SMART GRIDS

SMART METERS AND NON INTRUSIVE LOAD MONITORING

FINAL PROJECT REPORT

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SMART GRIDS: Smart Meters and Non Intrusive Load Monitoring

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ABSTRACT

The aim of this project is to explain the general concepts of Smart Grids,as well as the expected changes in the power supply and the main technologies to support the development of the same.

A Smart Grid is a system that allows two-way communication between consumers and utilities, in a way that the information provided by the consumer can be used by electricity companies for a more efficient operation of the electric network, as well as offer new services to customers.

The development of the Smart Grids is essential if the global community wants to achieve common goals of energy security, economic development and climate change mitigation.

To do so, they are developing and implementing new technologies such as Smart Meters and new techniques for measurement of power consumption as Non Intrusive Load Monitoring.

The Smart Meters are electricity, gas, or water meters that automatically collect measurement data and send them to the electricity companies to allow these to have a better view of the electrical distribution and provide their customers a greater understanding of their own consumption.

Non Intrusive Load Monitoring is a technique which detects the events of electrical appliances by analyzing total load demand. This is possible since devices are special features in the moments of connection and disconnection in changes both positive and negative in active and reactive power. As these characteristics are unique for each device, it is possible to recognize the profile of each one of them and know which devices are turning on or off, as well as the consumption of each one of them.

This is what offers the Plugwise technology, that through the use of their devices allows us to monitor and control the power consumption of a home, office or company and be able to see the results in our own Smartphone or PC.

The use of Plugwise technology in combination with a Smart Meter allows both customers and electricity companies be aware of how much, how and where electricity is consumed.

RESUMEN

El objetivo de este proyecto consiste en sintetizar los conceptos generales de las redes inteligentes (Smart Grids), los cambios que se prevén en la red eléctrica y las principales tecnologías que apoyaran el desarrollo de las mismas.

Una Smart Grid es una sistema que permite la comunicación bidireccional entre el consumidor final y las compañías eléctricas, de forma que la información proporcionada por los consumidores pueda ser utilizada por las compañías eléctricas para permitir una operación mas eficiente de las red eléctrica, así como ofrecer nuevos servicios a los clientes.

El desarrollo de las Smart Grids es esencial si la comunidad global quiere alcanzar objetivos comunes de seguridad energética, desarrollo económico y mitigación del cambio climático.

Para ello, se están desarrollando e implementando nuevas tecnologías como los medidores inteligentes (Smart Meters) y nuevas técnicas de medida de consumo eléctrico como la monitorización no intrusiva (Non Intrusive Load Monitoring).

Los Smart Meters son medidores de electricidad, agua o gas que recopilan de forma automática los datos de medida y los envían a las compañías eléctricas permitiendo a estas tener una mejor visión de la distribución eléctrica y proporcionan a sus clientes un mayor conocimiento de su propio consumo.

La monitorización no intrusiva es una técnica que detecta los eventos de aparatos eléctricos analizando la demanda total de la carga. Esto es posible debido a que los aparatos presentan características especiales en los momentos de conexión y desconexión consistentes en cambios tanto positivos como negativos en las potencias activa y reactiva. Como dichas características son únicas en cada dispositivo, es posible reconocer el perfil de cada uno de ellos pudiendo saber que dispositivos se están encendiendo o apagando, así como el consumo eléctrico de cada uno de ellos.

Esto es lo que ofrece la tecnología Plugwise, que mediante el uso de sus dispositivos permite monitorizar y controlar el consumo eléctrico de una vivienda, oficina o empresa y poder ver los resultados en nuestro propio Smartphone o PC.

El uso de tecnología Plugwise en combinación con un Smart Meter permite que tanto clientes como compañías eléctricas sean conscientes de cuanto, como y donde se consume la electricidad.

ACKNOWLEDGEMENTS

'Let us be grateful to people who make us happy, they are the charming gardeners who make our soul flower.'

Marcel Proust

The culmination of this work represents the end of a big stage of my life, which has been marked by traces of all the people who I've been finding along the way. So I want to thank all them its support, compression, effort and patience.

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'Seamos agradecidos con las personas que nos hacen felices, ellos son los encantadores jardineros que hacen florecer nuestra alma.'

Marcel Proust

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Pablo Rodes

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1. INTRODUCTION

This project can be divided into a theoretical and practical part. The goal of the theoretical part has been study, understand and analyze everything relating to Smart Grids, Smart Meters and Non Intrusive Load Monitoring.

About the Smart Grids, i have tried to provide an overview of their current situation and how they will be in the future. Its operation and features. The real need of them, as well as the advantages and disadvantages.

With regard to Smart Meters, i have also offered a vision on their operation and features, its deployment process, especially in its situation in the Netherlands, his problems with the security and all the concern that there is toward them.

Finally, on Non Intrusive Load Monitoring (NILM), i have explained what it is and how it is used, being used then the concept with the use of the Plugwise technology, which uses this technique in their devices.

The aim of practical part has been to simulate a normal household and measure and monitor the power consumption of some appliances in order to see how much energy we really consume, how we consume it and then try to reduce that consumption somehow.

To do this, we have used the Plugwise technology, that has allowed us monitor our consumption through our computer. In addition to this, we have worked with one Smart Meter understanding how it works, what are their functions and how to use it properly.

2. SMART GRIDS

2.1. Purpose and Reach

A Smart Grid is a network of transmission and distribution of electrical energy that has the ability to understand, assimilate, develop information and use it properly, making intensive use of information technologies and communications.

A Smart Grid is a system that allows two-way communication between the end consumer (home users or industrial) and the electric companies, so that the information provided by consumers is used by companies to allow a more efficient operation of the electricity network. In addition, all that information will allow to offer new services to customers complementarily to power itself.

Another important aspect associated with Smart Grids is that they must facilitate the incorporation of renewable energies, with the peculiarities associated with the limitations of alternative energy sources and the lack of electricity infrastructure in their usual locations. We must also highlight the advantages of Smart Grids they provide for the integration of the electric vehicle.

2.2. Electrical network. Toward the Smart Grids.

Electricity use has become indispensable in the life of modern societies coming to the point that a prolonged power failure it will lead to a chaos in the life of any developed country.

In a general way, the electrical network is the set of lines, transformers and infrastructures that carry electric power from the centers of production to all consumers. These networks are in charge of transport and distribute electricity generated in the plants (whether nuclear, hydraulic, coal or renewable) to the point of final consumption. However, the current electrical network is designed and in operation since the middle of the last century.
Thus, it is not surprising that the strain on this aging system is beginning to show.

For roughly a century, electric power in the industrialized countries has been delivered using the same basic four – step approach:

1) *Generation* of electric power in large, centralized plants.
2) Step up of the generated power to higher voltages and *transmit* it, over longer distances, to regional utilities and load centers (transmission network).
3) Step down of the power to medium voltages to *distribute* it locally (distribution network).
4) Step down the power a final time to deliver electricity to the *customer / end – user*.

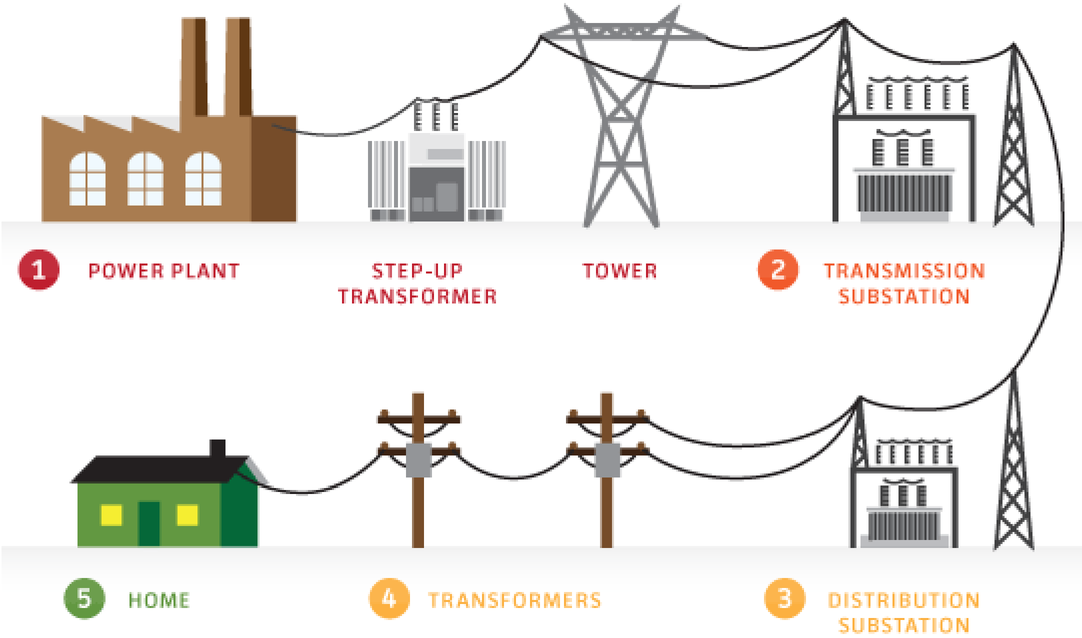

Fig. 1. Transmission and delivery of electricity

Even though the operation of the current networks is correct, needs arise which forces us to think about a change in the models of today's networks, focusing toward the Smart Grids.

The main reasons leading to the deployment of Smart Grids are:

1) Obsolete network mainly analogical. Digitization of the society. Increasingly, society is being digitized. Increasingly there are more microprocessors within any device that we use daily (computers, mobile phones, televisions, audio and video players...), in short is an important development of ICTs.
These digital devices are highly sensitive to even the slightest disruption in power, as well as variations in power quality due to transients, harmonics, voltage surges and sags.
These digital loads connected to the grid are continously increasing; however, the current power delivery system, designed and installed decades ago, to serve mainly analog electric loads, is unable to consistently provide the level of digital quality power required by our digital manufacturing assembly lines, information systems, and soon even our home appliances. Another is the fact that much of the legacy grid still consists of the older electromechanical technology, such as mechanical switches (e.g. circuit breakers which are relatively slow in response), and analog controllers.

2) Imbalance between supply and demand. For example, in the US in the decade 1988 – 1998 total electricity demand rose by nearly 30%, but the capacity of the transmission network grew by only 15%. This disparity continued in the decades that follow.

3) Need to match consumption and generation. Electricity cannot be stored in large quantities. This implies that its production should equal to consumption at all time and there must be a constant balance of production with demand. Smart grids must provide for the consumption and monitor in real time the generation and transport facilities so that the production of plants is real demand from consumers. If there are deviations must send the necessary orders (both of increase and decrease) stations so suit the production and is equal to the demand.

4) Reduction of the peaks of demand. There is the problem that occurs during the peaks of demand, which requires to activate special plants to be able to supply these energy needs. These plants are used only during those periods, with the additional costs to this implies and which has a direct impact on the bills we pay. The peaks are usually produce in time zones where all consumers they simultaneously access their appliances, although they are not in general aware of this. The possibility of knowing in real time the cost of energy by part of the end user makes that you can choose when to use certain appliances that are impacting on the final cost of your bills and reduce the peaks of consumption. For this it would be necessary to have smart meters in all points consumption, mainly home users.

5) Integration of renewable energies. The classic model of the power stations, does not conform to the renewable energies, since they do not provide a constant flow of energy (dependent on the Sun, the wind...). The idea is to create smart power stations able to supply energy in a dynamic way to be able to adapt to these new forms of energy. Another aspect that these counters would improve would be the integration of renewable energies for the end users that have solar panels for example (or elements of Microgeneration) allowing, in addition to generating its own electricity, the injection in the network (and its corresponding payment) of the energy generated during consumption peaks.

6) The reliability of energy and its distribution. The reliability of power and its distribution is another nuance to consider. While today the reliability is very high, there is still a great social and economic loss due to the lack of electricity in certain occasions. In addition, many times the companies themselves not detected these blackouts until end users report them, and it is usual that the physical displacement of employees is necessary to determine which parts of the network are damaged. Another additional problem is that if the failure is not quickly solved, it may cause a failure in waterfall due to congestion and overloads that occur. The implementation of intelligent automatic systems can do that electric companies have a knowledge in real time across the network, allowing a rapid reaction, the upon detection of potential problems and the minimization of the impact of a failure. In addition, if you have a direct connection with all final customers can check the status of their lines, consumption, and supplies, able to act before causing the error message.

7) Trend toward energy saving and efficiency. Also mentioned above that the infrastructures that are currently generating electricity are works that have been made many years ago and therefore with a technology and features very obsolete. As well as in the field of telecommunications there has been a lot of changes and investments, it has not been in the electricity sector that still works with facilities and services for many years. Necessary investment in new infrastructures, which associates to reduce telecommunications costs, advances in sensors and systems smarter and more powerful and faster processors will make the generation, distribution and management of energy is cheap, eco-friendly and allows to offer a new series of new services to end users.

In short, the smart grid will expand the current capabilities of generation, transmission, and distribution systems to provide an infrastructure capable of handling future requirements for distributed generation, renewable energy sources, electric vehicles, storage elements and DSM.

2.3. Need of Smart Grids

Humanity has experienced in the last century a huge development based on the energy consumption based on the exploitation of sources of fossil energy. These energies have been exploited by assuming a unlimited availability, and without rating the environmental costs at any time caused.

However, the change in this model is more than a necessity today, tending the new model to the diversification of sources of energy, a wholesale use of the renewable energy and efficiency and energy saving.

The new energy model aims to transform the current system into a system distributed, in which any agent that is connected to the network have the possibility to provide energy, enabling the creation of generators, in a way that there is not a so direct dependence as with current power generation unit.

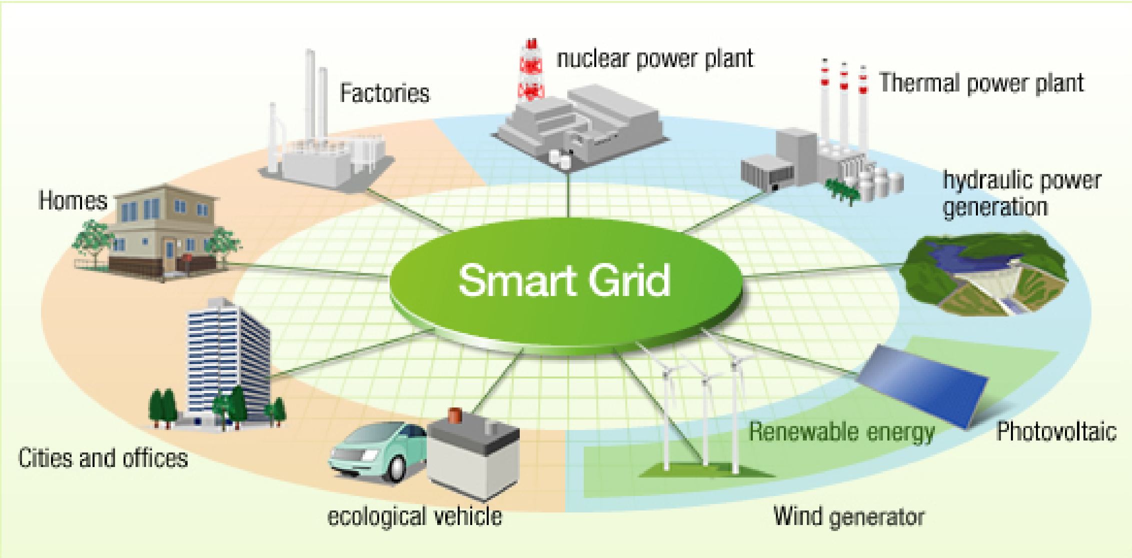

Fig. 2. Get Smart

Thanks to this type of network it is possible to drastically reduce losses by the transportation energy, facilitate the connection to the network of all kinds of renewable energy , support the capacities of energy storage, support the mass connection of electric or hybrid vehicles, etc.

In order to carry out the actions mentioned above, the "Network of the future" must:

· Allow the self-management of incidences, treating the produced errors in the network and ensuring the electrical flow in all points.

· Be endowed with resistance against attacks and destabilizations.

· Promote the active participation of consumers, encouraging the local power generation and delivery of excess energy to the network in peak hours.

