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A management application for the small distributed generation systems of electric power based on renewable energy

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Abstract

A multitude of factors, from the technological ones to the availability of primary resources and not least the current trend of electricity production at small capacities, led to a significant development of distributed generation. The problems they bring requires a special attention provided by supervisory control and data acquisition (SCADA) solutions. These systems can include or can be extended with new facilities such as the one proposed in this paper. The present paper aims to implement a management solution for isolated or connected to local grid systems of energy production from renewable sources, with small production capacity. The idea at the basis of the proposed solution focuses on using the existing energy management principles for distributed energy production facilities and on the accessible existing communication infrastructure. The proposed system allows the management of multiple energy production systems based on renewable energy including the using of mobile devices.

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Keywords: renewable energy; power system; power management; software implementation, remote monitoring

1. Introduction

The increasingly significant contribution of power generation systems based on renewable energy (RE) brings about a series of new challenges related both to the actual current power systems integration and to the management of these systems. Nowadays there are known solutions for managing energy production systems that can be found as SCADA implementation. They were developed in a context sustained by available

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hardware computing equipment, with restricted accessibility and limitations due to space layout, to primary energy resource availability that needs special attention and to the limited capacity of production. A solution to these problems can be resorting to the new IT&C technologies such as mobile communications, cloud computing, etc., in order to extend the functionality of the newly or existing system. However, such systems have not only numerous advantages but they also introduce new issues. The most important problem is related to computer security systems, issue which should be given a special attention. The main functionalities of such systems cover aspects as monitoring, and in some conditions control of electrical, mechanical or economical parameters. The proposed solution in this paper is based on these given objectives but it is adapted for small electricity production capacities and distributed power generation. The structure of the paper consists of a chapter dedicated to the theoretical background on distributed renewable energy systems (RES), a chapter containing the proposed new approach, a chapter with the main contributions, developments, results and a conclusion section.

2. Background aspects related to RES production management

2.1. RES management

Energy management has emerged as a result of energy policies implementation, of continuous development of technologies and measurement possibilities, of results analysis and interpretation and of opportunities for quick action on power systems components to connect and even rehabilitate them. Energy management systems are conceived to cover the energy needs of the consumer, both economically and by securing them. The ongoing trend of evolution of these systems is to reduce the total costs of ensuring energy supply, which implies distinct and iterative stages approach for the two components involved in the energy balance of a consumer, namely:

- forecasting energy consumption, the maximum values of these consumption and the loading profiles;
- optimizing the power supply system.

While for the first point there are well-known approaches, in the case of the second there are much more complex problems that lead to the need of considering an optimization criterion and the system restrictions. The optimization criterion, in a traditional version, is represented by the criterion of minimum total cost of the power supply system, which is the most comprehensive and economically justified. System restrictions are generally generated by technical and technological aspects, by the investments, by the structure of used primary resources for energy production and not least, by the acceptable impact on the environment (Leca, A., et al., 1997). Current requirements in decision-making and management are focused on the availability of optimal control of power flow and power by ensuring power quality and minimal operation and maintenance costs. Therefore, it is necessary to develop and adapt existing systems to interconnecting platforms at operational and information level. This objective can be reached by using available technologies of microelectronics and information technology industry, but it is necessary to integrate these achievements at power systems level to allow information manipulation, in the present or in the future, for the smallest indivisible relevant component used as a source or as an information receiver.

The main management functions of a management system based on intelligent software architectures are related, but not limited to (Dumitru, 2006):

- system monitoring and control ;
- operational management of the system by modifying and automatically or semi-automatically remote adjusting of (in time) the significant operating parameters;
- the optimization of the system by means of identification and generation of the commands on the basis of intelligent algorithms, which ,according to certain values or restrictions, will ensure minimum operating costs;

- the system security by operating in real time, according to the alarms generated to avoid damage;
- measuring and distributing the costs by monitoring the energy flows and the proper distribution of costs for the beneficiaries of shared facilities.

The management functions are oriented in order to interact with the following elements (Eremia, et al., 2008):

- information network consisting of devices and equipment for data communication;
- computing resources, such as automation systems, servers or data servers for the trading platforms of electricity markets;
- software services, such as SCADA, EMS and GIS components, alongside management systems of the databases;
- business services and functions such as pricing management servers, and security or operational policy servers;
- storage systems.

