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Smart Meters

Basic Elements in the Development of Smart Grids

Yago Martinez Parrondo

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Supervisor: Olav B Fosso, ELKRAFT

Norwegian University of Science and Technology
Department of Electric Power Engineering

Preface

This thesis was performed at the Norwegian University of Science and Technology in collaboration with Universidade de Vigo, Spain. It constitutes the last step in my studies as an Industrial Engineer, Department of Electrical Engineering.

The thesis has been supervised by Professor Olav Bjarte Fosso (NTNU), with Professor Fernando Manzanedo (Universidade de Vigo) as co-supervisor.

I would like to thank Olav Bjarte Fosso for giving me the opportunity of working in so interesting and important topic; for all the collaboration, motivation and wise advice during all these months. I would also like to thank Fernando Manzanedo for bringing me the chance to develop my thesis at NTNU, with all the good consequences and experiences that it entailed. I am very pleased with the entire job done and I hope that someone can find some interesting information among all these paragraphs.

Also my good friends and kjæresten min must appear in these acknowledgments, all the experienced moments along these years of study will be unforgettable. Friends from La Coruña, Vigo and Trondheim (the indivisible group of five), thanks!

And finally I want to thank my family, for all they had to endure from me, all their good tips and for their continued support. I am 100% sure that without them this would never have gone ahead. Gracias.

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Yago Martínez Parrondo

Abstract

In a world where technology is present in each of our days, the energy dependence on oil and the age of the current electrical system represent a great risk and threat to the development of everyday tasks.

The objective of this thesis is to investigate and represent the enormous opportunities that can be achieved by developing a new electric infrastructure. Through the installation of Smart Grid, greater security and reliability of supply can be reached, while reducing the emission of polluting gases.

Due to the wide range that smart grids cover, this thesis focuses on an essential element and pillar in its evolution, the Smart Meters. The reason for choosing this area is because it is the pillar element that builds the electrical network of the future; research and development is being supported by many international institutions, and companies are adopting this new model of meter.

In order to understand the basics of smart grids, it is important to perform a description and comparison of both the current and the next-gen electrical systems. Emphasizing the advantages and opportunities obtained by changing into the smart grids, it demonstrates the importance of moving towards a more modern measurement system.

A very important issue is to decide which should be the minimum features in Smart Meters, therefore this thesis analyzes the different exiting models and also proposes several suggestions for the future. With the implementation of the new electronic meters, a variety of assistive devices are required to accompany the new structure, in order to facilitate tasks to both users and suppliers.

Among the great amount of benefits offered by Smart Meters, we can find not only the improvement of the electric system's reliability, but also a wide range of possibilities for the client. The main purpose is to improve user's experience through comprehensive monitoring of their activity, and also the possibility of reducing energy

bills by planning the use of appliances. For companies represents a reduction of unnecessary costs and total state control of its network.

And finally, it was conducted a report of the current deployment situation of this new technology in various representative countries. Describing the settings and options chosen by each country, we can achieve a conclusion that unifies a standard solution by the choice of the best proposals. Although they all have a common backdrop, we can see that in each area, the specification selected vary according to the country's existing legislation. Italy requires a special mention for being the first country to step forward, make a great effort and investment to upgrade its electrical system.

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List of abbreviations

AMI	Advanced Meter Infrastructure
AMR	Automated Meter Reading
BPL	Broadband over Power Line
CEER	Council of European Energy Regulators
DG	Distributed Generation
DSO	Distribution System Operator
FAN	Field Area Network
GSM	Global System for Communications
HAN	Home Area Network
IP	Internet Protocol
JSON	JavaScript Object Notation
LAN	Local Area Network
LNS	L2TP Network Server
MDMS	Meter Data Management System
PLC	Power Line Communication
QoS	Quality of Service
RD&D	Research Development and Demonstration
RTO	Region Transmission Organization
RTP	Real Time Pricing
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCADA	Supervisory Control and Data Acquisition
SML	Smart Message Language
SMS	Short Message Service
ToU	Time of Use
TSO	Transmission System Operator
UI	User Interface
UPS	Uninterrupted Power System
WAN	Wide Area Network
WiMAX	Worldwide Interoperability for Microwave Acces

1 - Introduction

Since 600 BC when electricity was just a concept mentioned by the Greek philosopher Thales of Miletus, after performing some experiments with amber rods, this physical phenomenon has evolved in a huge way during thousands of years.

The consequences of the great curiosity felt by many scientists around this field throughout history have meant in many inventions that have changed our lifestyles. No one can imagine a common day without access to basic resources like computers or Internet, elevators or mobiles phones; and all these services are now available thanks to the effort and research of many geniuses until our times.