· Have ability to supply power quality appropriate to the Digital era, thanks to a greater number of points of generation that will allow the delivery of different qualities of energy for each type of application.

· Accommodate a wide variety of forms of generation and storage, thanks to the micro and power generation distributed.

· Facilitate the increase of markets, due to the inclusion of new elements in the network as the electric vehicle, a larger number of renewable energy, etc.

· Make a most efficient optimization of their assets and operation, thanks to the automation of all the elements involved.

As mentioned previously, one of the main motivations for the change in the energy model is the environmental aspect. In this new model sustainable development, renewable energies, are considered as inexhaustible, and the peculiarity of being clean energy, sources of energy with the following characteristics: assume a zero or low environmental impact, use has no added risks, indirectly represent an enrichment of natural resources and are an alternative to conventional energy sources, being able to replace them gradually.

Taking into account these aspects among others, the European Commission met in 2008 to develop the plan known as Plan 20-20-20. Strategy 20-20 - 20 is an initiative launched to combat climate change with an aim to clear: reduce by 20% greenhouse gas emissions; Save 20% on consumption energy; and provide the energy system with at least one 20% renewable energy; all for 2020.

2.4. Security problems in the Smart Grids

The security problems that have been detected at the beginning of 2009 in the deployment of Smart Grids in the United States have demonstrated the need of a new architecture of communications. The security that must be added to the IP networks is the most complex in the history of communications (firewalls, IDSs, spam, spoofing, Trojans, virus, phishing,...).

The customer's data and privacy-related issues are in the today hot points of contention in the evolution of electric networks Smart. The issue of who has the data and why is a question that concerned legislators. There is growing concern that these data they are used in ways that customers would have never foreseen.

The information from these devices can be combined in ways unexpected and revealing information that consumers do not want to know it.

The subject of the problems of security in the Smart Grids will be treated more deeply in point 3.8 .Smart Meter Security

2.5. Key findings

1. The development of smart grids is essential if the global community is to achieve shared goals for energy security, economic development and climate change mitigation. Smart grids enable increased demand response and energy efficiency, integration of variable renewable

energy resources and electric vehicle recharging services, while reducing peak demand and stabilising the electricity system.

2. The physical and institutional complexity of electricity systems makes it unlikely that the market alone will implement smart grids on the scale that is needed. Governments, the prívate sector, and consumer and environmental advocacy groups must work together to define electricity system needs and determine smart grid solutions.

3. Rapid expansion of smart grids is hindered by a tendency on the part of governments to shy away from taking ownership of and responsibility for actively evolving or developing new electricity system regulations, policy and technology. These trends have led to a diffusion of roles and responsibilities among government and industry actors, and have reduced overall expenditure on technology development and demonstration, and policy development. The result has been slow progress on a number of regional smart grid pilot projects that are needed.

4. The “smartening” of grids is already happening; it is not a one-time event. However, large-scale, system-wide demonstrations are urgently needed to determine solutions that can be deployed at full scale, integrating the full set of smart grid technologies with existing electricity infrastructure.

5. Large-scale pilot projects are urgently needed in all world regions to test various business models and then adapt them to the local circumstances. Countries and regions will use smart grids for different purposes; emerging economies may leapfrog directly to smart electricity infrastructure, while OECD countries* are already investing in incremental improvements to existing grids and small-scale pilot projects.

6. Current regulatory and market systems can hinder demonstration and deployment of smart grids. Regulatory and market models – such as those addressing system investment, prices and customer participation – must evolve as technologies offer new options over the course of long-term, incremental smart grid deployment.

7. Regulators and consumer advocates need to engage in system demonstration and deployment to ensure that customers benefit from smart grids. Building awareness and seeking consensus on the value of smart grids must be a priority, with energy utilities and regulators having a key role in justifying investments.

8. Greater international collaboration is needed to share experiences with pilot programmes, to leverage national investments in technology development, and to develop common smart grid technology standards that optimise and accelerate technology development and deployment while reducing costs for all stakeholders.

9. Peak demand will increase between 2010 and 2050 in all regions. Smart grids deployment could reduce projected peak demand increases by 13% to 24% over this frame for the four regions analysed in this roadmap.

10. Smart grids can provide significant benefits to developing countries. Capacity building, targeted analysis and roadmaps – created collaboratively with developed and developing countries – are required to determine specific needs and solutions in technology and regulation.

* The Organisation for Economic Co-operation and Development (OECD) is an international economic organisation of 34 countries founded in 1961 to stimulate economic progress and world trade. It is a forum of countries committed to democracy and the market economy, providing a platform to compare policy experiences, seek answers to common problems, identify good practices and co-ordinate domestic and international policies of its members.

2.6. In summary

A Smart Grid is based on the use of sensors, communications, computing and control, form that is improved in all aspects the features of the power supply. A system becomes intelligent acquiring data, communicating, processing information and exercising control through feedback that allows to adjust to the variations that can be arise in a real operation.

Smart grids can play an important role in addressing increasingly untenable economic, environmental, and social trends in the supply and use of energy. By enabling increased awareness of system operation and better informed participation by electricity users, smart grids will increase electricity end-use efficiency while optimising network asset utilisation and increasing grid resiliency. They will also enable efficient integration of variable renewables and electric vehicles, as well as new products and services.

Smart grids co-ordinate the needs and capabilities of all generators, grid operators, end-users and electricity market stakeholders. This allows the grid system to operate as efficiently as possible, minimising costs and environmental impacts while maximising system reliability, resilience and stability. Smart grids accomplish this optimisation by using digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end users. These technologies are essential if the global community is to achieve shared goals for energy security, economic development and climate change mitigation.

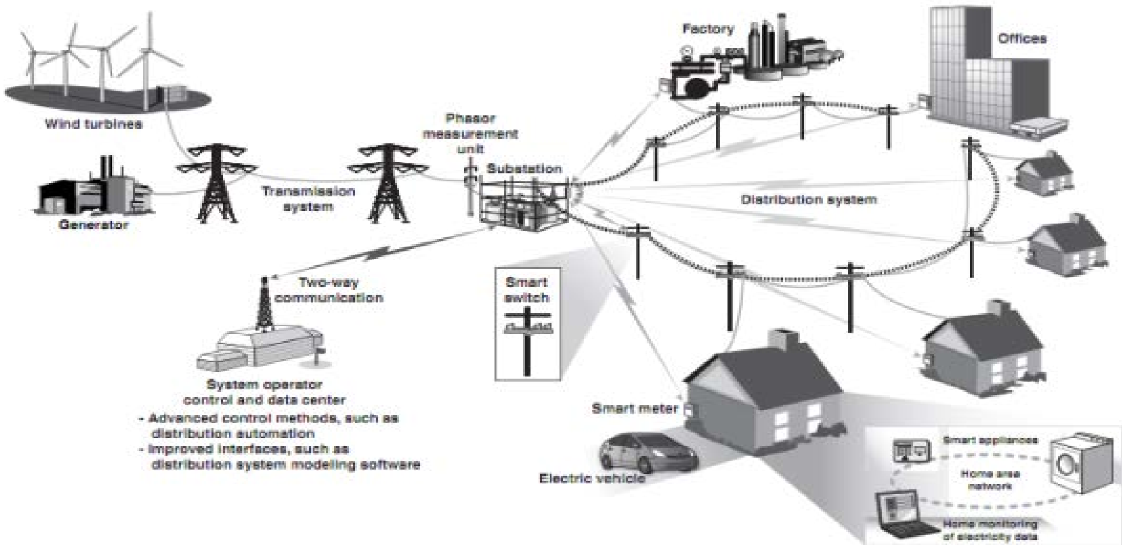

Fig. 3. Topography of a Smart Grid

3. SMART METERS

3.1. Classification

A Smart Meter refers to an electricity, gas or water meter that passes its metering data automatically to the utility company on a regular basis. This provides utility companies with new means to monitor their distribution network and gives customers an opportunity to gain insight in their consumption.

The Smart Meter offers advantages for both the consumer and the energy supplier. Consumers will receive better service and gain insight in their energy usage. Suppliers can introduce new services enabled by the Smart Meter like providing customers with advice about their usage and energy savings. Grid companies can get a better view in the actual consumer energy usage to improve demand and supply in the energy grid.

The equipment for the measurement of the electrical energy consumed is an electrical counter or meter that consists of three main elements, such as the system of measurement, the element of memory and the device information.

The equipment of measure of electrical energy can be classified according to their features:

· Technological, it can be electronic or electromechanical counters.
· Functional as single or three phase.
· Energy counters as active and/or reactive counters.
· Operative as devices of type recorder or programmable recorder that allow the remote control.

The devices of type recorder may be of the two technologies:

Electromechanical devices that measure only one type of energy, kWh accumulated or kVAh accumulated, do not possess tariff discrimination being the standard counters electromechanical induction.

Electronic, Automatic Meter Reading (AMR), allow only measure energy accumulated, they record the measure of total energy or by monthly time intervals predefined. Provide basic bi-directional communication between the meter and the data server, allowing on the basis of this technology the time measurements of use, Time of Use (ToU).

Thanks to replace electromechanical meters counters by solid state electronics counters, it is possible to obtain the information energy in digital form. With this step, it is possible to add capacity to communication to the device, allowing the interested use the AMR technology for remotely access to data through the communication layer. AMR is the technology of automatically collecting diagnostic, consumption, and status data from energy metering devices. Then, transferring these data to a central data base for billing, trouble shooting, and analyzing. Therefore, nearly all of this information is available in real time and on demand, allowing for improved system operations and customer power demand management.

An example of this, is the system of reading through driving, thanks to which the company sends a vehicle that is driven by a neighborhood getting very quick action of all the homes thanks to a system of communication wireless.

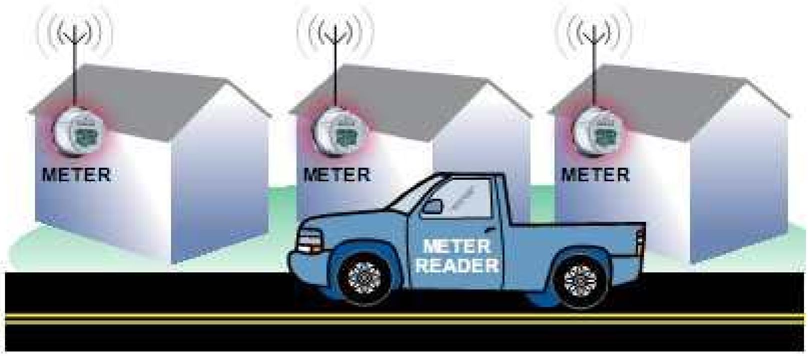

Fig. 4. Meter reader example

Programmable measuring equipment, electronic type are:

Advanced Meter Infraestructure (AMI), they can be considered an extension of the AMR, these devices allow the reading of the energy consumption accumulated or the instantaneous power, they support different pricing options by type of measure and records demand, or intervals of "load" programming agreed with each client. AMI includes all the components that allow two-way communication between Smart Meters and energy systems to improve demand in reponse. AMI incorporates:

*Smart Metering

*Telecommunication system and radio system

*Meter data management system

In total, AMI helps utilities repond in real time to demand for electricity more quickly and efficiently.

Smart Meters, these appliances provided through the center of management, information and control of parameters of quality and service programming along with the measurement of form software update telematics. The Smart Meters provide enhanced communication with the network manager and Home Area Network (HAN) with the local teams of consumption.

Initially, the introduction of AMR systems and the elimination of manual reading, were carried out to reduce the cost of labor in the reading of the data energy. Currently, however, the industry has realized that the AMR systems allow companies to produce greater benefits and services, such as pricing in real time to promote energy efficiency, immediate detection of faults in the system and more advanced data and accurate user with those who form their consumption profile.

3.2. Definition

The Smart Meter is basically part of AMI that includes at least the following supplements, energy through programmable PCS (Power Control Switch) to control the limit of consumption, a port HAN (Home Area Network) and services of pricing on request.

The general structure of the counter maintains the three main elements such as measurement system, memory and device of main information, which until now were the only communications system. In order to expand its operational capacity, additional elements are added:

· Power systems.
· Spreadsheet processor.
· Communications processor.
· Drive / control device.

It is expected that the Smart Meters, to comply with the following features:

- Determines and stores in real – time or near real – time energy consumption.

- Automatically precesses, transfers, management and utilization of metering data.

- Automatic management of meters from the electricity companies.

- Two – way communication.

- Provides meaningful and timely consumption information to the relevant actors and their systems, including the energy consumer.

- Supports services that improve the energy efficiency of energy consumption and energy system.

3.3. Scientific study

A Smart Meter measurement system exists of an electricity meter and possibly water and gas meter coupled to each other. With the Smart Meter, we don't have to send our readings to the electricity company and the electricity company doesn't need to send a technicien once a year to read the meter. The Smart Meter will send the readings every 15 minutes to a Central Access Server (CAS) system. This way the electricity company can send a technicien once every 5 years and save a lot of money. Because the electricity company gets data every 15 minutes it can adjust the billing to our usage and so we don't have to pay extra at the end of the year when we have used more energy.

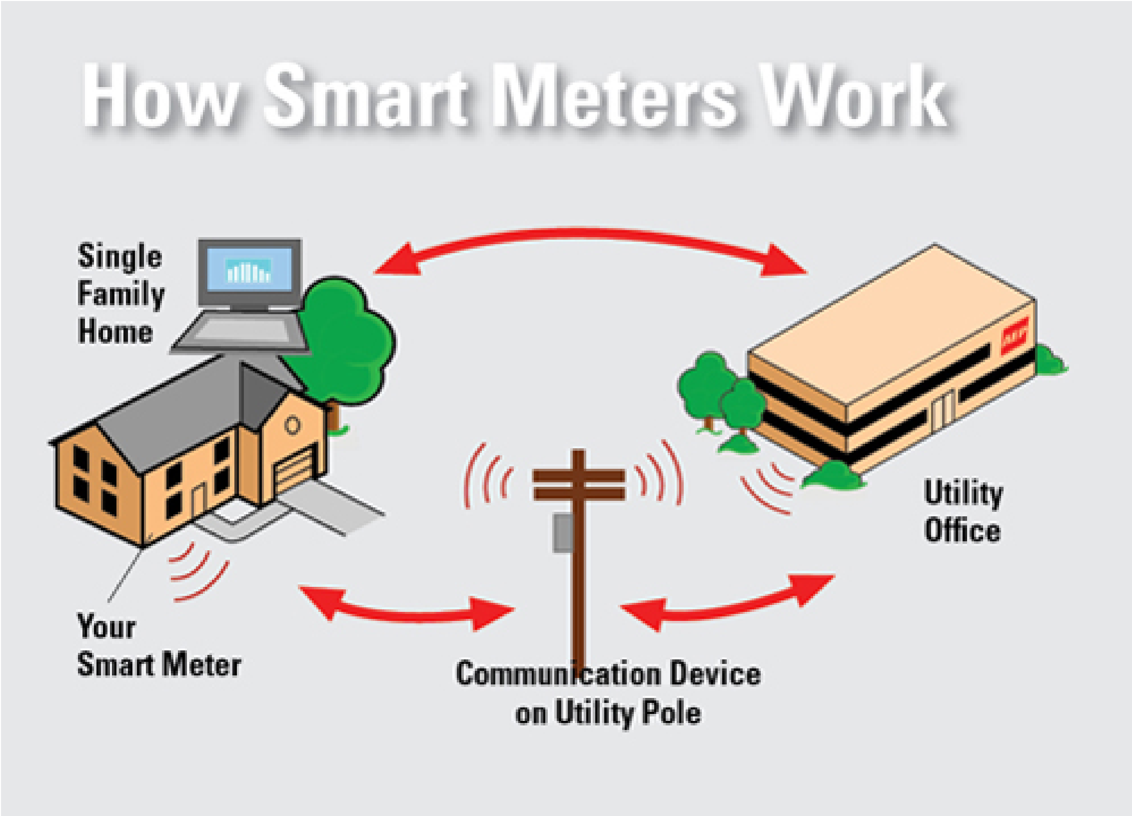

Fig. 5. How Smart Meters work

3.4. Smart Meters P-Ports

Although in our Project we only use the P1 Port, I'll describe all the ports available in a Smart Meter. These ports can be physical connections or logical relations between the different components that exist in a smart metering environment:

*Port P1: is used for communication between the customer's metering system and one or more modules that can use the information from the meter system. Acess to this port is read only.

