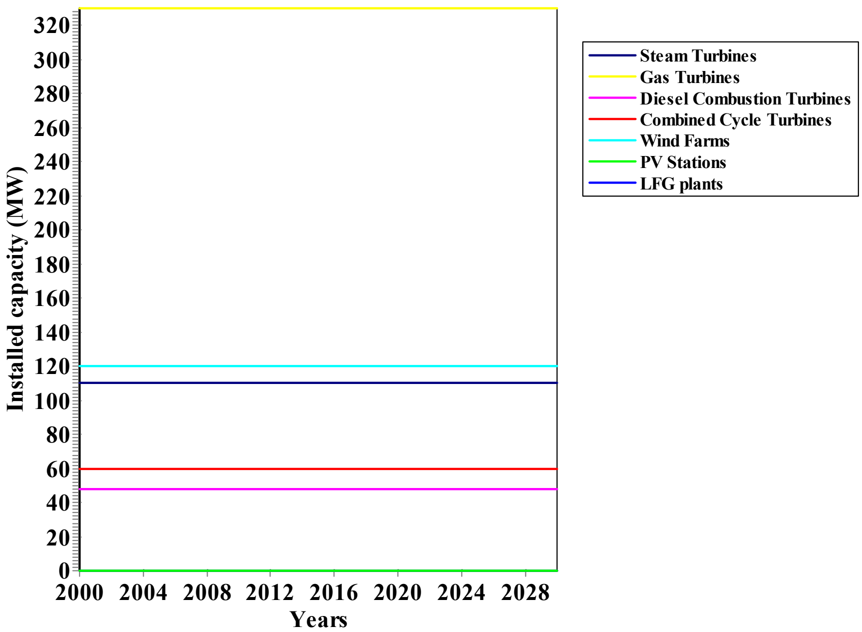


**Figure 1**. Electric power generation units' installed capacity

In the current scenario, a 5% growth of rate in the building sector as well as 2% and 3% in electricity and diesel cost correspondingly was taken into account.

In Figure 2, the annual energy demand of Crete's building sector is represented. The energy demand of the building stock is comprised by the electric energy consumptions of end use technologies (sub sectors) such as lighting, water heating and space conditioning, [6].