When in 1752 Benjamin Franklin was taking his kite-flying experiments in Scotland, he accidentally discovered that lightning is electricity. It is supposed to be the first man that used the term electricity as something physically demonstrable and called the terms positive and negative charge. The Italian physicists Alessandro Volta also accidentally discovered an essential concept called voltage, and in his honor it is known the measure of battery power in volts. Thanks to his studies about contact potential he could build the first electric cell that produced a reliable, steady current of electricity. By connecting several of these cells together, a small battery was able to string a current.

Due to this discover, the German high school teacher Georg Ohm started his research in electrochemical cells and determined the direct proportionality between potential difference applied in a conductor and the electric current resultant, this relationship is called as Ohm's law and now it is the starting point for all students to introduce themselves in the basic circuits' area.

Some years later, one of the most relevant discoveries in the history of electricity was being developed by the Englishman Michael Faraday, the electromagnetic induction. He devised a mill in which a wire with current could turn around a magnet, so it was transforming electricity in movement, known as the first basic engine. Also a primary electrical device as the transformer was managed by him by performing experiments on induction between coils of wire, creating the first toroidal closed-core transformer. Many of the questions of Faraday were solved hundreds of years later and because of him the dynamo was manufactured. In his honor the unit of capacitance is named the farad.

The Scottish mathematician James Maxwell is one of the most relevant investigators related with the electrical field. His systematic investigations about the relations founded by Faraday between light, magnetism and electricity took him to made four mathematical expressions describing all the behavior of electricity and magnetism. Many theoretical developments that we use at the current moment to try to explain and understand are solved thanks to these well-known equations. A maxwell is the electromagnetic unit of magnetic flux, named in his honor.

In this globalized world of continuous technology advances and unceasing communication, we think that something so rudimentary like lighting our houses or streets seems something from the middle ages, but what an irony, until 1879 when Thomas Edison built the first original carbon-filament bulb, this basic service was not as extended as we can imagine. The need of lighting dark places in an affordable way took the American inventor to try to find a way quitting off the burnt-fuel lamps for another based in electricity. A new era was coming; the industrialization was arriving to our lives.

Many others remarkable scientists and researchers have been involved in this continuous evolution and development of this way of energy, achieving great benefits to the society and collaborating in the development of the industrialization. The next challenge was developing an electrical system that could provide electricity wherever they need it, and in the exact moment they demand it. It’s no sense keeping investigating in how to create new and better electronic devices if they don’t have access to power supply. The electricity system is in charge of this task, and it is currently based of five subsystems interconnected and coordinated in real time.