*Port P2: communicates between the metering system and additional meter sensors, such as a gas or water meter.

*Port P3: is used for communication between the metering system and the Central Acess Server (CAS) that collects metering information from the connected metering systems and can send control commands to the connected devices.

*Port P4: is the port as the CAS which is located at the grid operator and will also be accesible to independent services providers and suppliers.

Besides these four ports, some smart meters are equipped with two more ports:

*Port P0: provides a connection between the meter and a external device that allows engineers to perform on-site maintenance of the meter.

*Port P5: is basically an extensión to port P4 that enables the costumer to get information about their energy usage from the supplier.

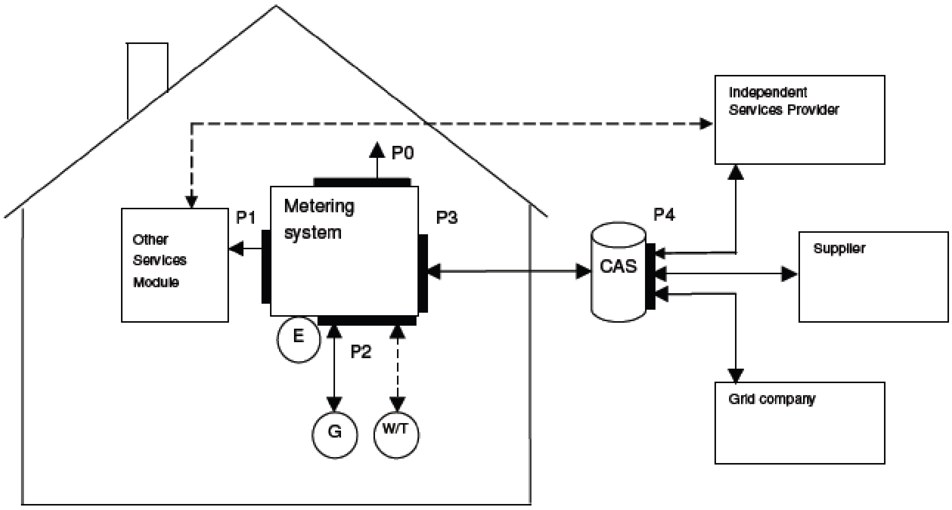

Fig. 6. Smart Meter ports

3.5. Energy market

A few of the goals of this new market model are to make it easier to switch to a new energy supplier, to provide clear and correct billing of energy usage and a single communication cannel for consumers. In the new market model the following parties in the Dutch energy market can be identified: suppliers, grid operators and metering companies.

1) Supplier

Suppliers are responsible for all customer related processes and are the central point of communication for the customer. A supplier is responsable for the checking and gathering of metering data, which they collected through a certified metering company. Based on the metering data from this metering company, the suppliers can bill its customers.

2) Grid Operator

Grid operators are the owners of the physical regional electricity grids. They are responsable for the transportation of electricity from various power stations or other grids to the consumer. The grid operators are also responsable for the administration and the installation of the Smart Meters.

3) Metering Company

Suppliers hire metering companies to gather raw metering data from their costumers. The metering data is gathered from various grid operators that have customers from the supplier connected to their grid. Once the data is gathered, the metering company will check and validate this data, after which the clean data is send to the supplier.

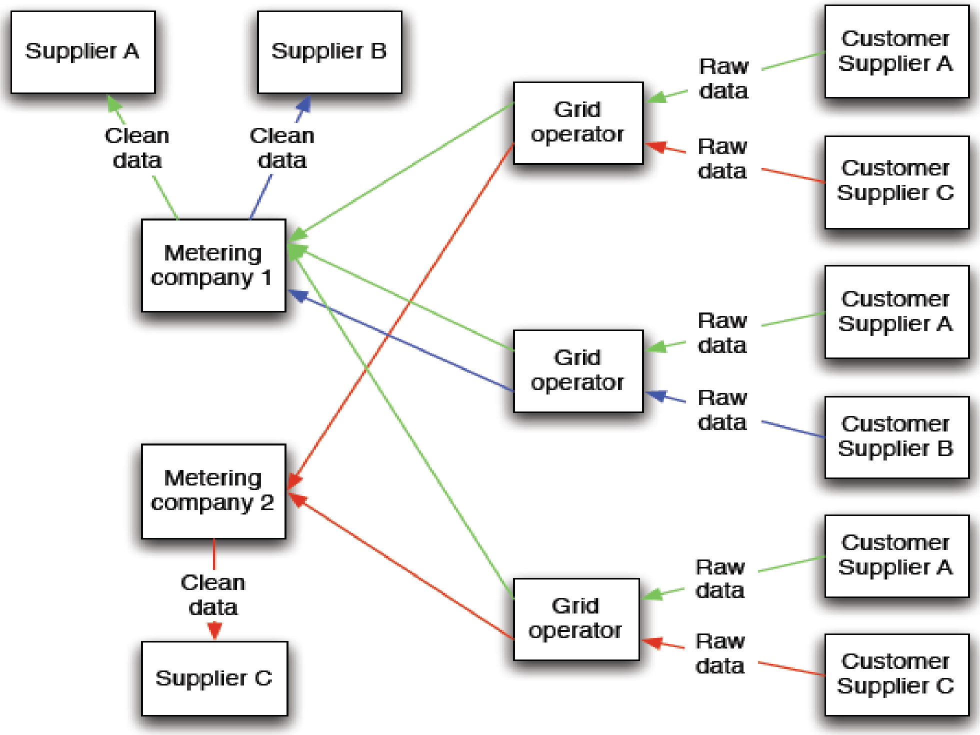

Fig. 7. Dutch metering information flow

3.6. Smart metering landscape in Europe

The legislative push by the European Union is currently the main driver for the introduction of intelligent metering systems in Europe. As a consequence, the smart metering landscape is highly dynamic at the moment with many Member States adjusting their energy legislation to comply with the third EU energy market package and the Energy Services Directive.

On the other hand, across the European Union, countries are moving towards electronic energy metering as a means to modernise electricity grids and improve the information that is available for grid operators. The modernisation of the electricity grids is key for the integration of highly volatile sources of electricity such as wind. An intelligent grid does not stop at electricity production but includes flexible consumers that help to balance demand and supply.

There are various layers of action in and between EU Member States and different EU institutions that are currently working on standardisation, regulatory recommendations, technical functionalities, and other issues of importance. While some Member States await the results of these various working groups and task forces, some actively move towards smart metering and start with a rollout independent of existing barriers to the deployment of smart grids.

The overall goal of this, is to promote innovative smart metering services in all Member States that have the potential to achieve energy savings and peak load reduction. That is to say that to accomplish this the matter of importance is the contribution of innovative metering technology and metering services to a sustainable energy system.

Due to the regulatory push and the efforts of market actors, the development of legislation and regulation for smart metering in Europe is highly dynamic. The Member states can be arranged into five groups:

1. Dynamic movers are characterised by a clear path towards a full rollout of smart metering. Either the mandatory rollout is already decided, or there are major pilot projects that are paving the way for a subsequent decision. Denmark, Finland, France, Ireland, Italy, Malta, The Netherlands, Norway, Spain, Sweden and the UK are part of this group.

2. M*arket drivers* are countries where there are no legal requirements for a rollout. Some legally responsible metering companies nevertheless go ahead with the installation of electronic meters either because of internal synergetic effects or because of customer demands.Estonia, Germany, Czech Republic, Slovenia, and Romania are in this group.

3. A*mbiguous movers* like Austria, Belgium and Portugal represent a situation where a legal and/or regulatory framework has been established to some extent and the issue is high on the agenda of the relevant stakeholders. However, due to lack of clarity within the framework, at this point only some of them have decided to install smart meters.

4. W*averers* show some interest in smart metering from regulators, the utilities or the ministries. However, corresponding initiatives have either just started, are still in progress or have not yet resulted in a regulatory push towards smart metering implementation. Bulgaria, Cyprus, Greece, Hungary and Poland are ranked in this group.

5. L*aggards* are countries where smart metering is not yet an issue. This group consists of Latvia, Lithuania, Luxembourg and the Slovak Republic.

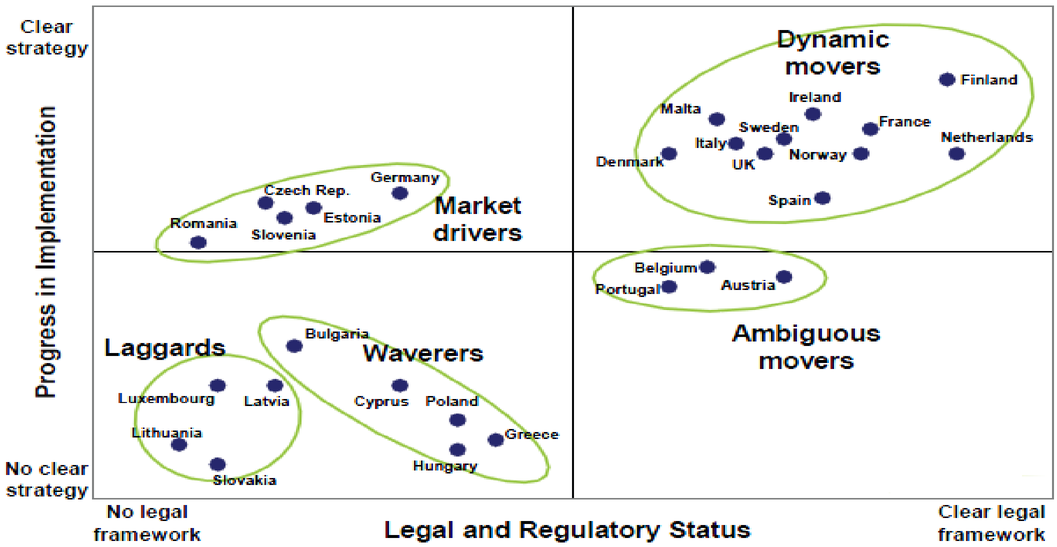

Fig. 8. Regulation and implementation of smart metering in Europe

3.7. Smart metering in Netherlands

The Netherlands is one of the front runners in smart metering in Europe.

The revised Dutch Electricity Act and the Gas Act (approved in 2011, in force since 2012) obliges network operators (owners of the smart meters) to offer all small customers (households and small businesses) a smart meter. Customers have a legal choice over whether they accept a smart meter, ranging from having no smart meter at all to a smart meter with full functionality to provide interval data to the network operator and a chosen service provider.

When accepting a smart meter, the customer has to authorise the network operator to collect and use a minimum set of consumption data for specific regulated purposes such as bimonthly cost statements, annual billing, switching supplier and moving home.

The revised law requires energy companies to provide customers with these bimonthly cost statements as a basic form of feedback. Additional regulation sets out the minimum information requirements for these cost statements.
Providing customers with more detailed consumption and cost information for household energy management is considered to be a market responsibility. The customer will choose and authorise a commercial service provider to use (real time) data beyond the minimum regulated level.

To be able to access the measurement data, the network operators set up uniform authorisation and authentication procedures. These procedures ensure that individual measurement data is only used for the specific purposes for which the customer has given their consent.

The rollout of smart meters in the Netherlands will take place in two stages. From 2012 until 2014 a small-scale rollout will take place for experience purposes. The small-scale rollout will take place in case of regular meter replacements (e.g. malfunctions), new meters to be placed in newly built houses / renovated houses and new meters at the request of customers. Important aspect, that will extensively be monitored during the small-scale rollout are related to technical and economic matters and the level of energy savings and smart metering services market development.

From 2014, the rollout will continue on a larger scale, based on the experiences mentioned above. The large-scale rollout aims to have a smart meter fitted by at least 80% of households and small businesses in 2020.

The Dutch government wants to stimulate the liberalization of the Dutch energy market with the following goals:

- A consumer market which ensures the freedom of choice for the consumer.
- Give an impulse for energy saving.

– Easy access to metering data service.

The government determined the following goals for smart meters:

▪ Remote redout of consumed and provided energy (metering).

-Improve the operational management of the suppliers (switching, moving, billing).

-Improve the insight of the consumer in his actual energy usage and cost.

▪ Remote capacity management (switching).

-Facilitate operational task of grid managers.

-Disabling of energy supply during emergencies.

-Enabling and disabling of energy supply in case consumers move house (temporary vacancy).

-Limit supply or disconnection in case of arreas.

▪ Remote measurement and signaling of energy consumption (signaling).

-Improving operation management for grid managers.

-Detection of energy leaks or fraud.

-Detection of supply fluctuactions, discontinuances and link impact.

▪ Online interaction between consumers and suppliers (communication).

-Online offerings of innovative and services (energy-saving recommendations, special for certain hours).

-Consumer can react real time on market, product and price development of suppliers.

-Support for payment methods like prepaid.

▪ Quick reponse of energy producers to influence demand.

-Connection with home automation appliances.

-Connection with decentralized (durable) generation.

-Facilitate decentralized supply and demand guidance (coordinate own production with purchases against a favorable rate).

Important drivers in other countries as limiting peak load demand to reduce the size of máximum demands in capacity (e.g. on hot summer days) are less important drivers for smart metering in the Netherlands.

The current state of smart metering services in Netherlands is also closely linked related to the four legal options for a consumer in accepting a smart meter:

a) The option to refuse the installation of a smart meter and keep the traditional meter.

b) The option to have a smart meter fitted / installed, but opt out of sending meter readings automatically (i.e. the smart meter functions as a traditional meter, and meter Reading is still required).

c) The option to have a smart meter fitted, but with a limited set of automatic reading capabilities.

d) The option of a smart meter fitted, with full automatic smart meter readings. This is the preferred option for the governement and energy market players.

3.8. Smart Meter Security

Security is a very important point during the entire lifecycle of any system. In particular, the new intelligent network which, in contrast to the old network, this much more connected to the Internet which makes it more vulnerable to cyber attacks. It is more likely now that theft, malicious attacks and fraud are brought out by people who are thousands of miles away or even in another country. We must also consider, the classic physical attacks which, because of the size and complexity of the network, are difficult to avoid.

The potential risks faced by the security of the Smart Grids are:

National Espionage: Use of external agents to get information or classified criticism from politically opposing countries to obtain advantages economic, military or political.

Hackers: Group of individuals attacking networks and systems for the purpose of exploiting vulnerabilities in operating systems.

Cyberterrorists: Individuals or groups operating locally or internationally, that represent various terrorist groups or extremists who use the violence to cause fear to the society to make the Government succumb to their proposals.

Organized Crime: Organized criminal activities involving games of chance, extortion, drug trafficking and many others.

Industrial Competitors: Local and foreign, operating in a market competitive, to try to obtain illegal information of their direct competitors.

Disgusted Employees : Individuals unhappy with their treatment, which have the potential to Inflict damage to the electricity network or its associated systems

3.9. Advantages and disadvantages

*Advantages:

-Utility benefits

- Accurate meter reading, disappears the estimated reading

-Improving the billing

- Profile Classes of precise measurement and classes, the true costs applied

- Improvements in the safety and the detection of tampering with the equipment

- Energy Management through data profiles of graphics

- Less financial load to correct errors

- Transparency of the costs of 'read' the measurement

<u>*Disadvantages:</u>

- The loss of privacy (revelation about user activities)

- Great potential for follow-up by third parties of other / unauthorized

- The increased risks of network security or remote access.

- Risks of electromagnetic pollution by using wifi or microwave systems.

- The loss of many jobs (meter reader).

3.10. Opposition and concern

Mainly two important and dangerous pitfalls: Privacy, independence of being anonymous disappears raising many doubts users. Wireless Pollution, In United States or Canada, it is generating an excess of radiation in the environment, already loaded by other infrastructures of this type of communication, this leading to an increase in headaches, lack of concentration, problems dizziness...