According to (Bonnano and Patane, 1998), energy flow management requires great attention from designers and from those exploiting systems based on renewable energy resources because long-term operation of these systems is highly dependent on weather conditions. Integrating sources such as photovoltaic panels, wind groups, hydropower generators etc, in a hybrid system based on renewable sources must be thoroughly analyzed, because these sources provide intermittent electricity. It is no less true that many hybrid systems based on renewable energy sources benefit from the presence of existing power grids, thus having the possibility of power supply from alternative sources considering the local unavailability of primary renewable resources (Sorensen, 2004,). But this aspect of centralization - decentralization of power supply plays an important role when considering the system management and the distribution system and involves a number of technological and economic calculations about resource consumption and production. Based on these considerations it is required to develop and implement management systems for individual local or interconnected power systems, conventional or intelligent, based on new sources of energy.

2.2. Architecture and principles

The directions of development also show a particular trend that targets smart energy management systems. The principles and functions of such a system according to Winkler et al., 2001 may be summarized as in the schematic diagram of Fig. 1. As shown in Fig. 1, intelligent energy management is focused on the three main components of energy systems, namely: production, consumption and energy storage. These management systems must provide a technical-economical optimum based on certain estimated predictions concerning demand and consumption, while taking into account the emergence of unexpected energy consumption or the unavailability of certain primary energy sources. To this goal, one must consider the possibility of energy storage as different forms of potential energy in accumulators, including rechargeable batteries. A typical system of distributed generation based on renewable energy (Fig. 2) consists of hydro generators, wind generators and photovoltaic solar panels with the related equipment and accumulators to ensure energy reserve in case of the unavailability of local power grid or renewable energy resources. The systems containing solutions of obtaining electricity from different resources are known as hybrid systems. Generator groups supply a DC voltage bar to which accumulators can be switched on or off by means of an electronic switch. In case the inverter input voltage should drop below nominal voltage, it turns off from the DC bar and the consumer is switched off (when the power supplied by the inverter is less than required) in order to protect itself, but also to protect the accumulators. The inverter remains connected if the extra energy is purchased from the local network.

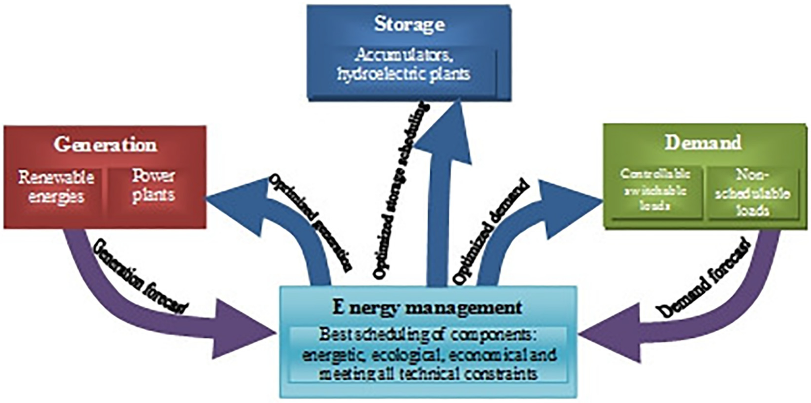

Fig. 1. Principles of energy management systems (Winkler et al., 2001)

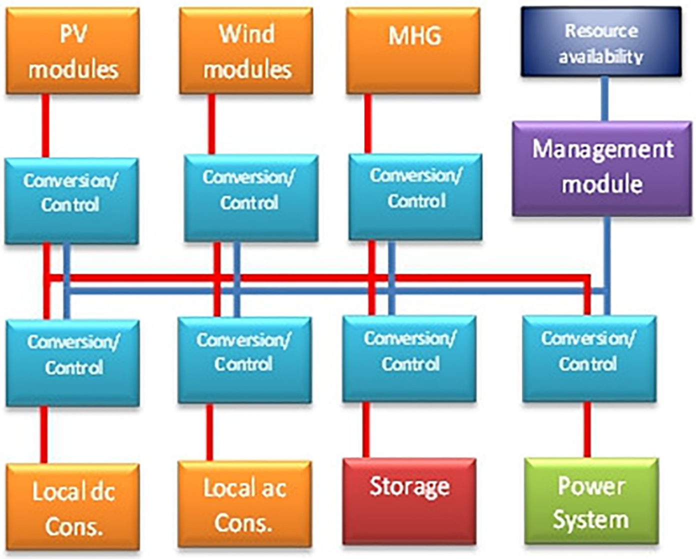

Fig. 2. Distributed generation system based on renewable energy

2.3. Problems of connecting RES with power systems

The accumulation of advantages and disadvantages of RES systems demand the introduction of advanced control methods, of energy management and of monitoring systems in order to ensure power quality and to increase the economic efficiency associated with the production and distribution of electricity.