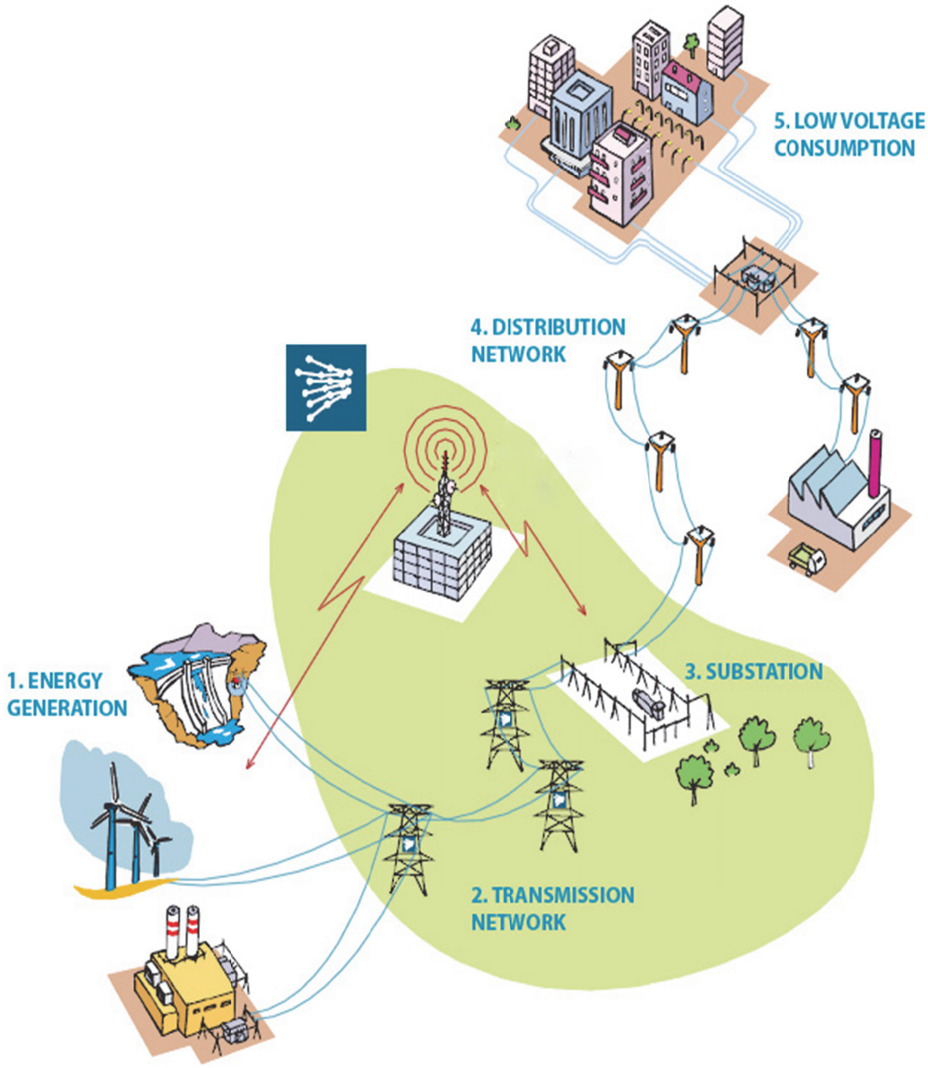


Figure 1: *The current electricity system [1]*

1- Energy Generation: electrical energy is generated in the central power plants. A simple way of explaining how a power plant works, it is by using a primary energy that makes a turbine rotate. At the same time it turns an alternator, an electromechanical device used to convert this mechanical energy onto electrical energy in the way of alternating current with sinusoidal shape and intermediate voltages.
2- Transmission: electricity is transported frequently far from its point of production, through a highly integrated system compound of high voltage

transmission lines, responsible of bringing together centrals with points of electrical energy use.

3- Substation: these plants are found near power plants and the periphery of various areas of consumption, linked together by the transport network. The substation equipment is formed by several accessories such as transformers, relays and circuit breakers.
4- Distribution: power distribution networks are located in urban and rural areas, and they can be aerial or underground. The distribution network consists of the HV and LV network.
5- Consumption: centers of power consumption, which can be either in low or high voltage.

This electrical system has been deployed many years ago, with the great expansion of the industrialized world, and since that, few innovations and technology advances have been incorporated. Only maintenance and conservation works have been taken. The current Electricity Networks in Europe are mostly based on technology that was developed more than 30 years ago. This model is so outdated, that we can ensure that if someone from the beginning of the electrical development comes to our time, that person would be able of perfectly recognize all the devices and structures we are still using. This is something totally unthinkable if we talk about other technologies as mobile phones or computers, which suffered a great evolution in the last years.

The need of an evolution and change seems to be obvious; there is no reason of why the system has not evolved while the rest of elements in the electrical and electronic field have suffered large and constantly changes. Also the present awareness on environment supports the idea of using a revolutionary technology; cleaner and more friendly with the world we are living on, that claims for greater use of renewable energies.

All these reasons lead us to the development and implementation of the smart grids, a new way of thinking and address the electrical system for the coming years. They support the monitoring and management of renewable energy systems through two-way communication and distributed generation. The aim is that smart grids accommodate more decentralized generation services. Fossil fuels are running out and the security of electricity supplies is under threat. The ageing of the infrastructure is threatening security, reliability and quality of supply. The solution may be possible with incorporating new generation technologies. Distributed generation can have a material impact on local grids, for example causing reversal of power flows and variations of local grid voltages. That is why it has to be improved the security and reliability among the infrastructure that runs all the way from generation to distribution, businesses and homes. All supply sources such as large-scale centrals of power generation, renewable energies and ancillary services; electrical systems and consumers must be able to interact with each other.