Smart meters are supposed to help to give us more control over our energy use. But many experts doubt that we'll ever see the electricity and cost savings that electric companies and smart-meter manufacturers tout. Based on expert's inventigations, it's clear that smart meters won't soon deliver the promised benefits, particularly the energy and pocketbook savings that are being touted by practically everyone who's connected to smart meters.

A few experts suggest that smart-meter conversion represents little more than a boondoggle that is being foisted on consumers by the politically influential companies that make the hardware and software that are required for the smart-meter conversion.

Smart-meter supporters also promise that the reduction in electricity use will save consumers money and will cut the amount of greenhouse gases that power plants spew. And they argue that smart meters are needed to fully build out the smart grid, which uses digital technology to create a more efficient power-distribution system. But these potential benefits, have not been proved.

So, in short, in the view of experts, smart metering offers potential benefits to utility companies in that they will be able to eliminate many jobs, but there are concerns that many of the proposed "benefits" to consumers, not only will fail to be realized, but to the contrary, could increase costs to the consumers.

4. NON INTRUSIVE LOAD MONITORING

4.1. Introduction

In the following point, I want to introduce the concept of *smart meter disaggregation*, also known as "non-intrusive load monitoring" or NILM for short. The main aim of smart meter disaggregation is to infer two things from a smart meter signal: 1) which appliances are active in the signal and 2) how much energy has each device consumed.

Today, one of the greatest challenges in a matter of power consumption, is energy conservation. Let us assume that people are motivated to improve their energy management. Do they have a sufficiently quantitative understanding of their energy consumption to prioritise correctly?

In today's industrialised societies, we do not have such a concrete, tangible understanding of the amount of energy we use. When we turn on an electrical device, it just works, without any indication of how much energy it's consuming. Hence, when faced with rising electricity bills, we struggle to prioritise correctly when deciding which devices to turn off or replace.

Studies on residential energy users show that the vast majority are poor at estimating either the consumption of individual devices or their total aggregate consumption. Residents often underestimate the energy used by heating and overestimate the consumption of perceptually salient devices like lights and televisions. Residents' failure to correctly estimate energy consumption leads to higher total consumption.

How significant is occupant behaviour in determining total energy usage? Energy use can differ by two or three times among identical homes with similar appliances occupied by people from similar demographics. These large differences in energy consumption are attributed to differences in consumption behaviour. If the home provided better feedback about which devices used the most energy then users could tweak their behaviour to make more efficient use of appliances.

The current Smart Meters, provide information about the aggregate consumption of a family, or even of an entire building. However, for a more detailed knowledge of the electric bill, there is a need for a breakdown of total consumption.

To achieve this, research efforts have lead to the development of appliance load monitoring (ALM) methods. The goal of ALM is to perform detailed energy sensing and to provide information on the breakdown of the energy spent.

There are two different types of load monitoring methods: intrusive and non-intrusive.

The most common monitoring system is the intrusive, where multiple sensors measure the power consumption of each appliance. As this method requires multiple sensors in order to monitor the different appliances, it imposes costs and a complex installation which usually requires wiring and data storage centers.

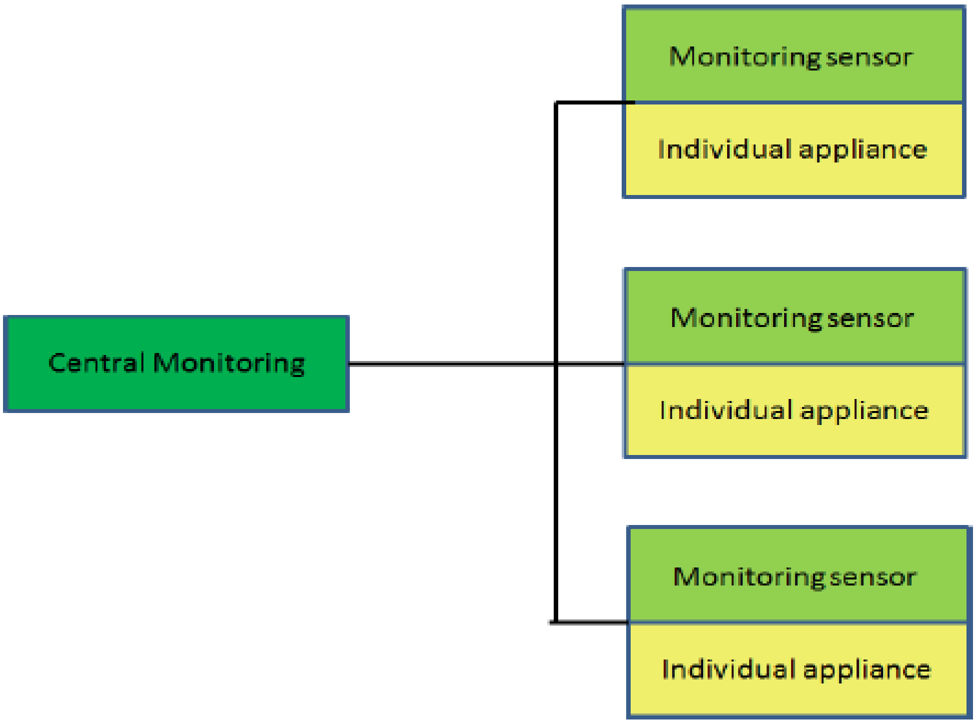

Fig. 9. Intrusive Monitoring system

Non-intrusive systems on the contrary, do not require to intrude into an appliance when measuring its power consumption. Since this monitoring system presents significant advantages in terms of cost and convenience, it has been chosen for the development of this work.

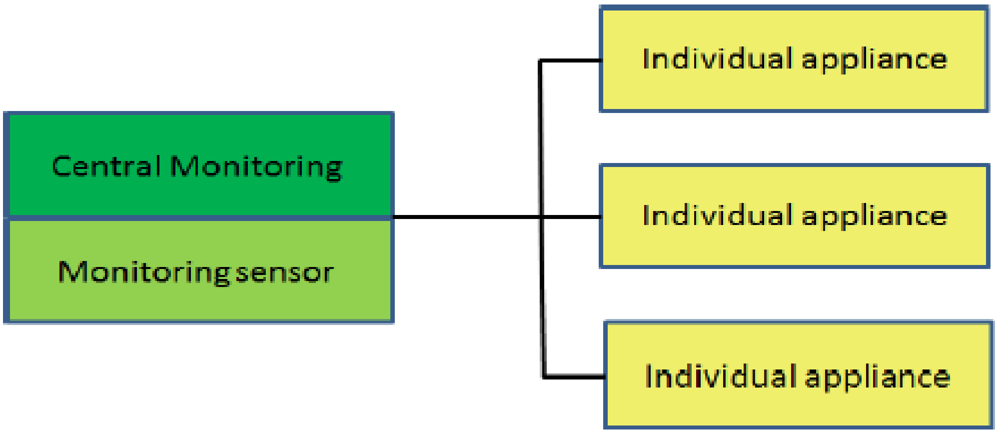

Fig. 10. Non Intrusive Monitoring system

4.2. Background

Non-intrusive Load Monitoring (NILM) is a recent method to estímate load profiles of individual electrical devices by collecting and disseminating the power-draw information. It was originally developed in 1982 by the Massachusets Institute of Technology (USA). The idea started when the professor George W. Hart was collecting and analyzing load data as part of a residential photo-voltaic systems study.

Fig. 11. George W. Hart

After measuring the electricity consumption of homes, Hart discovered that it was possible to analyze the obtained results to tell what was happening in the monitoring homes. As a result, the professor and the MIT Energy Laboratory Staff realized that this kind of system could have significant value to utilities.

The Electric Power Research Institute (EPRI) has sponsored NILM research since its origin. EPRI chose Telog Instruments to commercialize the NILM into a research tool available to electric utilities. First commercial product was developed in the United States at the end of last century. However, several research and development projects have been performed along the years in many countries such as Japan, France, Finland, or Denmark.

4.3. Applications

NILM can be used in different fields from residential to industrial. Some of these applications are:

• Energy Management: NILM can be used to give feedback on energy usage in order to reduce electricity bills. As an example, the system can be temporarily installed at the customer's house in order to analyze the characteristics of the appliances and how electricity is used. After some time, it would be possible to suggest how to reduce consumption and costs.

• Load Forecast: It is possible to estimate future energy demands by a continuous analysis of the power consumption. This will optimize the energy production implying savings for the power suppliers. In addition, it will help planning transmission and distribution infraestructures.

• System Failures: NILM allows to reveal system failures by detecting unusual information from the electrical consumption behaviour. Therefore, it can be used in security control applications such as failure of monitoring devices.

4.4. NILM Basics

Basically, it's a device that sits on a home wall socket (or the electrical panel), and monitors voltage/current fluctuacions. It's smart enough to distinguish between fluctuations caused by a cofee pot and a TV set being turned on. By using a learning algorithm and signal processing techniques, it's able to discern when these devices are turned on/off, and how much power is used by each device.

The main goal of NILM is to partition the whole house – building data into its major constituents, like:

$$P(t) = p_1(t) + p_2(t) + ... + p_n(t)$$

The task of NILM is to perform decomposition of *P(t)* into appliance specific power signals in order to achieve disaggregated energy sensing.

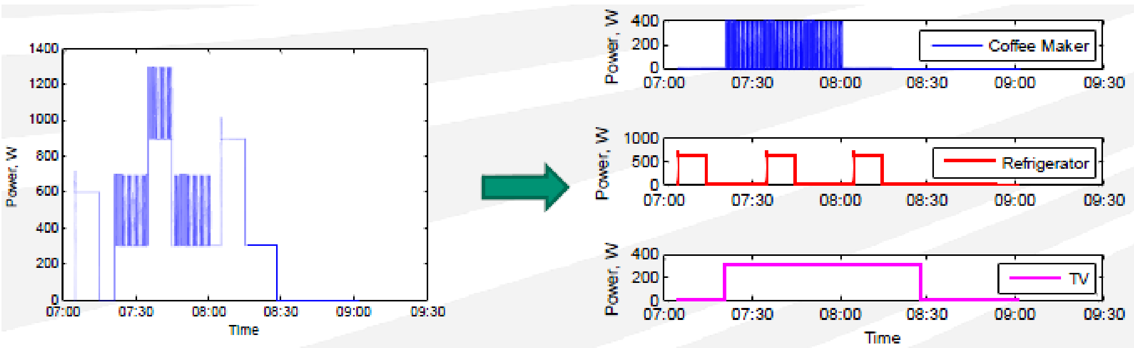

Fig. 12. Decomposition of aggregated load power into individual appliances

Electrical loads exhibits a unique energy consumption pattern often termed as "*load or appliance signatures*" that enables the disaggregation algorithms to discern and recognize appliance operations from the aggregated load measurements.

<u>NILM: Types of Appliances:</u>

1. ON/OFF Appliances: Only two states of operation. E.g. table lamp, toaster…

2. Multi State Appliances: with a finite number of operating states also referred to as Finite State Machines (FSMs). E.g. washing machine, stove burner…

3. Variable Appliances: their variable power draw characteristics with no fixed number of states. E.g. power drill… It is very challenging for NILM methods to disaggregate these type of appliance from the aggregated load measurements.

4. Permanent Appliances: appliances that remain active throughout weeks or days consuming energy at a constant rate. E.g. telephone sets, smoke detectors…

Appliances that should not be taken as target of NILM can be classified as follows:

*Appliances with very small power consumption

*Appliances which are always on.

*Continuosly variable Appliances

Small appliances cannot be measured because of noise in the recording equipment. Appliances that are always on can not be recorded because of missing signatures.

NILM Approach:

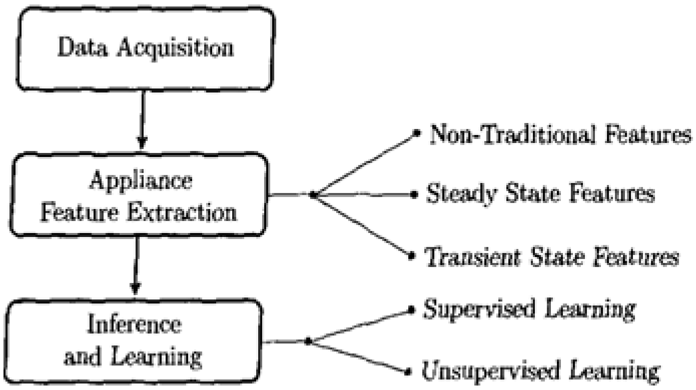

Fig. 13. General framework of NILM approach

Data acquisition (hardware) and disaggregation algorithms (software).

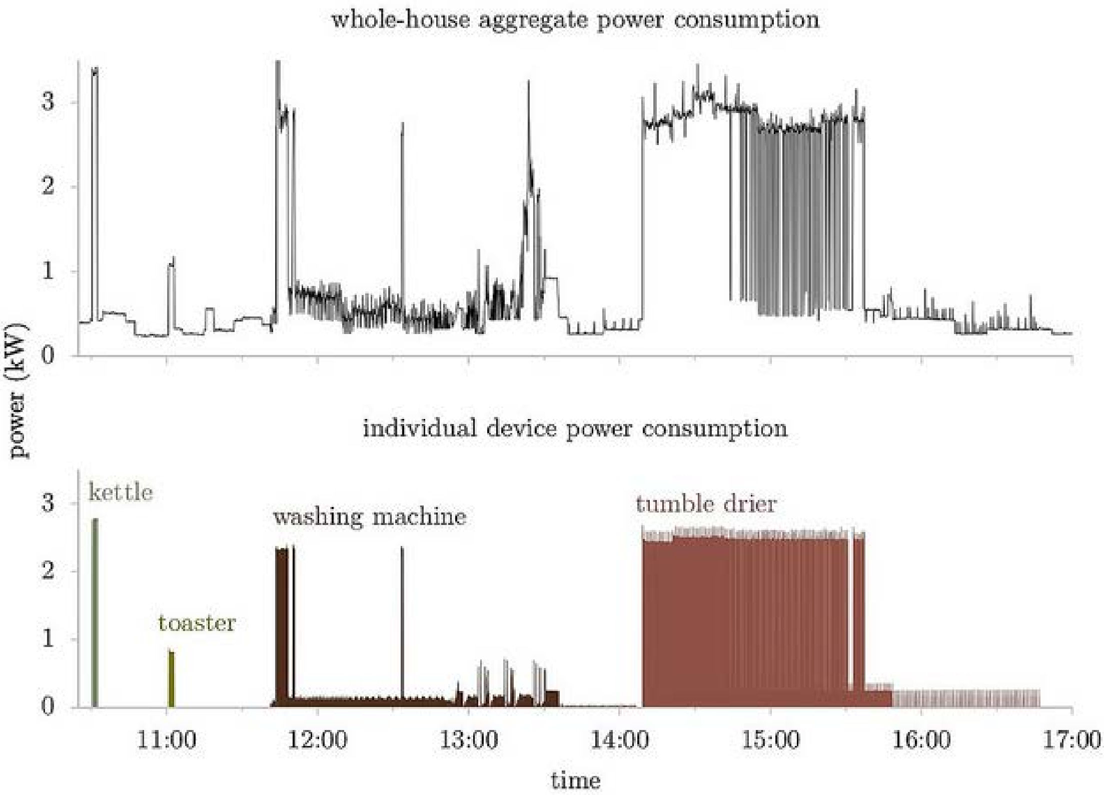

Fig. 14. Power consumption

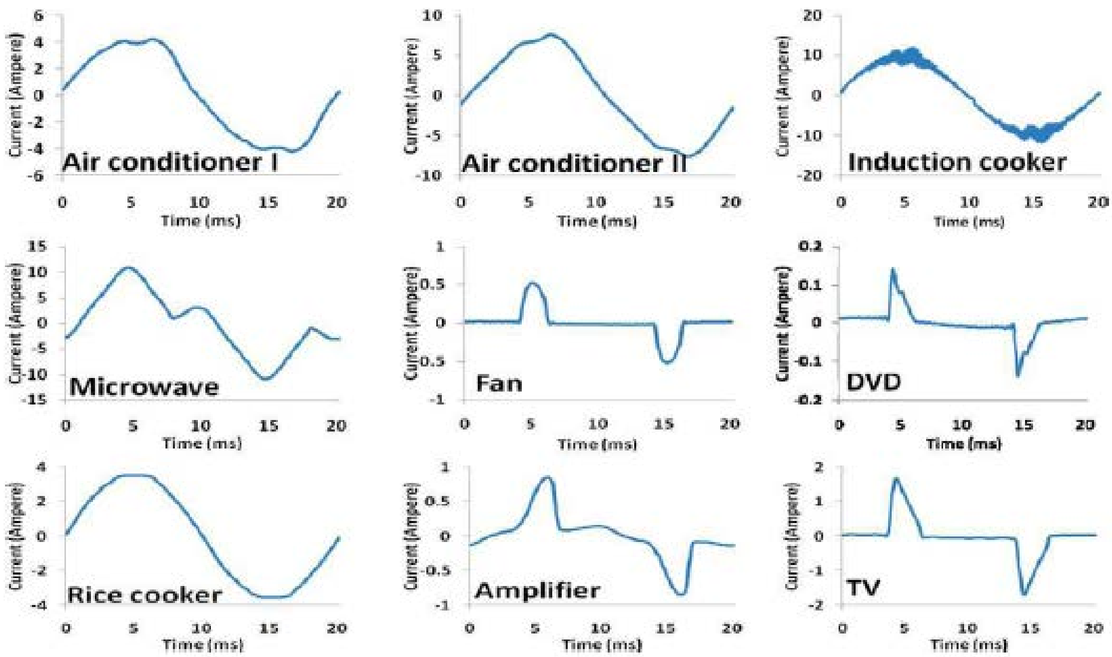

Fig. 15. Examples of different current signatures

4.5. Data acquisition module

The role of the data acquisition module is to acquire aggregated load measurement at an adequate rate so that distinctive load patterns can be identified. There is a wide variety of power meters designed to measure the aggregated load of the building that can be further classified as follows:

Low-Frequency Energy Meters: The sampling rate determines the type of information that can be extracted from the electrical signals. In order to capture the higher order harmonics of the electrical signals, which are integral multiples of fundamental frequency (*i.e.*50 / 60 Hz), the sampling rate of the energy meter must fulfill the Nyquist–Shannon sampling criteria. In addition, traditional power metrics such as real power, reactive power, Root Mean Square (RMS) voltage and current values can be computed at a low sampling rate (*i.e.*, 120 Hz).