The main advantages of systems based on renewable energy sources are:

- practical contribution in the functioning period to generate zero greenhouse gas emissions because fossil fuels are not involved;
- insensitivity to the price of oil;
- additional benefits related to energy production (reducing load during peak hours, avoiding overloading conventional power plants, reducing network losses) and the network in which they operate (redistribution of the costs of distribution network infrastructure, support for quality improvement energy, increasing reliability).

However, the following disadvantages must be considered:

- major initial investments;
- specific location requests (problems with impact on the environment can be sometimes experienced);
- unpredictability of the energy delivered (this means a higher cost to ensure energy balance and maintaining other capacities retired);
- connection costs, measuring and balancing (between 10% and 30% of total investment);
- influences on grid performances (Chindriş, et al., 2008).

3. The implementation of the management system for the small distributed generation systems of electric power based on renewable energy

The development and implementation of a system for monitoring, command and control of a hybrid system based on renewable sources for electricity production and consumption primarily involves the identification of the main system components and of the monitored electrical and non-electrical parameters. The parameters that can be controlled and the methods of controlling them are to be identified. However, it is imperative to consider the constraints imposed by both the generator and consumer groups. Based on these considerations a well-defined set of rules will be determined and implemented. The set is to be found in the software implementation.

The main objectives of the monitoring and control technology to be developed and implemented are: tracking the electrical and non-electrical parameters of the hybrid system of production and consumption of electricity based on renewable energy sources, the control over decision-making elements implemented within the system of monitoring, and the control of the system.

The proposed solution for the management system (Fig.3) consists in a software prototype decision system, a human-machine-interface with local and remote accessibility and field control modules. The communications between field devices are performed through the field bus, while remote interaction are based on Ethernet network.

The renewable energy management prototype application is implemented on a platform based on ARM9 microcontroller with the role of automatic energy flow planning. Decisions transferred to the field control modules come from the implemented rule base, historical data, information from consumers conversion/control devices and from the transducers of primary energy availability.

The architecture of the management application is shown in Fig. 4, where the main functional modules such as: the planning and the control of the system core, the communication module for managing remote communications, the data acquisition for communicating with field devices, the data management for data logging and rule base storage, the remote monitoring and the user interface for monitoring and managing the system remotely and locally are revealed. Only a web based client capable device to manage the user interface is needed for remote monitoring, which is a function useful for isolated areas.