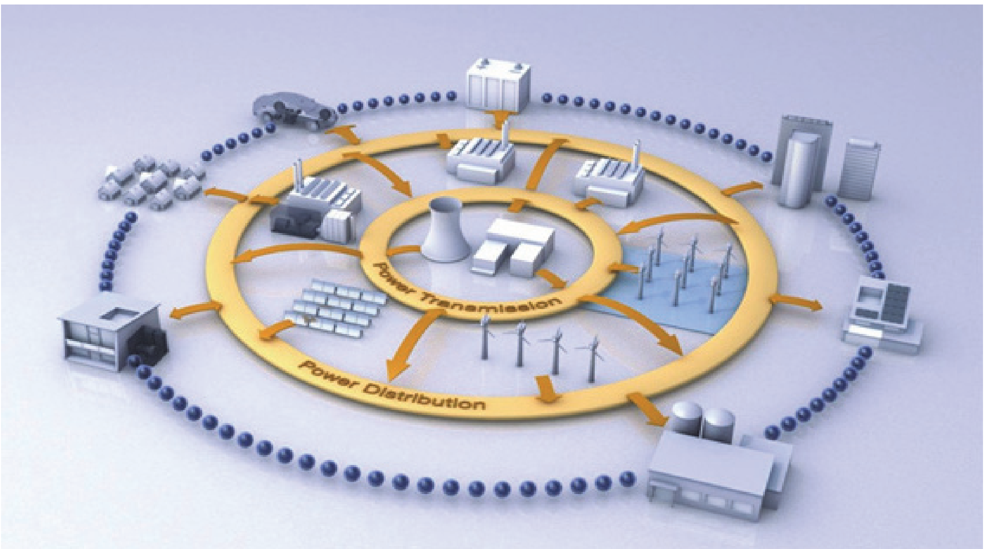


Figure 2: *Smart Grid structure [2]*

A smart meter provides highly detailed data about energy consumption that is useful to both energy providers and energy users.

Traditionally, the primary role of utility's metering device has been to accurately measure the consumption of electricity, gas, water and heat. Until now, this usage data has been manually collected by utilities. Consequently utilities have lack of information about the consumption of their customers. These problems limit the frequency and accuracy on consumers' bills, and also their ability to engage with them. The flow of information in this traditional system is only in one-way; there is no feedback loop. But the metering market is currently undergoing a considerable change, a smarter metering system is becoming available, and it is considered to be the future for utilities, providing significant benefits for both companies and customers. The smart meter is the fundamental building block of the smart grids.

The goals are bringing a more active role to customers and building a robust and inter-operable grid structure. Electricity markets will adopt the structure of an Internet-like model. Smart grids will also help to meet the EU's 20/20/20 climate change objectives. These ambitious targets for the year 2020 include:

- A reduction in EU greenhouse gas emissions of at least 20% below 1990 levels
- 20% of EU energy consumption to come from renewable resources (today 6,5%)
- A 20% reduction in primary energy use compared with projected levels, to be achieved by improving energy efficiency (saving 16% compared to 2006 levels)

This we be only able by using and developing a new way of electricity network, where losses will be miserable and renewable energies will be a real part of the generation system.

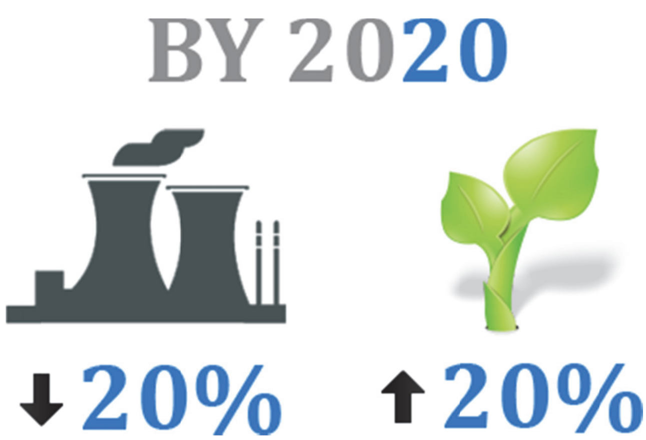


Figure 3: *The "20-20-20" targets of EU*

It is time to redesign the electricity grids; successful examples of new generation technologies are coming to us and they have to be integrated in the existing transmission and distribution networks. The actual system is completely out-of-date and cannot support the newest and renewable ways of producing electricity, at least in the scale that is required today, mainly because it was not initially designed for that purpose. Now, in this emerging clean-tech economy, it seems to be mandatory developing a newer infrastructure to take advantage of these green advances, which will contribute to reach the promoted ecological targets and contribute onto a healthier world.

2 - Definition

2.1 - Smart Grids

The smart grid is a new way of how energy is transmitted, distributed, planned and measured. It supports the monitoring and management of renewable energy systems through a two-way communication system and distributed generation. Efficient transmission and distribution of electricity is a fundamental requirement for providing citizens, societies and economies with essential energy resources. Electricity networks will be:

- Flexible: adapted to customer's needs while responding to changes
- Accessible: ensuring access to all consumers
- Reliable: improving security and quality of supply
- Economic: efficient energy management, competition and regulation

Smart grids networks will, in addition to electricity flows, establish a two-way information flow between suppliers and users. This will be a breakthrough compared with the current system, in which companies have to instruct their employees to visit customers in order to review monthly's consumption, and to perform appropriate maintenance actions. With the new way of understanding the electricity market, all these unnecessary costs will be drastically reduced, and thanks to a more efficient network, many significant savings will be achieved for both retailers and final customers.

As businesses and homes are starting to generate their own renewable electricity, such as wind and solar power, the actual one-way delivery model is becoming obsolete. The power flows in one direction from the power stations to the final customer, now the objective is enabling them to sell surplus energy back to their utilities and benefits for this.