High-Frequency Energy Meters: In order to capture the transient events or the electrical noise generated by the electrical signals, the waveforms must be sampled at a much higher frequency in a range of 10 to 100 MHz.

The typical NILM system makes use of whole-house data acquired from a single meter. However, one limitation of such an approach is that the identification of low-power and variable appliances in the presence of high-power loads from the whole-house data, which often becomes quite challenging. An alternative approach is to make use of the circuit-level power measurements, as it is often the case that high-power appliances receive a dedicated circuit within homes. The task of power decomposition becomes much easier as there are fewer devices on each circuit in contrast to the whole-house NILM, but at the expense of increased installation complexity and cost.

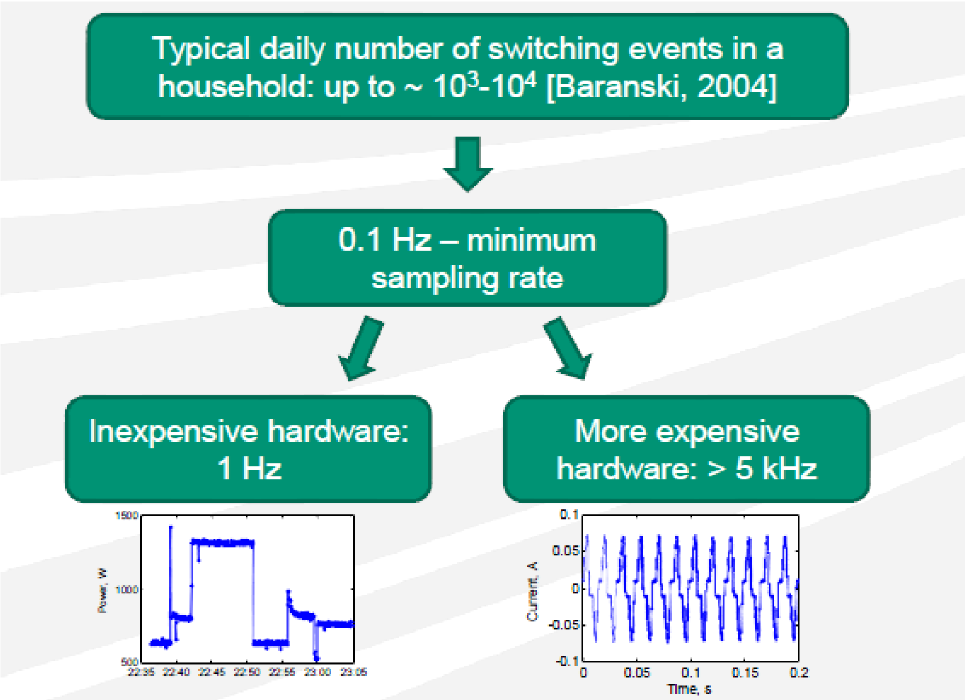

Fig. 16. Data for NILM sampling rate

4.6. Feature extraction

A non intrusive signature is one which can be measured by passively observing the normal operation of the load, e.g., a step change in the measured power. Within the non intrusive signatures there is a natural dichotomy according to whether information about the appliance state change is continuously present in the load as it operates (steady-state changes) or only briefly present during times of state transition (transient changes).

• Steady-state changes: Steady-state signatures are much easier to detect than transient signatures. The sampling rates and processing requirements necessary to detect a step change in power are far less demanding then those required to capture and analyze a transient current spike. Real power(P) and Reactive power(Q) are two of the most commonly used steady-state signatures in NILM for tracking ON/OFF operations of appliances. Steady-state signatures relate to more sustained changes in power characteristics when an appliance is turned ON/OFF, which can be captured with low – frequency sampling.

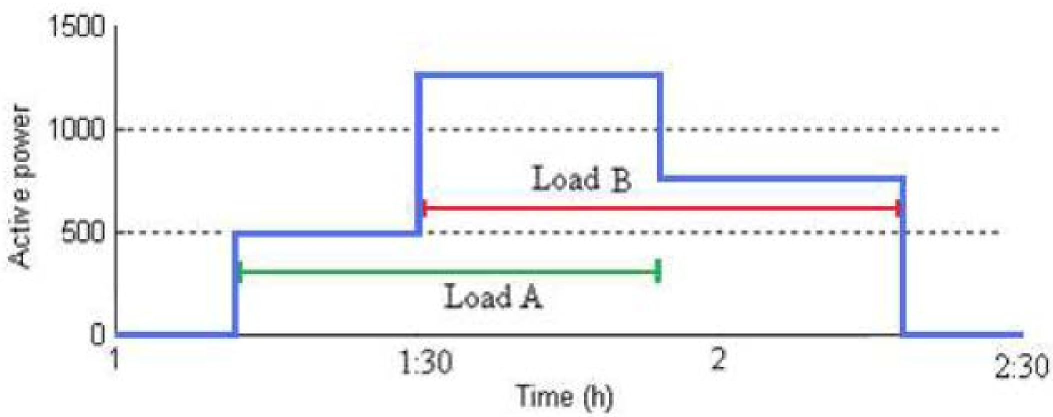

Fig. 17. Active power changes during appliances application

• Transient changes: The transient methods make use of transient signatures that uniquely define appliance state transitions by extracting features like shape, size, duration and harmonics of the transient waveforms. However, distinctive transient signatures can only be extracted if the sampling rate is higher than 1000 samples per second. Transient signatures are more difficult to detect and provide less information than steady-state signatures. However, they can provide useful information to augment that from steady-state signatures. For example, appliances having similar steady-state signatures may have very different transient turn-on currents. Analysis of the transient could provide the deciding information to determine which of the two actually is on in the total load.

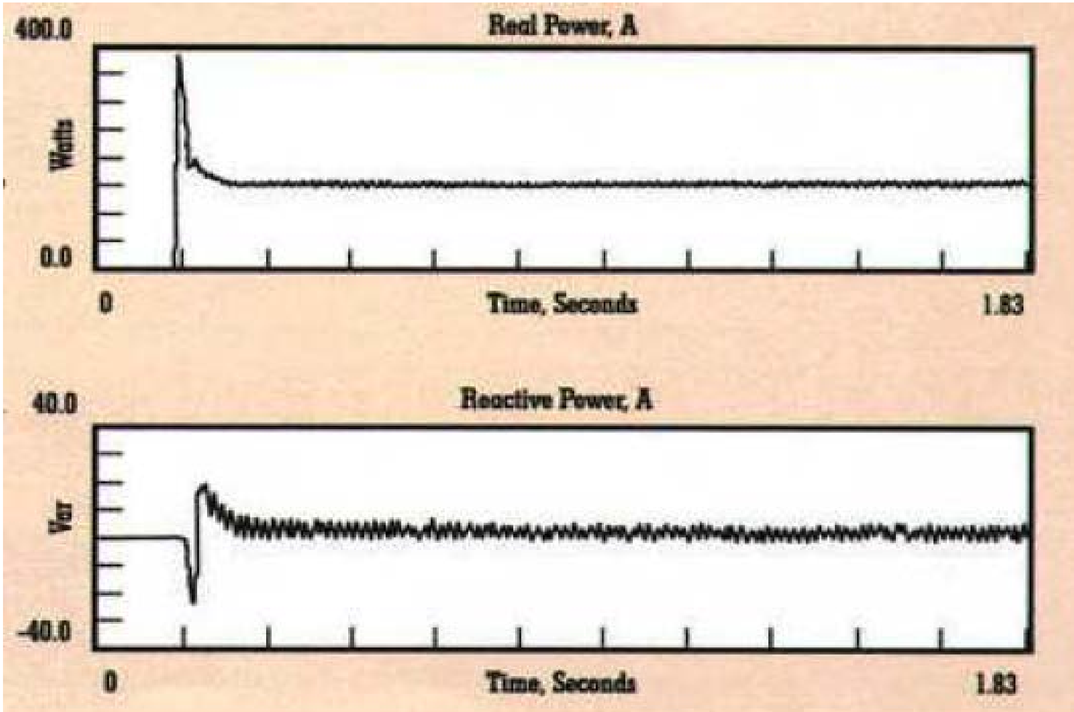

Fig. 18. Example of an instant-start fluorescent lamp bank transient

There has been a debate considering the use of either steady-state or transient based features extraction methods for load disaggregation as both of these approaches have their advantages and disadvantages.

Transient signatures are more difficult to detect than steady-state signatures as they measure a switching mode instead of a stabilized state. For this reason, transient analysis require a measurement device to a considerably higher sampling rate.
Bearing in mind the cost of the solution, the steady state methods seem to be a more feasible approach because it requires low-cost hardware. In additon, transient signatures provide less information than steady-state signatures because they are available for registration only the switch-on at the time.

However, as they provide different information, they might be useful to identify appliances that exhibit similar steady-state behaviour.

For this reason, load disaggregation algorithms can incorporate transient features to improve the segregation of appliances with overlapping steady-state features, but at the cost of expensive hardware.

Next, I presented in two tables, the steady-state and transient changes:

Table 1: Summary of steady-state methods:

Steady-State Methods	Features	Advantages	Shortcomings
Power Change	Steady State Variation of Real and Reactive Power, ΔP, ΔQ	High-Power Residential Loads can easily be identified, Low-sampling rate requirement,	Low power appliances overlap in P-Q plane, Poor performance in recognizing Type-II, III and Type-IV loads.
Time and Frequency Domain Characteristics of VI Waveforms	Higher order Steady-State Harmonics, Irms, Iavg,Ipeak, Vrms, Power factor	Device classes can easily be categorized into resistive, inductive and electronic loads	High sampling rate requirement, Low accuracy for Type-III loads, overlapping features for consumer electronics of Type-I and II category, unable to distinguish between overlapping activation events
V-I Trajectory	Shape features of V-I trajectory : asymmetry, looping direction, area, curvature of mean line, self-intersection, slope of middle, segment, area of segments and peak of middle segment	Detail taxonomy of electrical appliances can be formed due to distinctive V-I curves	Sensitive to multi-load operation scenario, computationally intensive, smaller loads have no distinct trajectory patterns
Steady-State Voltage Noise	EMI signatures	Motor-based appliances are easily distinguishable as they generate synchronous voltage noise, Detection of simultaneous activation events, Consumer appliances equipped with SMPS can be recognized with high accuracy	Sensitive to wiring architecture, EMI signatures overlap, Not all appliances are equipped with SMPS

Table 2: Summary of transient-state methods.

Transient Methods	Features	Advantages	Shortcomings
Transient Power	Repeatable transient power profile, spectral envelopes	Appliances with same power draw characteristics can be easily differentiated, Recognition of Type I,II,III loads	Continuous monitoring, high sampling rate requirement, not suitable for Type IV loads
Start-Up Current Transients	Current spikes, size, duration, shape of switching transients, transient response time	Works well for Type I and II loads, distinct transient behavior in multiple load operation scenario	Poor detection of simultaneous activation deactivation of sequences, unable to characterize Type III and IV loads, sensitive to wiring architecture, appliance specific
High Frequency Sampling of Voltage Noise	Noise FFT	Multi-state devices, consumer Electronics with SMPS	Appliance specific, computationally expensive, Data annotation is very hard

4.7. Learning and inference in NILM systems

The supervised disaggregation methods for NILM systems can broadly be divided into optimization or pattern recognition based algorithms. The supervised learning mechanism requires labeled data sets to train the classifier so it would be able to recognize appliance operations from the aggregated load measurement. However, system training requires setting up initial instrumentation, which incurs extra cost and human effort. Therefore, lately researchers are actively looking to devise completely unsupervised or semi-supervised methods that can reduce the effort of acquiring the training data.

4.7.1. Supervised learning approaches

The supervised disaggregation algorithms need adequate labeled data for learning the model parameters in order to perform the task of appliance recognition. This approach can be divided into:

a) Optimisation methods: Optimization based methods deal with the task of load disaggregation as an optimization problem. In the case of single load recognition, it compares the extracted feature vector of an unknown load to that of known loads present in the pool of the appliance database and tries to minimize the error between them to find the closest possible match.

b) Pattern reconigtion methods: Pattern matching approaches are the ones most frequently used by the researchers for load disaggregation. The appliance database contains multiple appliance specific features that are used to define the structure and parameters of the recognition algorithm.

4.7.2. Unsupervised learning approaches

Recently researchers have started to explore methods to achieve disaggregated energy sensing without *a-priori* information. It is highly desirable for the NILM systems to be installed in a target environment with a minimal setup cost as the training requirement for the supervised load identification algorithms is expensive and laborious. Hence, unsupervised learning approaches are needed for a wider applicability of NILM techniques.

4.8. Non Intrusive Load Shedding Verification (NILSV)

A significant AMI application is demand response, in which meters collect interval readings, transmit signals to appliances, and provide usage data to consumer portals to support power-use patterns that reduce electricity costs. One strategy gives indirect control to a consumer. The electricity service provider (ESP) assigns a price for electricity in a given time interval; the customer uses this information to make decisions about power use. In direct-control strategies, the ESP sends signals to consumer appliances to alter their use, typically by limiting use during peak demand periods. Each approach has advantages and disadvantages.

Demand response, a cornerstone of smart-grid technology, lets consumers participate directly in energy markets by limiting their energy use during periods of emergency or peak demand. In a direct-control strategy,ESP offers consumers discounts or other incentives if they agree to let the ESP send load-shed instructions (LSIs) to specified appliances.

Direct control can save consumers money and provide ESPs with valuable tools for controlling energy generation costs and grid stability. But these benefits depend on the LSIs producing the expected response from appliances. Load-shed verification (LSV) can improve reliability and eliminate freeloaders who accept incentives without implementing direct controls. However, this generates many trust challenges because the consumer owns and operates the appliance and because effective demand response depends on the integrity of the appliances' responses to LSIs.

To address these challenges, it has been implemented an algorithm based on a non intrusive load monitoring learning phase that runs during an initialization period at the ESP. The result is a distributed NILM algorithm—a non intrusive load-shed verification (NILSV) algorithm deployed on the residential meter.