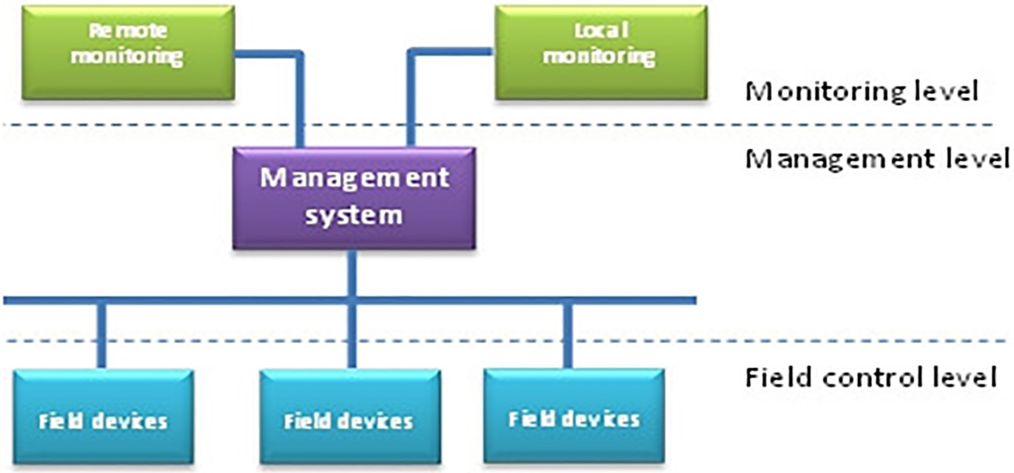

Fig. 3. Structure of the management system for DG based on RES

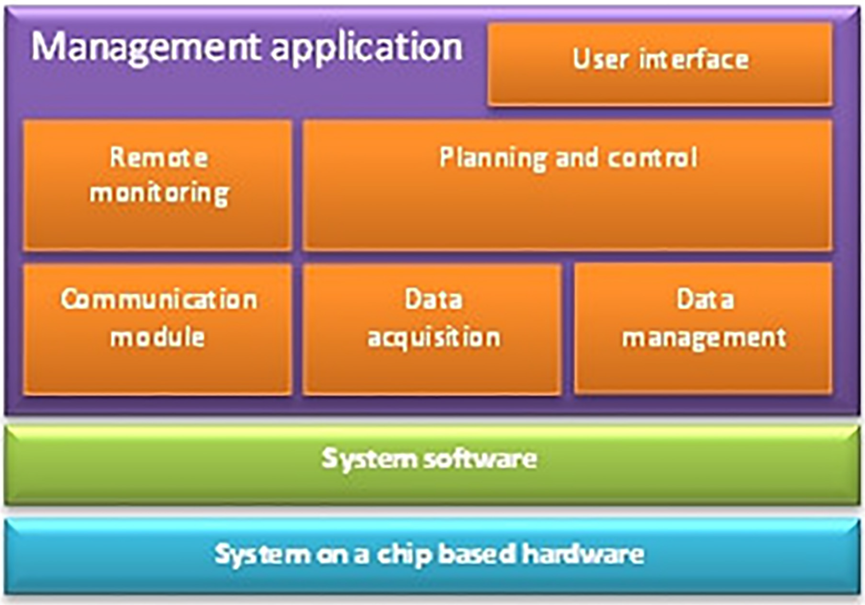

Fig. 4. Structure of the software application

The implementation of the management application is designed for the system software on embedded Linux platform.

The planning and control module uses the forecast availability of energy resources and calculates on data provided by the sensors and on mathematical expressions the power that can be obtained and later used as reference for users. In consequence the equation (1) was implemented for the photovoltaic solar panels.

$$P_{el} = \left[\frac{kT}{q}\ln\left(1-\frac{I-I_{PV}}{I_0}\right)\right]\times\left[I_{PV}-I_0\left(e^{\frac{qU}{kT}}-1\right)\right] \tag{1}$$

where:
k - Boltzmann constant (1.3806 10^{-23} J/K);
T – reference temperature of solar cell;
q – elementary charge (1.6021 10^{-19} As);
U – solar cell voltage (V);
I_0 – saturation current of the diode (A);
I_{PV} – photovoltaic current (A).

The electrical power obtained under the assumptions of a wind generator's electrical and mechanical part efficiency is given by:

$$P_{el} = \frac{1}{2}C_e\rho A v_1^3 \tag{2}$$

where: C_e represents the total net efficiency coefficient at the transformer terminals (Golovanov, 2007).

The electrical power obtained for hydro generator is given by:

$$P_{el} = \rho_{water} g \dot{q}_{water}(h_{am}-h_{av})\eta_h\eta_m\eta_g \tag{3}$$

where:
ρ_{water} - density of water;
g - gravitational acceleration;
$\dot{q}_{water}$ - flow rate the entry into hydropower;
h_{am} – upstream geodesic water height;
h_{av} – downstream geodesic water height;
η_h - the hydraulic efficiency of the turbine;
η_m - the mechanical efficiency of the turbine;
η_g - the efficiency of the generator.

Equation (3) expresses the rate of water energy conversion into mechanical power at the generator shaft with the yield η_m. The generator turns this mechanical power into electrical power with the yield η_g.

The implemented solution presents the advantages of low cost, high dependability, low energy consumption. However, limitations may occur in case of very complex systems because of limited data storage and computing power. These shortcomings can be solved by multiplying the hardware or migrating to an upper level hardware solution.

The main advantages of the presented solution consist of designing an open system, developed on a high level language, with its major feature of interconnecting with other management systems contributing as a solution ready for the compatibility with the new smart-grids technologies.

4. Discussions and results

In order to analyze the behavior of the proposed solution the case of a consumer characterized by a mean daily consumption of 677 kWh, based on the load profile shown in Fig. 5, was considered.

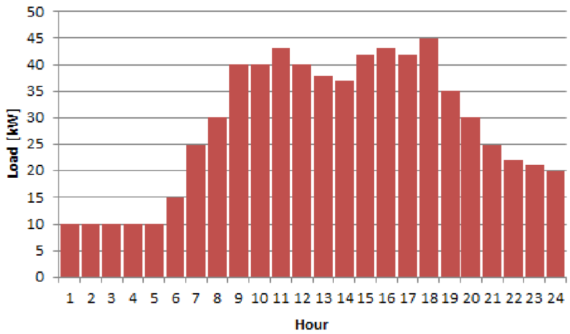

Fig. 5. Load profile of the consumer

The renewable energy system consists of photovoltaic solar panels (insures about 11% of needed power), a wind group (insures about 46% of needed power), a hydro group (insures about 32% of needed power) and accumulators to insure energy independence.

The analyzed cases, depending on the availability of the energy sources, as shown in Fig. 6, are:

- local power supply network – wind – hydro – solar panels;
- local power supply network – wind – hydro;
- local power supply network – wind – solar panels;
- local power supply network – hydro – solar panels;
- local power supply network – wind;
- local power supply network – hydro;
- local power supply network – solar panels;
- local power supply network.