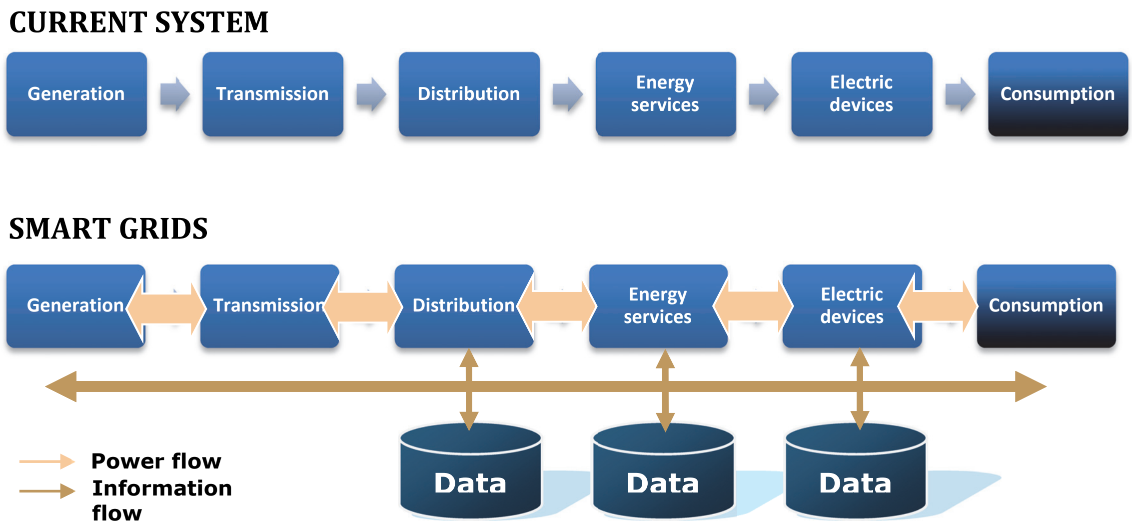


Figure 4: *Structure of the current electric system and the Smart Grids*

The evolution will be significant; a huge budget and tons of hours of engineering studies will be needed to materialize the change. That is the main reason for deciding which features smart grids should offer to the network, and after that, begin to develop the technology to meet the initial settled goals. The basic characteristics are the following ones:

- Bidirectional power flow
- Automatically detection of outages and self-healing
- Greater efficiency, helping to reduce CO_2 emissions
- Enable decentralized and distributed power generation
- Time of use tariffs
- Dynamic control techniques with high levels of power security, quality and availability
- Two way communication between providers and end users
- Interactivity for the customer, who will be able to choose in each moment which kind of generated electricity wants to consume, controlling energy usage

- Capacity of managing power in more optimal ways due to answer a wide range of conditions
- Perfect integration of renewable energies into the network
- Detect and charge an extra fee to those that use energy during peak hours
- Enable and integrate new electricity uses, in particular the recharging infrastructure for electric vehicles.

A smart grid supports a new range of products offerings, services and opportunities that create value for users, electricity companies, and most governments.

Due to the complex of the communication issues and the necessity of interoperability between all parties involved in this huge project, global standardization is essential for the deployment and successful operation of smart grids.

A very significant investment will be required to renew the entire infrastructure (transmission and distribution), due to incorporate new technologies into the system and face the aging of the actual structure. The benefits of this investment are not questioned; the main aims of smart grids are achieving sustainable development and also a more efficient transmission grid, by improving the opportunities for renewable energies sources and distributed generation. It will facilitate the interconnection of regions that have different but complementary renewable sources. Conceptually, a demand reduction is equivalent to a generation increase in the balancing process, so demand management can be treated as a form of indirect generation.

2.1.1 Microgrids

The highest level of power that can be controlled by a smart grid is around 50MW [3]. If we want to plan a smaller network designated for an isolated place for example, we can choose for another option that can fits better. It's the time of talking about a new concept, talk about microgrids.

Microgrids can be defined as a low voltage network with decentralized generation sources, together with local storage devices and controllable loads. This is an interesting idea because if something characterizes microgrids is that they can be connected and disconnected independently of the rest of the distribution network, being able to work in an islanded mode. This has a lot of advantages; one region can be treated as a singular entity, which operates as a load or as a generation source; isolated of the rest of the network in case of troubleshooting and being able of working by itself, independently of its surroundings.