Ideally, when residential consumers register an appliance for direct control, that appliance can receive LSIs but isn't required to provide confirmation of compliance. NILM conducted through the residential meter can confirm that the appliance has acted on the LSIs. For instance, suppose an ESP sends a household an LSI to turn off a 1000 W appliance. In a predefined time frame, the meter will respond with an LSV indicating the appliance's transition. The correct behavior is on to off or off to off. We call this NILSV. NILSV's key challenge is handling the large amounts of detailed data and complex calculations that aren't naively suited to typical residential meters' low bandwidth, computing, and sensor capabilities.

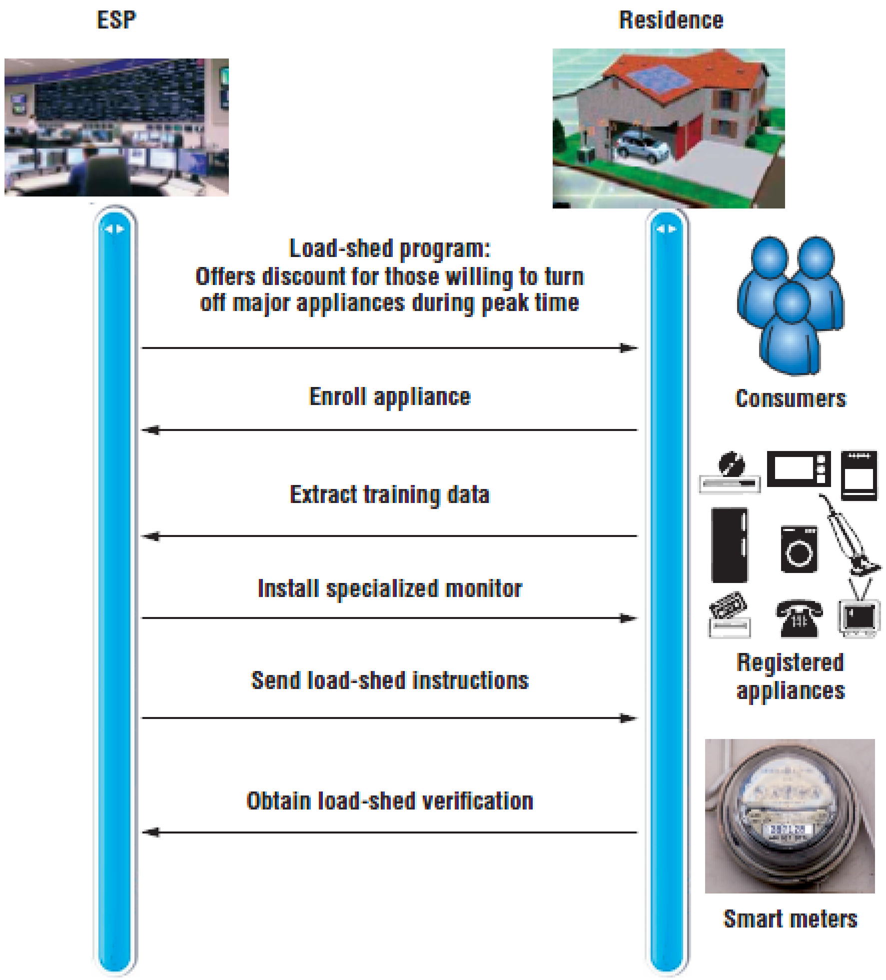

Fig. 19. The Non Intrusive Load-Shield Verification (NILSV) process

4.9. NILM: Advantages and disadvantages

Unlike ordinary monitoring systems which utilize multiple sensors or meters, NILM collects electrical data by sampling the power consumption at a single point. This means fewer components to install, mantain, and remove.

Besides, remote monitoring makes possible to access the data anytime and anywhere through Smartphone or PC. This represents a great advantage because of a reduction in cost and simplified installation.

Intrusive methods require a certain degree of equipment to do the installation and stored the data. Therefore, they are not the same attractive solution than non-intrusive systems. However, in situations where non-intrusive techniques do not provide enough information, intrusive techniques are necessary. This means that NILM also presents some cons.

First of all, NILM systems involve simple hardware but complex software due to the signal processing and analysis. In addition, a manual set-up is needed in order to name the devices and define the signatures.

Secondly, the system is not always able to detect every device.Sometimes, the noise from the recording equipment makes it impossible to identify low power consumption appliances.

Besides the mentioned disadvantages, NILM has privacy concerns as it provides private information. For example, it is possible to know whether a person is at home or not, and even more where exactly in the house that person is and what he or she is doing.

5. PLUGWISE

5.1. What is Plugwise?

There are two basic arragements for load/energy usage monitoring:

*Intrusive Monitoring

*Non Intrusive Monitoring

Non Intrusive Monitoring is the technique of taking a whole-home energy signal and separating it into its component appliances. Studies have shown that having device level energy information can cause users to conserve significant amounts of energy, but current electricity meters only report whole-home data. Thus, developing algorithmic methods for disaggregation presents a key technical challenge in the effort to maximize energy conservation. This is the role that develops the Plugwise technology.

Plugwise is a system which enables the electricity usage of individual appliances to be monitored in real time wirelessly.

Plugwise helps individuals and organizations achieve rapid gains in their commitment to sustainable business operations. Plugwise reserves since 2006 engaged in the design, development and production of wireless energy management and control systems. This gives individuals and organizations accurately understand their energy use and can save between 10 and 40 percent on energy bills.

Plugwise is a rapidly growing international company with fully automated production in Eindhoven and offices in Germany, the United Kingdom and the United States. These are controlled from the head office in Sassenheim. Additionally Plugwise both within the Netherlands and internationally through distributors in the various local markets.
In the Netherlands, Plugwise sells its products both directly to end users through a growing network of selected plant and distribution partners.

Plugwise has a clear philosophy: the greenest energy is the energy you do not use. This is the foundation of everything they do. And rightly so, because data from Plugwise business users shows that on average half of all electricity is used outside office hours. Moreover, 30 percent of the energy wasted. This intervention is the fastest and most cost effective way to increase energy footprint and thus reduce CO_2 to penetrate emissions.

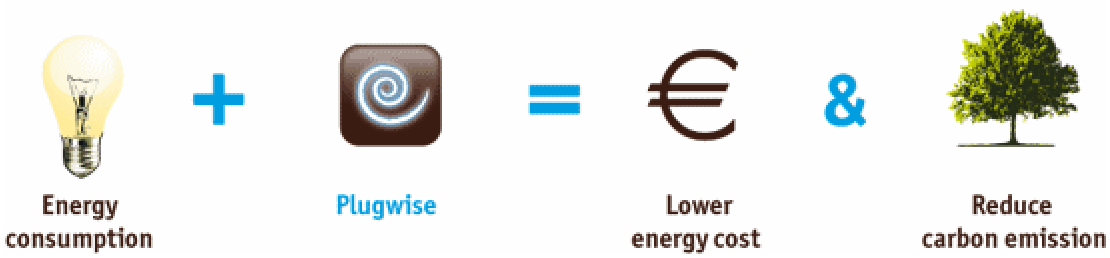

Fig. 20. Plugwise Formule

5.2. The benefits of Plugwise

One of the best ways to start reducing your energy usage is to track exactly how much electricity you use using a plug-in power meter or wireless energy monitor.When you can see exactly where electricity is being used, it's too much easier to understand how you can reduce your consumption.

Plugwise is primarily designed as an energy saving product. By being made aware of where electricity is used in the home and office, it's possible to identify ways to reduce consumption. Since Plugwise can be used to turn appliances on and off (as well as measuring their electricity consumption), it opens up the unique posibility of Peak Shavings, which reduces peak demand by automatically switching off certain (non – critical) appliances in homes and offices when demand for electricity is about to exceed supply. Consumers who sign up to peak shavings programmes can expect reduced tariffs.

For those on electricity tariffs with different pricing at differents times of the day, the Plugwise Source software can be set up to schedule tasks to benefit from the lowest rates. This reduces the cost of electricity for the consumers, and again reduces peak demand for the utility company so that less new power stations will need to be built.

In the near future energy supply and demand will be even more closely linked, using the Smart Grids. Although such systems are still in their infancy, the Plugwise system has been designed to cooperate with intelligent meters and smart grids.

5.3. Products

Although in our Project we have only used the Home Basic Pack, Plugwise offers a wide range of products, which can be easily combined and thanks to the ZigBee MESH network it is possible to add, move or remove components; the network adapts automatically to any changes.

At the REFERENCES SECTION, I attach the link to the FULL PLUGWISE PRODUCT CATALOGE

6. EQUIPMENT USED

6.1. Plugwise Home Basic

The Plugwise network allows us to gain insight in our energy usage and to be in control of it. Although Plugwise offers a wide range of products, we purchased the Home Basic Pack, which is composed of 8 Circles, 1 Circle+, 1 Stick and 1 Source License:

6.1.1. Circle

The Circle is the basic element of the Plugwise system. It is easily placed between the power socket and the plug of an appliance. It measures the energy consumption of the connected appliance and is able to switch it on and off. The Circle can send the measured energy consumption data to the Plugwise software via wireless MESH network (ZigBee). The software will process the energy consumption of the connected appliance, resulting in clear overwievs and graphs.

6.1.2. Circle+:

The Circle+ has the same functionalities as the Circle, but also serves as the network coordinator. The Circle+ is equipped with a clock that is used to synchronize the time with the other Plugwise modules and our PC.

6.1.3. Stick:

The Stick is the connection between the Plugwise software, the installed plugs and other Plugwise products. The Stick receives data from and transmits commands to the installed Plugwise modules via wireless MESH network (ZigBee).

6.1.4. Source:

The Source is the Plugwise software for use in-home. The Source gives insight in energy usage of each device which is connected to a Circle. Energy usage becomes visible in graphs and concrete results (KwH and costs). Source allows to switch devices, rooms and groups or set up time-schedules, which ensure our devices will automatically be switched during certain time periods.

Fig. 21. Plugwise Home Basic

6.1.5. ZigBee

ZigBee is a wireles MESH network technology (like Wifi). Almost all Plugwise products run on ZigBee. The modules whitin a Plugwise network communicate with each other via ZigBee. The main properties of ZigBee are its great reliability and being highly secured against unauthorized access. Zigbee runs without it requiring any attention. When a Plugwise network has been installed, the modules will automatically find each other via ZigBee and send measurement data to the Plugwise software installed on our computer.

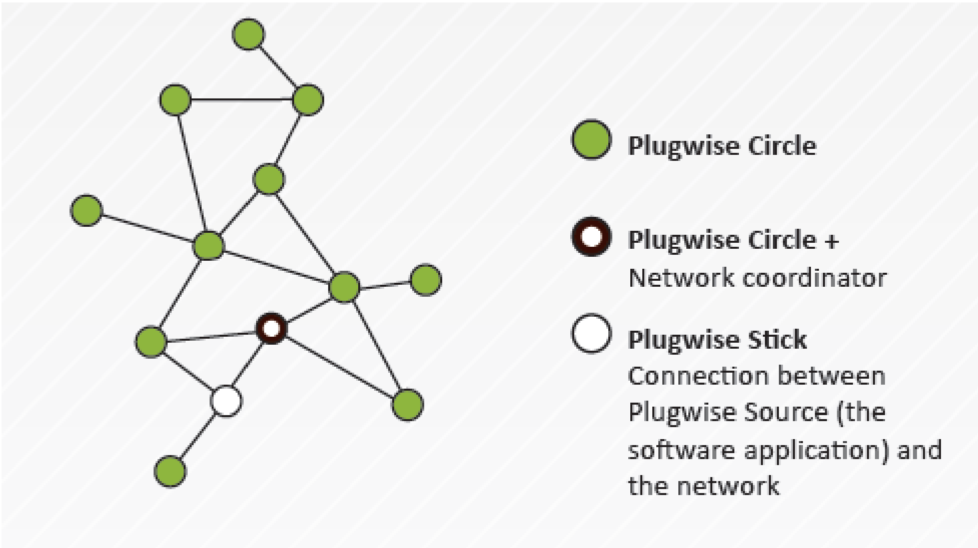

Fig. 22. ZigBee

This technology offers many advantages:

-The energy consumed by a Plugwise system is a mere fraction of the energy saved.

-Your energy consumption data is safe and privacy is guaranteed.

-The network reorganices itself; new appliances are recognized and incorporated automatically.

-Future-proof and easily extendable with other Plugwise modules.

-Each element has its own unique code and is therefore identifiable.

6.2. Kamstrup Smart Meter

6.2.1. Overview

The new generation of electric meters from Kamstrup have energy saving at a higher level. With a consumption of just 0.6 W a Kamstrup electricity meter is a true low-power device. It not only incorporates all the functions of a smart meter, but it also provides a considerable reduction in the power consumption of a park of meters.
This really ecological difference translates into significant economic savings throughout the useful life of equipment, at the same time fulfilling the basic requirements of energy saving.

Any unauthorized attempt to access a Kamstrup meter can be found at the instant. Intelligent disconnection allows cutting of supply according to a pre-set limit and when is integrated into a network AMR / AMM the meter can be used for functions of prepayment. All these features improve and streamline services to customer and protect their income.

Flexibility and easy integration are key factors to exploit all the potential of communication technologies. Kamstrup meters incorporate mass readings DLMS / COSEM Protocol as interface for the integration of systems. This ensures an interface standardized between the meter and any AMM system incorporating this open standard.

The model of Smart Meter we use for research is the Kamstrup 382 JxC. This is a Smart Meter designed in Denmark and is allready installed in many buildings in Netherlands.

The Kamstrup 382J is a directly connected Smart Meter for measurement of electricity energy. This Smart Meter uses the Shunt measurement principle, that gives a good linear and dynamic range of measuring.

With the readable display we can scroll automatically between readings. Next to the data that we are able to read of the display, there is an optical port and module area where it is possible to place an optical meter reader and several modules to program the Smart Meter.

Kamstrup 382 presents characteristics highly appropriate for use in NILM. The counter can be configured from the factory to measure both energy imported (consumption) as energy exported (production). The counter provides curve record in load into four quadrants.
This feature allows an analysis detailed of the energy consumed and produced. It has three build-in independent galvanically isolated measure systems. Each one of the galvanically isolated systems measures L1, L2 or L3 phases. The measures are being stored in RAM memory.

In addition, it provides measures of active power, reactive power, accumulated power, time and date of these consumption peaks, which facilitates the work of NILM.

As a problem, it presents that you have a low sampling rate, which means that it can not work with transient changes and only has the first harmonic waves analyzed.

6.2.2. Construction

The meter is designed as a three-piece plastic construction, consisting of a housing, verification and top covers, all parts made of fire resistant plastic. The verification cover protects the metrological functions. It is not possible to open the meter without breaking the metrological seal.

Fig. 23. Kamstrup Electricity Meter

7. HOW TO CONFIGURE IT / HOW IT WORKS

7.1. Home Basic

Each Circle must be plugged in between a devide and the socket. The Circle+ is the first Circle to be plugged in, as this is the coordinator of all the Circles. Each Circle measures the energy usage of a plugged in device.

After installing the software program Source, we have a real time insight our energy usage. The Stick creates the link between the ZigBee network and Source just plugging it into the USB gate of our computer. Then, the Stick automatically sends measurement data of our plugged in devices to Source, which provides detailed and historical information about energy usage per device.

Now we know exactly which devices are using energy when not necessary. The next step is to reduce energy usage by switching these devices off. In Source, we can set up time schedules to prevent energy waste. For example, turn grops of appliances off during the night.

7.2. Kamstrup 382

7.2.1. Start-Up the meter

In the first five seconds after being connected the power, the meter will show two differents numbers,

First, a 8 digits number which describes the software versión.

In the next five seconds, the 4 or 5 digits number which appears, indicates the ROM checksum number.

7.2.2. Registers

Kamstrup's direct meters are constructed as 4-quadrant meters, which provides safe registration of various measured data such as imported and exported energy both active and reactive energy, tariffed energy, power, voltage and current.