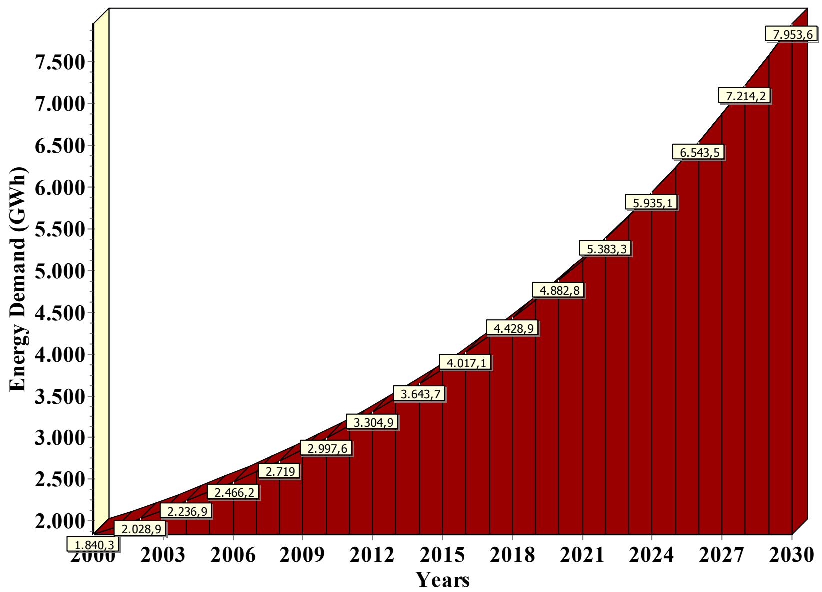


**Figure 2**. Annual energy demand in Crete

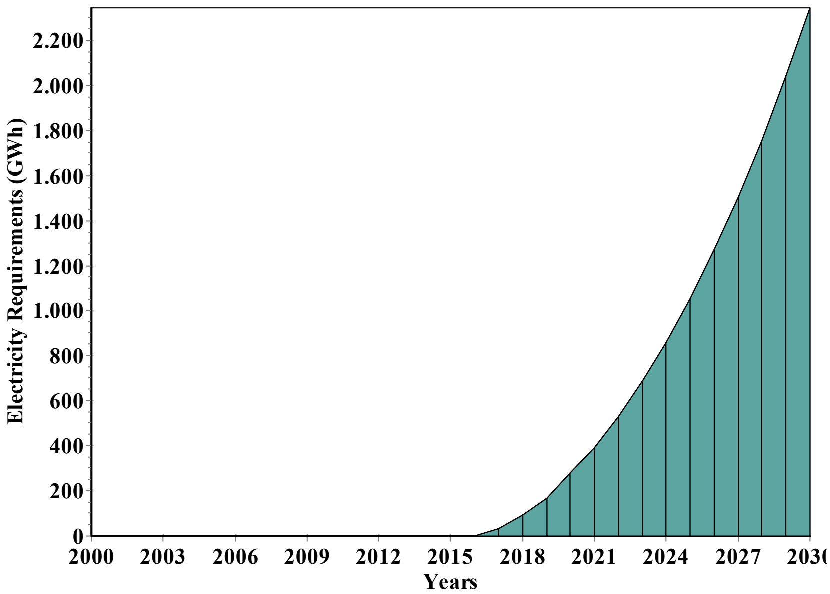


**Figure 3**. Annual requirements of electricity (reference scenario)

Considering the Figure 3, it is of vital importance the establishment of new electric power generation units or the increase of the installed capacity of the existent ones, as the electricity generation will not be sufficient to supply the needs of electricity after the year 2006. For this reason, an energy policy scenario is regarded to be essential.

## 3. Energy Policy Scenario

In accordance with the energy policy scenario, reference scenario's data were inherited in the current scenario and an increase in electric power generation units' installed capacity was implemented via interpolation methods.

More precisely, a new power plant of 570 MW installed capacity constituted by gas turbines will be established in 2014. Moreover, it is appraised that the installed capacity of PV stations will be increased in 52 and 104 MW in the year 2010 and 2020, correspondingly. In parallel, wind farms' installed capacity is regarded to be 200 MW in 2010 and 400 MW in 2020. Two biogas plants of 10 MW in 2010, 20 MW in 2020 and 30 MW in 2030 are going to be added in the total installed capacity of Crete' s electric generation units in order to satisfy the electricity needs, [7].

According to this future planning, Crete is not going to face inadequacy of electricity supply for a time horizon of thirty years, as shown in Figure 4.

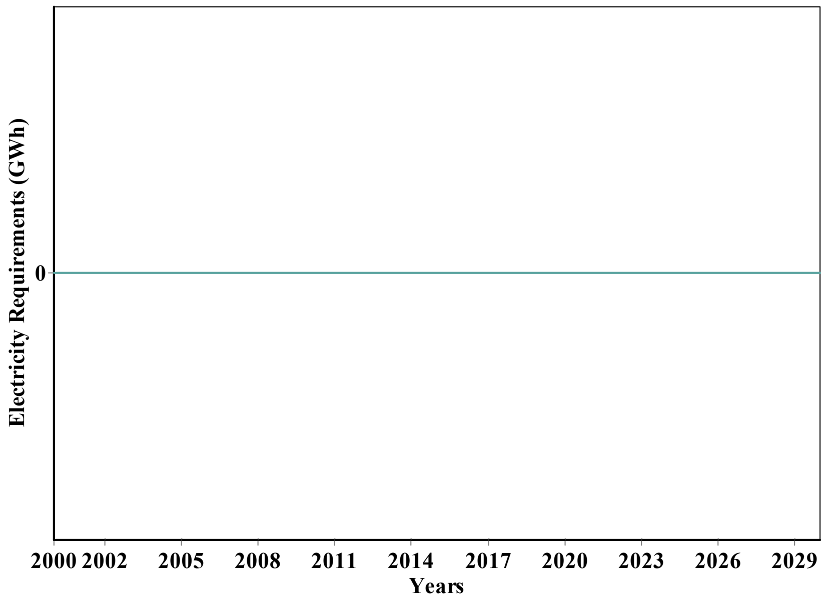


Figure 4. Annual requirements of electricity (energy policy scenario)

## 4. Conclusions

The energy production from renewable sources is one of the main issues to reduce environmental damage and greenhouse gases emissions, as climate agreements encourage non fossil fuel use in the future.

Landfill gas electricity generation constitutes an environmentally sound eliminating the emission of $CH_4$, one of the two greenhouse gases emitted by convert it to $CO_2$ via combustion.

According to the applied energy policy scenario, the contribution of renewable energy sources can assure the energy efficiency for Crete achieving at the same time the greenhouse gases (GHGs) emission reduction goals.

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ISBN 978-9944-5789-1-2

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