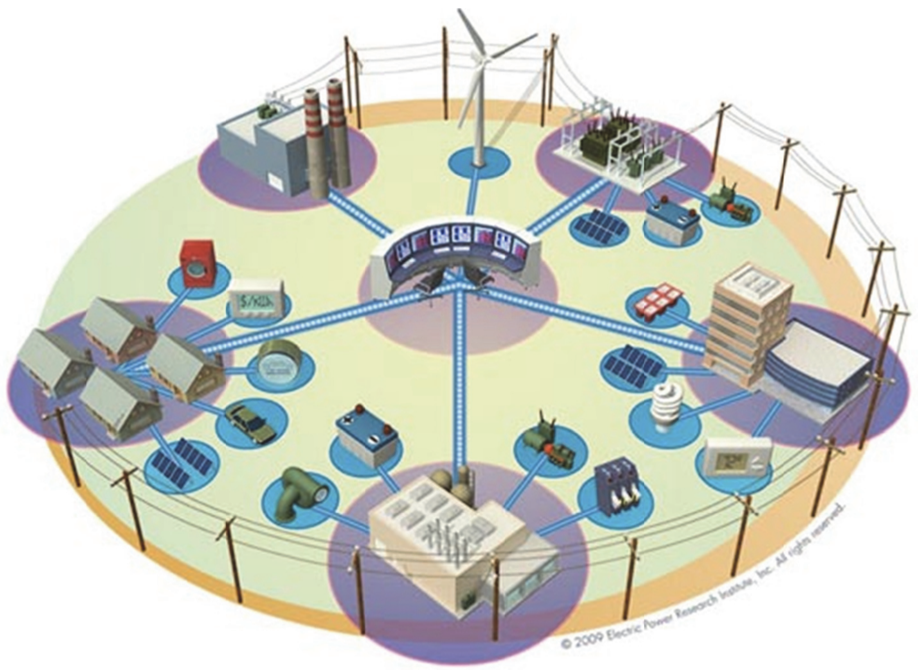


Figure 5: *Structure of a Microgrid [4]*

These small networks can control up to 10 MW [3] and for proper working mode, energy sources must be near of the selected area. They can be an easy and efficient solution in case of local networks with supply problems at small-scale.

Its use can be really useful in some special areas such as hospitals complex, universities, computer servers, military bases or scientific laboratories; locations where they are interested in possessing its own electrical circuit to ensure power quality and in a continuous way.

2.1.2 Comparison of the current grid and Smart Grids

Future grids will become smart, and in order to achieve this objective, several scenarios will be changed. It requires a mixture of revolution, evolution and investment.

Table 1: *Comparison of the current grid and Smart Grids*

Traditional Grid	Smart Grid
Electromechanical devices	Digital/microprocessor devices
Congestion and bottlenecks	Security and sustainability
Conventional meters	Smart Meters
Centralized generation	Distributed generation
Manual restoration	Self-hearing
One-way power flow	Two-ways power flow
One-way information flow	Two-ways information flow
Limited integration of renewable energies	Full integration of renewable energies
One kind of tariff	ToU tariffs
Estimated load profile	Accurate forecasting
Estimated billing	Precise billing
Outdated structure	Flexible and fluid structure
Differing regulatory	Cross-border trading
Centralized control	Optimal maintenance and operation
Radial topology	Network topology
	Real-time operations
	Active customers participation
	Monitoring real-time status
	Customers own generation
	Smart house control
	Power Storage

2.2 - Smart Meters

A smart meter is the electronic device in charge of obtaining all data consumption within a smart grid. It is also the responsible of bringing the opportunity to consumers to monitor, analyze, and control their personal energy use. By getting access to all these details, customers will have greater control over their energy bills. When electricity prices are high, for example during the peak evening periods or during cold winter nights, the smart meter informs householders about higher rates, allowing them to alter their habits in order to avoid bigger charges. Costumers could be able to reduce their bill by as much as one-half by taking care of energy prices and usages.