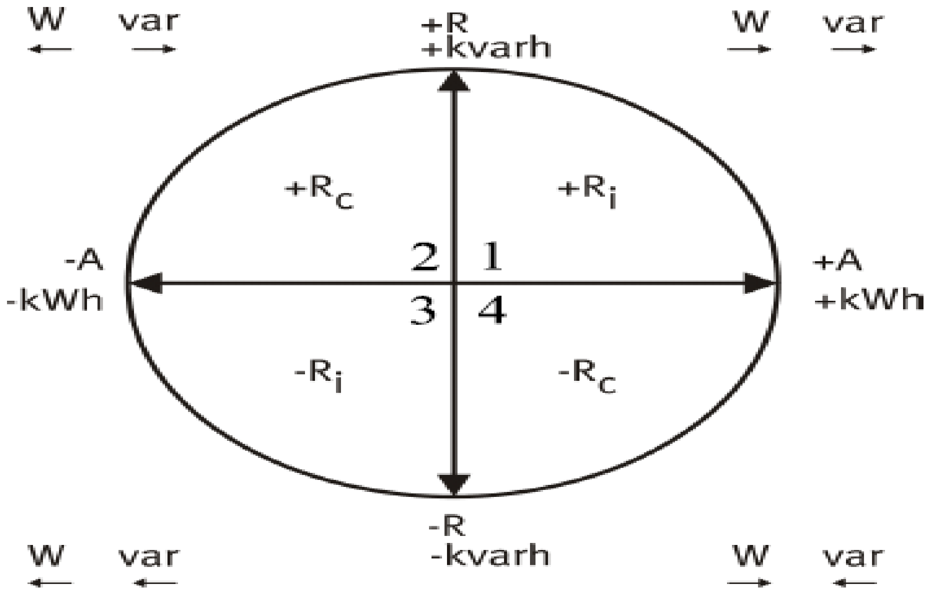

Fig. 24. Measurement in 4 quadrants

Every time you take a measurement, the meter indicates in which quadrant is working.

7.2.3. Display

The display makes it possible to read out the meter's registers. Which register depends on the current configuration. The required configuration can be preprogrammed from the factory or configured by means of the METERTOOL.

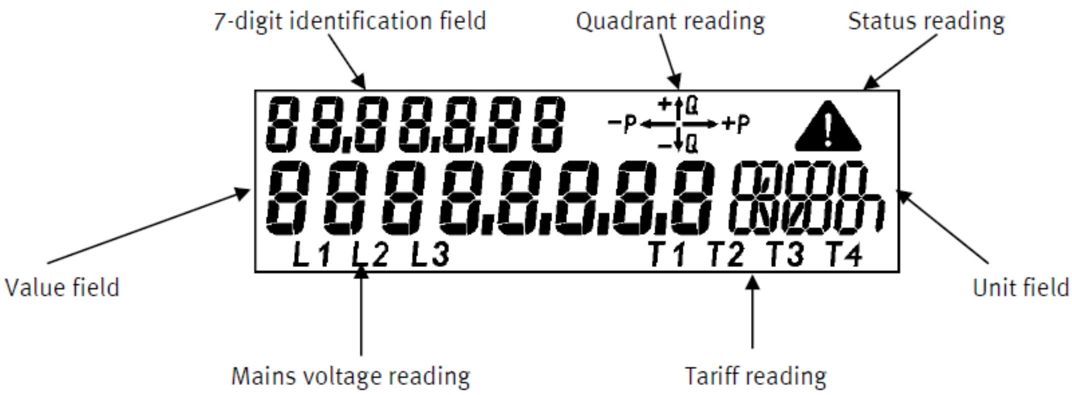

Fig. 25. Meter Display

7.2.4. Loggers

The meter has several different loggers for registration of data and events and a load profile logger, and in meters of generation K and later also an analysis logger. The load profile and analysis loggers share the same logging depth, which means that the depth of the analysis logger depends on the logging depth of the load profile logger and thus the configuration of the meter.

It is possible to configure the loggers and check their results throught the METERTOOL.

7.2.5. Energy measurement (Shunt measure method)

The power that we want to measure is led through a 'shunt' resistor, which is in serie with the power grid.

A shunt is a special type resistor whose resistor value is precisely yet. The shunt is capable of handling currents up to 63 amperes, which is much than practically ever occurs. The shunt replaces the "current transformers" from the former Ferraris meters and makes the measures much more accurate. The voltage over the shunt is directly proportional with the measured currents.

This is the most common method of current measurement, the internal shunt resistor of the Kamstrup is inserted into the circuit and using ohm's law it's possible to calculate the current based on the known resistance value and measured voltage value.

Using shunt as measuring principle for the current measurement where a resistance stable metal provokes a given drop of voltage at a given current, makes the energy measurement secure and reliable.

To summarize the measuring principle:

-Current: Single phased current measurement by current shunt.

-Voltage: Single phased voltage measurement by voltage divider.

Like voltage drop, energy consumption is calculated as an expression of the current compared to the phase voltage and time.

7.2.6. Permanent memory

Measured and calculated data is safely stored in the memory (EEprom). Data is stored by every change in energy register values.

Furthermore the values are stored at THE END of a debiting period.

Measured and claculated data can be read out using the Kamstrup KWh meter tool METERTOOL.

7.2.7. Power calculation method

There are different methods for the calculation of the registered total power in 3-phase meters. Our meter uses the next method:

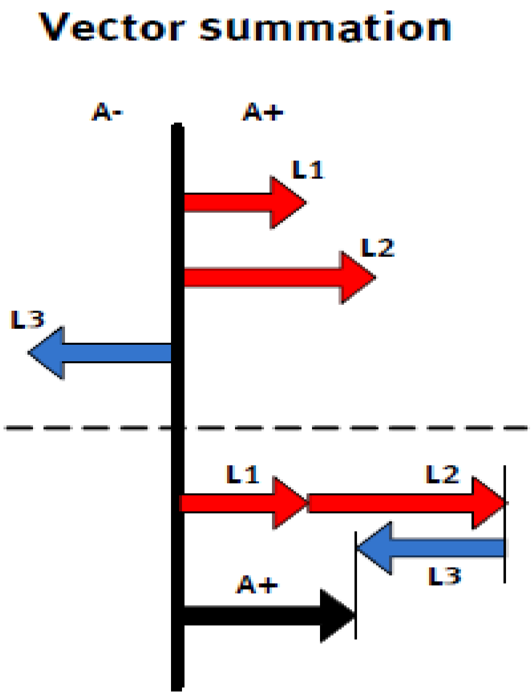

Fig. 26. Vector summation

The first one measures the incoming on L1 and L2 and adds them together. Meanwhile it measures L3 and substracts L3 from sum L1 and L2. This is also named Ferraris method and is based upon the old meters.

This calculation method is sensitive to incorrect installation and manipulation, especially if the meter does not have return flow lock.

7.2.8. METERTOOL

METERTOOL FOR Kamstrup kWh meter is a tool intented for techniciens and laboratorios to change configuration of meters. It can be also used as backup in communication networks to read out data.

It’s essential to have METERTOOL in order to set the meter up and get access to their lectures of measurements.

In the CD enclosed with this report, I attached the manual of METERTOOL, as well as the software to install it on PC's.

In order to connect the Smart Meter to the PC, a special extra module is needed.

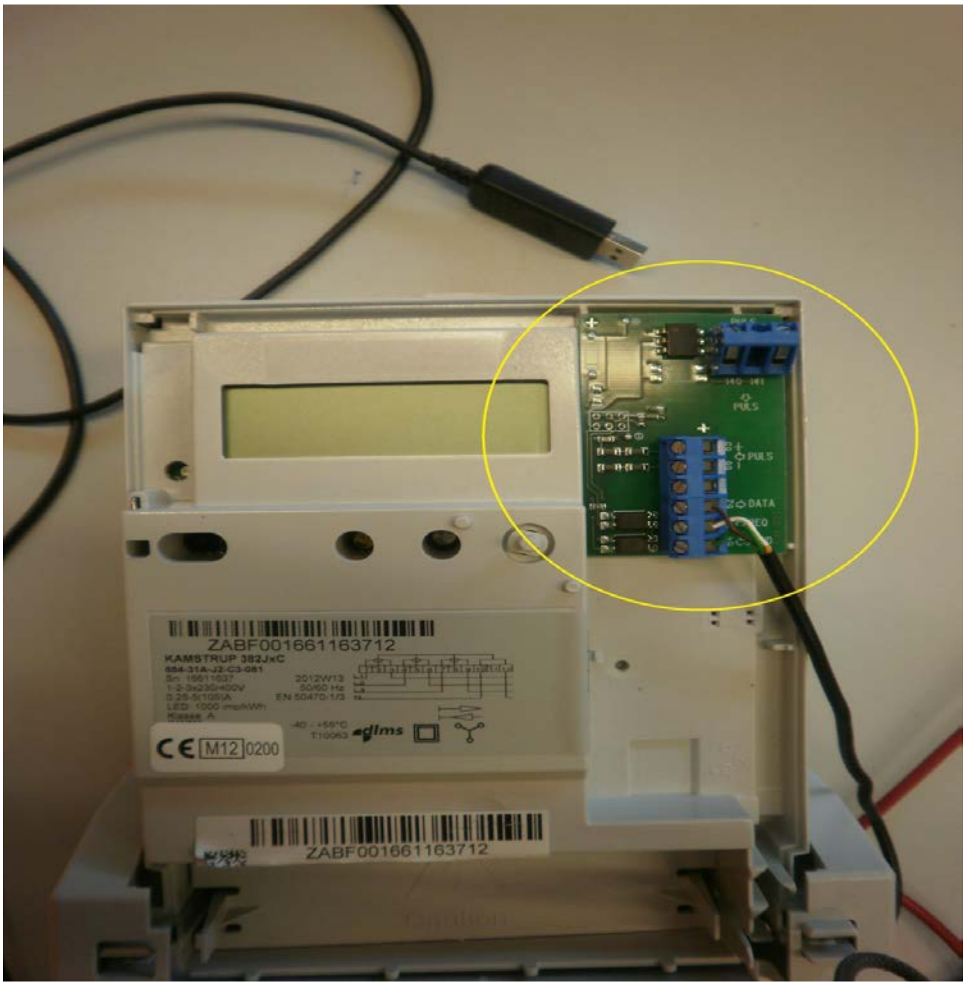

Fig. 27. Kamstrup - PC connection

7.2.9. Installation

The valid connection diagram appears from the type label on the front of the meter. In our case, Kamstrup 382J the connection is the following:

3 phases, 4 wires:

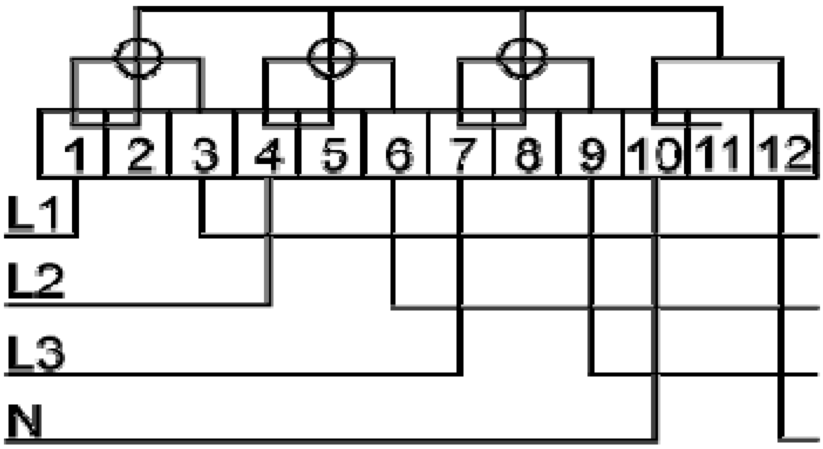

Fig. 28. 3P - 4W connection

This is the general connection when we use the Kamstrup 382J but in this case we only have used a monophasic load, therefore the connection has been just:

1 phase, 2 wires:

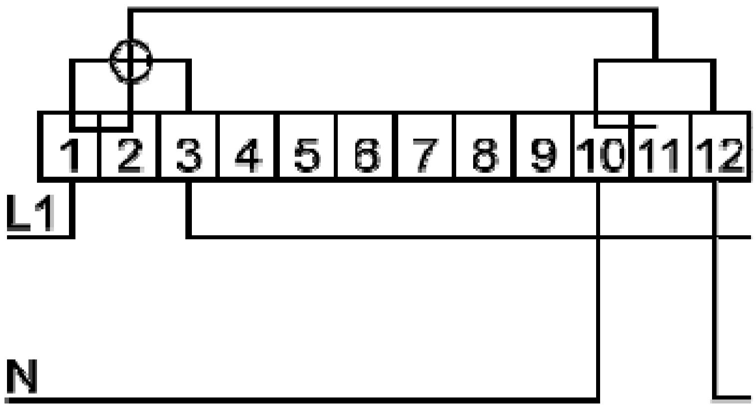

Fig. 29. 1P - 2W connection

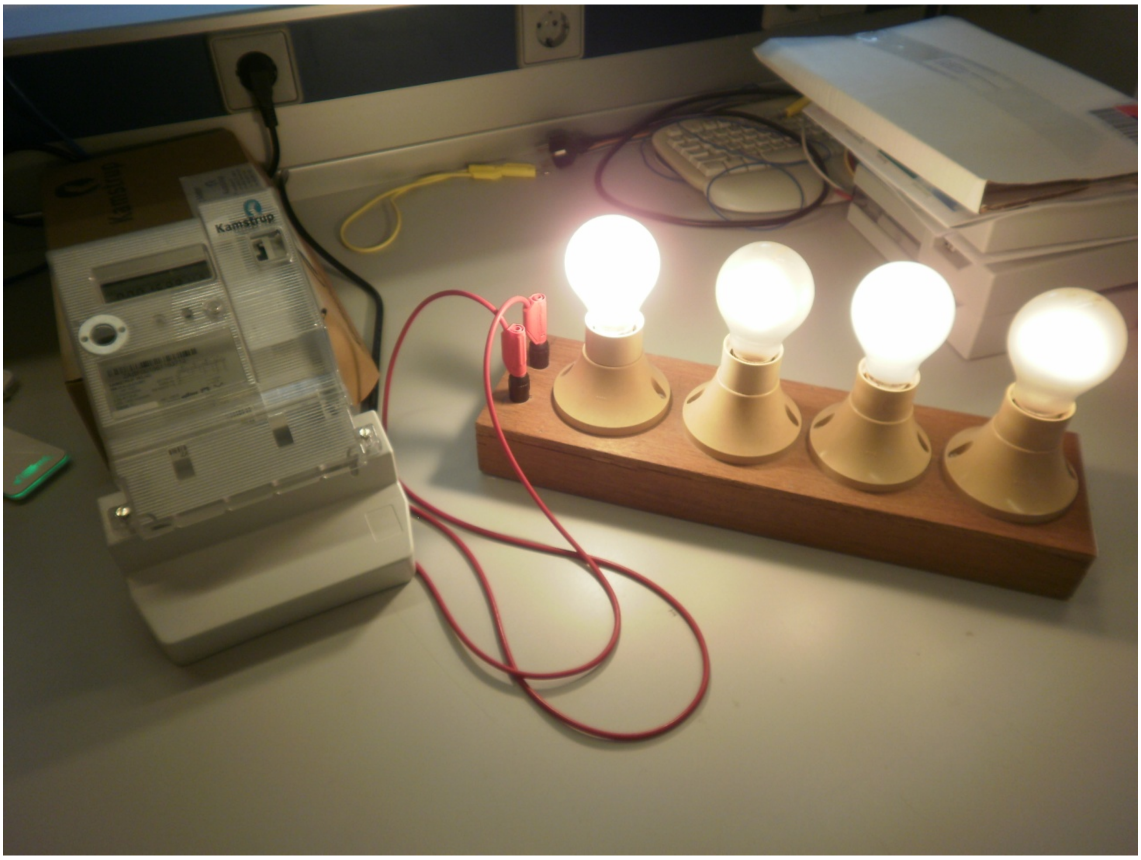

Fig. 30. Kamstrup - Bulbs connection

For more information and details, the Kamstrup Configuration manual is attached in the CD.