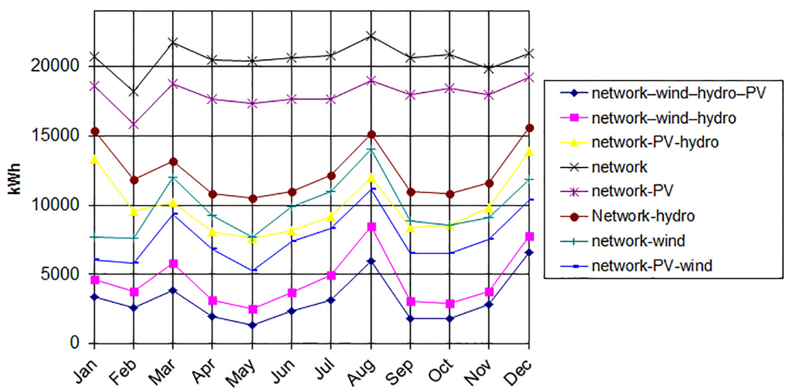

Fig. 6. Energy purchased over a year for different configurations and types of equipment

Fig. 7. shows the energy sold over a year to the local power supply network from the hybrid system.

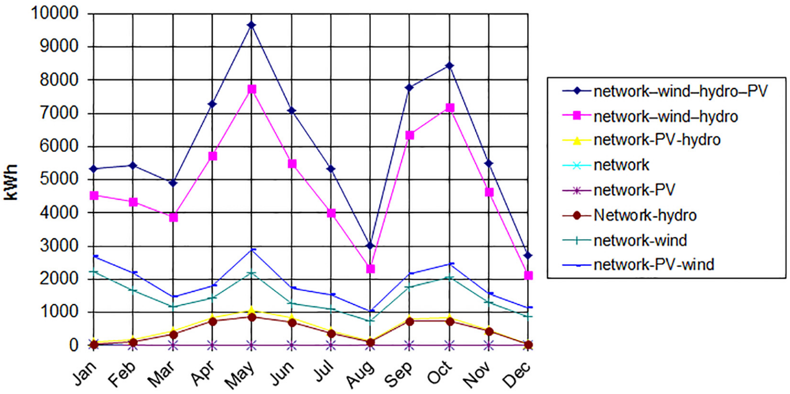

Fig. 7. Energy sold over a year for different configurations and type of equipment

Fig. 8 illustrates the energy quantities purchased / sold from / to local power supply network during a year for different scenarios of the hybrid system in the above-mentioned configuration.

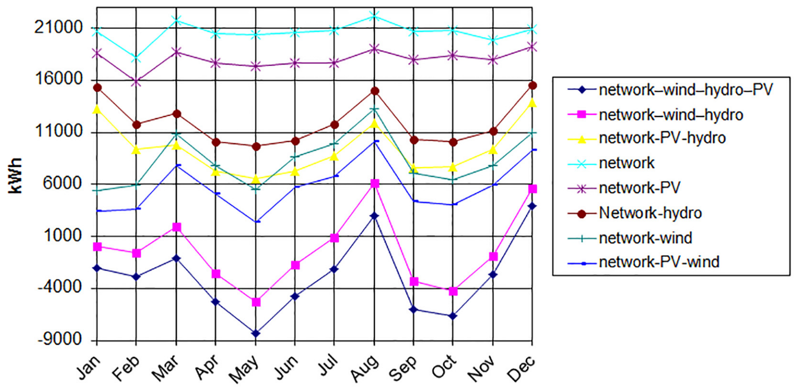

Fig. 8. Net purchases over a year for different configurations and type of equipment

5. Conclusions

The technical issues and rules imposed by the energy market require adopting adequate measures to allow the optimal functioning of the renewable energy sources and power system. One measure is the implementation of a management system for facilities based on renewable energy production. As shown in the paper the designed solution assures a balanced energy usage and an energy cost optimization.

The proposed solution is suitable for new renewable energy sources but also for the existing ones, the only significant effort being solving the communication compatibility with the management system. The presented configuration is optimal for medium-low renewable energy sources because of limited computing and communication resources. The solution may be used in complex systems too, after adopting hardware with proper computing power.

The integration of management systems from the implementation phase of renewable energy sources could lead to systems ready to be used in smart-grids configurations.

The management system assures efficient using and valuation of renewable resources for the beneficiaries and consists in lower costs for electricity and the decrease of the duration of the initial payback with energy production equipment.

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