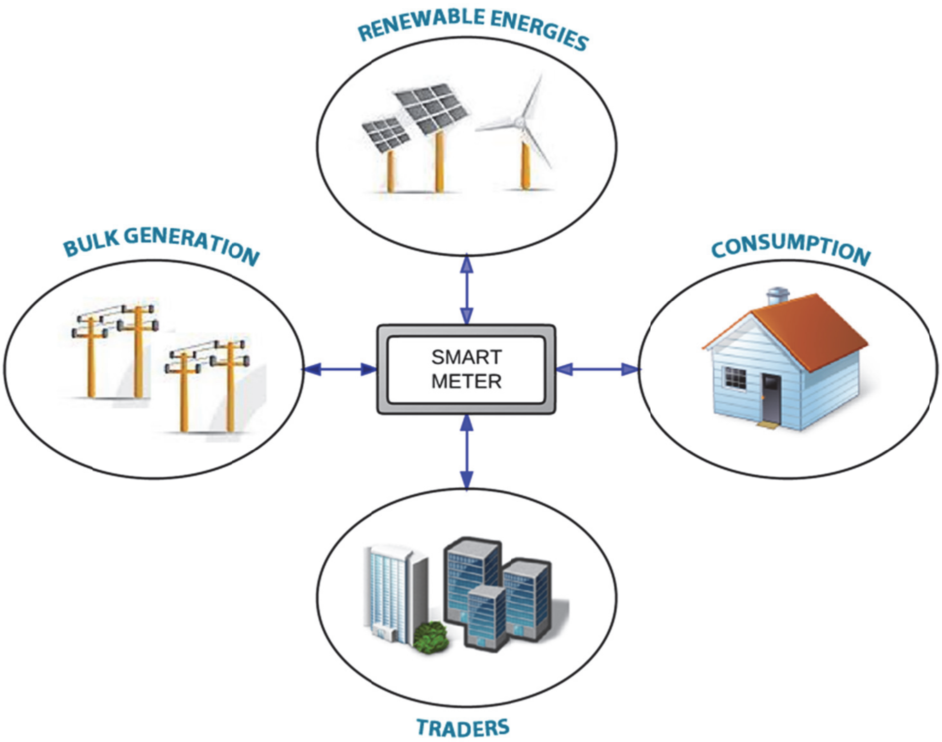


Figure 6: *Information flow using a Smart Meter*

These new measure devices are the elemental stone for the growth and building of smart grids. Without this basic element, it is no way of reaching the goals proposed of interactivity and participation of customers. Clients should always know what is going on with their energy consumption and smart meters are the responsible of facilitate this task.

The Smart Idea:

- Inform consumers about their actual energy consumption, costs and related carbon emissions
- Develop customers' capacity to make smart choices about energy use
- Provide utilities with first-class data about energy and water consumption enabling them to make relevant cost savings

The "intelligence" of smart meters is based in three basic functions:

- Measure of the used/generated electricity
- Remotely switch the customer off
- Remotely control of maximum electricity consumption

2.2.1 Implementation

In order to solve deployment barriers and to ensure the successful operation of smart grids, global standardization is totally required. Members of standards committees who perform the development work are restricted by anti-trust rules from engaging anti-competitive behavior. Regulatory bodies will develop harmonized rules due to encourage competition on a noun discriminatory basis and also to avoid duplicate efforts. This will guarantee open access at all levels, making possible the way to common benefits and incentives.

The system will be based on a new, non-proprietor open architecture. The goal is to develop a standard-based and interoperable customer-side energy management system, so that the customer can take full advantage of real-time energy prices and network status information. A specific combination of networks would offer synergic potential.

The main barriers to be overcome are:

Technology barriers: such as interoperability, cyber security and standardization. Getting global standards and interoperability in hardware and software platforms of different companies seems to be an essential issue, avoiding duplicating efforts and deployment costs.

Competence among companies is something natural in this market, but when a project like this is taking off, regulator institutions should encourage all the parts involved due to cooperate and work together to get the same purpose. Synergy will benefit them and great saving can be achieved.

RD&D barriers: not only duplication of efforts and fragmentation among Universities and institutions, but also different strategies according by countries do not contribute in a fast and consolidated research. A common institution should lead all this organizations by dictating guidelines and spreading tasks, trying to achieve targets without wasting time and money.

Public barriers: acceptance by customers can be an unexpected problem in the smart meters deployment. People are usually reluctant to change; when something is properly working they cannot guess the cause of why changing into a new system or device. Also the installation process of the new meters can be annoying for householders. That is the reason of why a detailed deployment strategy has to be delivered, trying to disturb clients as less as possible.

Before a new city area is starting with the installation process, meetings and announcements provided by the local city council and the retailer can be very positive. By informing customers of all the benefits that they can get with the modernization of their equipment, they will understand the reasons for the need to change.

Once the process is launched, it is very important to keep customers informed about their achievements; a real-time feedback system to let them know how much money they are saving thanks to smart meters will motivate their behavior and also ensure that they follow the project.

Market worries: the smart grid scenario is a topic pretty new for companies. For them, making a large investment in something that they are not completely sure of its success and revenue it is not very satisfying. Letting them know why they have to renew the electricity network, by providing true data of efficiency rates and related savings, can engage providers onto this project.

Incentives from Governments are also needed. In this great challenge many parties are benefited, specially the local areas because many of its inhabitants can work in the building tasks. Providers will collaborate in a huge way in the development of a region by employing workers and installing new infrastructure in their buildings.

Data security: with the great amount of data managed by smart meters, the security of householders can be threatened. If a not allowed third part gets access to this information, it could be possible a report of the common habits of the neighbors, getting knowledge of, for example, when they are at home or not. This is a sensitive topic that has to be carefully treated, not only for avoiding this kind of risks, but also to gain users´ trust.