8. FINAL RESULTS

8.1. Home Basic

I succesfully installed the Plugwise Home Basic in my own home and I measured and monitorized my consumption during almost 2 weeks. Exactly, the Plugwise system was installed since 27/04/13 untill 06/05/13. In this time, I was aware about the consumption at home and I made schedules to automatically swith ON/OFF some devices.

The appliances in which I installed the system were: TV, Laptop, Fridge, Microwave, Lamp, Adapter (In which they were connected speakers, router and video games console) and Printer.

Next, I show the characteristics of some appliances, as well as graphics on the daily measured consumption during the studied period.

a) Samsung CW683CNG 28" TV: 230V, 50Hz, 100W

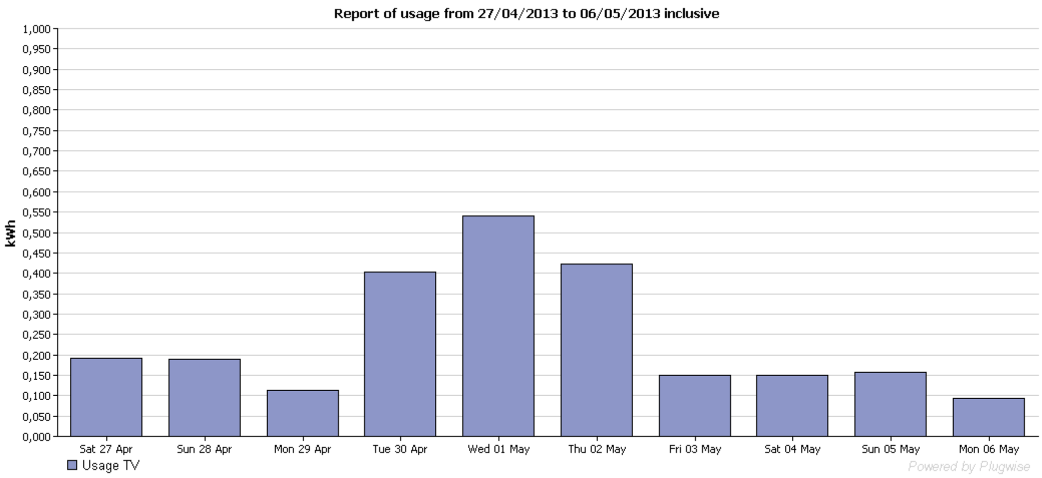

Fig. 31. TV report usage

b) Samsung NP-R580-JS07ES Laptop: 19V, 3.16A, 60W

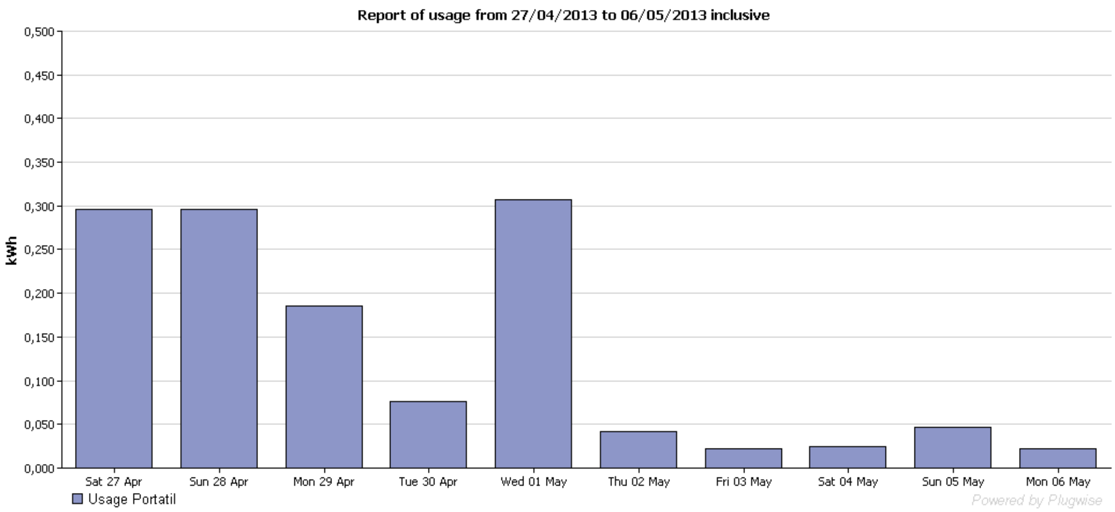

Fig. 32. Laptop report usage

c) Miele K328S Fridge: 220V, 50Hz, 120W

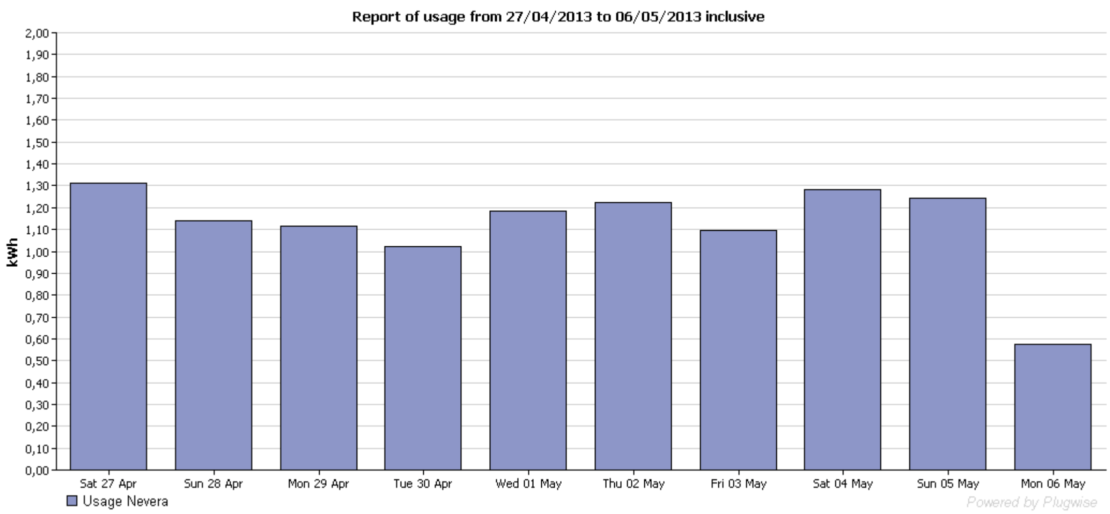

Fig. 33. Fridge report usage

d) Lifetec combimagnetron 4in1 microwave: 230V, 50Hz, 1450W

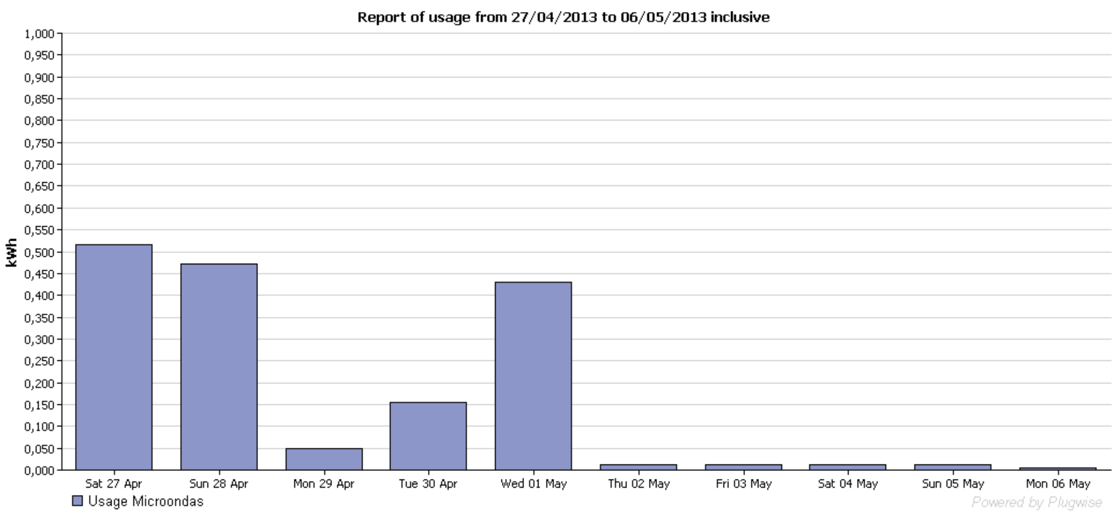

Fig. 34. Microwave report usage

e) Freelight J-Type Lamp: 230V, 50 Hz, 300W

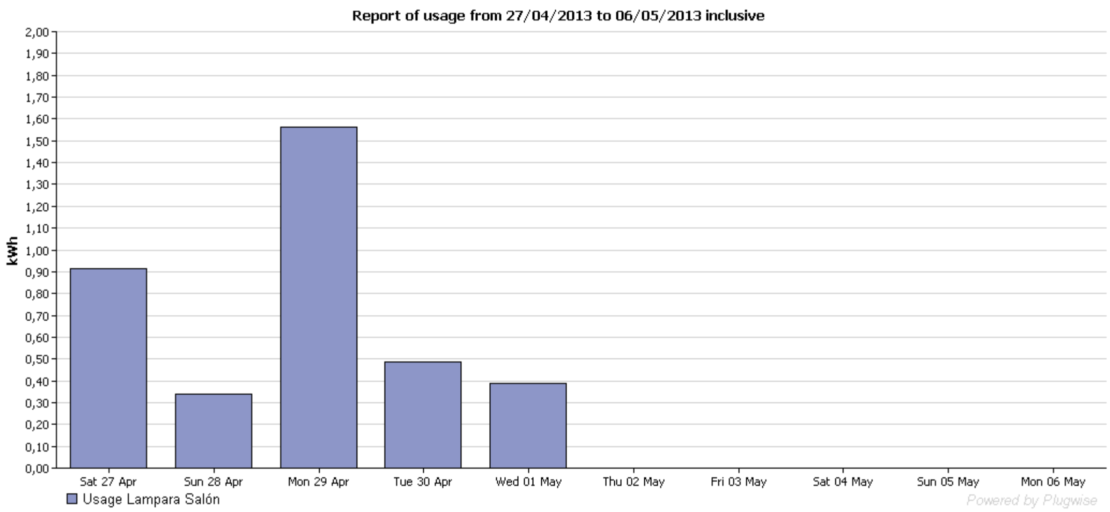

Fig. 35. Lamp report usage

In the back-up of the report usage attached in the CD, you will see the exactly consumption per appliance, room or group. Also you will see the consumption per hour, day or week. Likewise, the Plugwise Source offers you the estimated savings when you set a schedule in order to switch appliances off. For example, during the time I took control about the consumption, I made an schedule to automatically turn off some of the appliaces from 2 A.M. untill 7 A.M. every day. According to the Plugwise Source, if I used this schedule one year, I would save 131.69 KwH or 26.34 €.

8.2. Kamstrup 382

For our test, we have used as load a 4 bulbs pack with parallel connection. Because a linear (resistive) load is connected, there is no reactive power expected, which means that we only have measured active power, A+.

Establising a 1 phase, 2 wires connection and using the METERTOOL software, we have been able to check all the measures undertaken by the meter, as well as set up the the display functions.

The basic measures we have made are:

-Active energy A+: 1.547 kWh

-Actual Power P+: 0.109 kWh

-Active max power P+max: 0.112 kWh

-Date activate max power P+: 13/06/12

-Average power P+: 0.048 kWh

-Voltage L1: 225 V

-Current L1: 0.48 A

-Hour counter: 31 h

-Clock: 14:18

-Date: 25/06/13

-Meter Number 1: 16611637

-Internal number: 126068678

-Software revisión: 55020801

Depending on the connected load, the number of phases and user preferences, there are available many other configurable measures through METERTOOL.

9. CONCLUSIONS

During this research I have analyzed the whole issue about Smart Grids, Smart Meters and Non Intrusive Load Monitoring and obtained a high level overview of their current situation. Based on my research a few conclusions can be drawn:

We live in a world increasingly more populated and polluted where the demand of energy will increase between 2010 and 2050 in all the regions. Therefore it is necessary to follow a trend toward a way of life which is more focused on saving energy and caring of the environment. According to the investigations, the Smart Grids deployment could reduce the energy demand by 13% - 24% over this time frame.

In addition, the need for a new model of energy in which all members are connected that is, more and more necessary due to the rapid digitization of the society. And this can be achieved with the Smart Meters, for which the companies will give us the chance to save energy and to care of the environment.

At first the idea seemed good to everybody, but after reading and researching the subject, I discovered that there is many opposition regarding the implementation of these measurement systems.

Besides the alleged problems of invasion to privacy and possible damage caused by electromagnetic waves, is the issue which, in my opinion, removes more credibility to the intention of the companies to implement these new models: The business of electricity companies is to sell energy and there is a direct relationship between the energy they sell and their benefits. In this way, it is difficult that a company decides to promote the reduction of the consumption of its customers.

It's the same situation with regard to the NILM. It is a very useful technique which can estimate the number and nature of the individual loads, their energy consumption and time-day variables what makes possible to use it for monitoring people's activities and know when, where and how we consume our electricity. The results of this study reveal that it is possible to achieve the goals set by a simple graphical analysis.

This is what I did using the Plugwise technology. The Home Basic is easy to install and use for everybody. Great knowledge of electronics or computing is not required. Besides, one of the indirect benefits of the use of Plugwise, is that it can make the people realize about how much energy we waste and the necessity of avoid this waste.

However, we faced the same problem of invasion of the privacy of the users.

In summary, I think Smart Grids is an interesting topic, yet to be developed, in which it is worth to further investigate if it respects the privacy of users.

The future of NILM also seems to be promising because of the deregulated energy market's need for better customer measurements is growing and more meters with non-intrusive abilities will apparently come on the market in the future.

10. REFERENCES

Below are those documents that have been consulted or that are referred to throughout this report

-Security analysis of Dutch smart metereing systems. Sander Keemink and Bart Roos. Univeseteit van Amsterdam.

-Smart Grids y la evolución de la red eléctrica. Observatorio Industrial del sector de la electrónica, tecnologías de la información y telecomunicaciones.

-Smart Grids: Smart Meter and Non Intrusive Load Monitoring. Joost P. Rey. HSDE/NHL.

-Smart meter applications, benefits and issues. Joost P. Rey. HSDE/NHL.

-The Smart Meter: Integrating sustainable techniques into applied sciences. Jasper Westra, Sikke de Jong, Benjamin Feenstra. NHL Hogeschool.

-Reducing energy costs with peak shaving in industrial environments. Philip Yeung. Asia Pacific Business Development Power Monitoring & Control.

-Non Intrusive Appliance Load Monitoring (NIALM): Review and Outlook. Michael Zeifman, Kurt Roth. Fraunhofer Center for Suitainable Energy Systems.

-Non Intrusive Load-Shed Verification. David Bergman, Dong Jin, Joshua Juen, Naoki Tanaka and Carl Gunter. University of Illinois at Urbana-Champaign.

-European Smart Metering Landscape Report. Stephan Renner, Mihaela Albu, Henk van Elburg, Christoph Heinemann, Artur Lazicki, Lauri Penttinen, Francisco Puente and Hanne Saele.

-Kamstrup 162/382 Technical Description. Kamstrup.

-The Smart Grid in 2010: Market segments, applications and industry players. David J. Leeds. GTM Research.

-Plugwise Catalogue Products. Plugwise.

11. INTERESTING WEB PAGES

*Plugwise Web Site. http://www.plugwise.com/nl/idplugtype-f/

*Kamstrup Web Site. http://kamstrup.nl/

*Non Intrusive Appliance Monitoring. http://www.georgehart.com/research/nalm.html

*Plugwise Unleashed. http://www.maartendamen.com/wp-content/uploads/downloads/2010/08/Plugwise-unleashed-0.1.pdf

*Domotica Forum Europe: Plugwise. http://www.domoticaforum.eu/search.php

*How to configure a router to use DHCP. http://www.wikihow.com/Configure-a-Router-to-Use-DHCP

*Why Smart Meter might be a dumb idea. http://www.consumersdigest.com/special-reports/why-smart-meters-might-be-a-dumb-idea