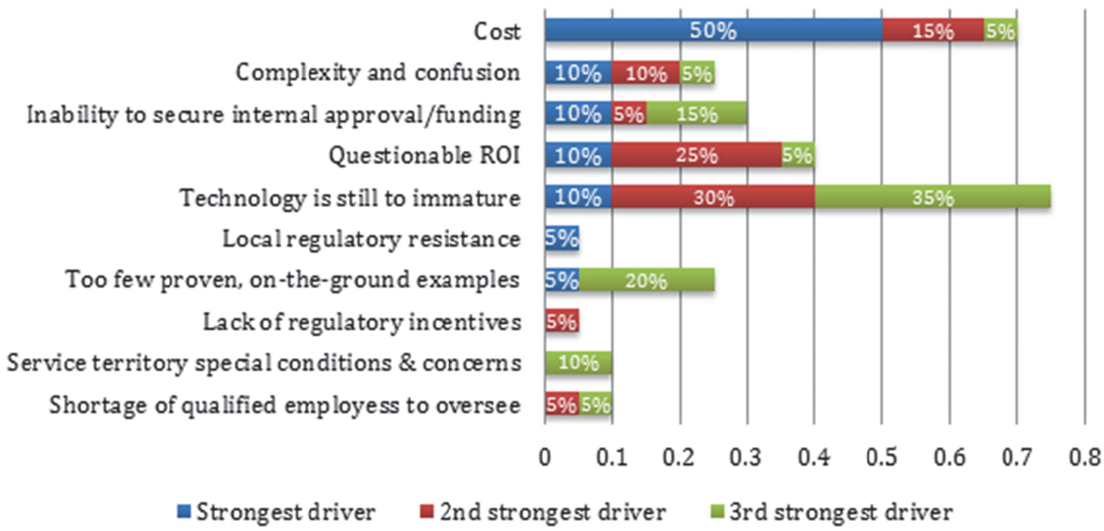


Figure 7: *Top 10 Smart Meters Barriers [5]*

The smart meter itself can be installed somewhere out of the owner's house, just in case of malfunction, helping fixing tasks, but detailed information should not be shown from this outdoor device. All the data required to interact with the client has to be showed in a visible place inside the house, in difficult visibility from outside. In case of data sharing, in order to use it for motivating issues or feedback, it will always be anonymous.

2.2.1.1 Parts involved

Smart meters offer benefits to multiples parties; including lower metering costs, savings for clients and easier blackout and fraud detection for suppliers. Each of the parts involved play a different role in this project, but the collaboration of all of them is required to make the evolution in the electric system success. Coordination at local, national and European levels is necessary, and at this moment, many institutions were founded with the purpose of facilitate this process.

Figure 8: *Parts involved in a Smart Metering system*

Customers: clients have the right of quality services and accuracy bills. They will be able to choose what kind of energy source they want to use, selling surplus generation back to the grid and real time knowledge of their consumption.

Suppliers: the current way of using the generated energy will change over the next years. Generator companies will get adapted to a new electricity scenario, in which renewable energies and distributed generation will supplant the actual bulk and fuel model.

Researchers: cooperation among Universities, research centers, laboratories and technology companies is needed to overcome barriers and also avoid duplicating efforts and money during their work. With a good coordination policy and by spreading the work between all parties involved, reaching the final goal will be faster and cheaper.

TSO/DSO: electricity companies affirm that the lack of efficiency in their networks starts most breakdowns and loss of money. Power quality and system security are threatened at this moment due to the ageing of the structure, so they really need an update to ensure the service they are providing to the society.

Regulator: national Governments have to spread the idea and incentive economically the development of smart meters creating a roll-out process. By using renewable energies, the country will be less energy-dependent of foreign fuels, like oil or coal; helping to stabilize its economy and providing them the possibility of being more self-sufficient.

3 - Features of the Smart Meters

The evolution of the characteristics of the current meters compared with the smart meters is significant. It progresses from a monthly or in some cases bimonthly value record, towards a variety of options that provide endless benefits for both the supplier companies and users.

Arguably, the key feature that opens a world of possibilities is the two-way communication between company-user. From this, they grow many other possibilities that manage to turn our network into an "intelligent network".

- Enablement of grid monitoring: improve reliability, power quality and security
- Remote disconnect/reconnect: useful for the company in case of problems in the network and also to manage it in case of excessive load
- Secure & Encrypted Data Transmissions: security is one of the main fears of users when accepting smart meters. If data are collected every 15 minutes, criminals or even employees of the company can know at every moment when is the house empty or not. They can also feel spied, looking at their load profile to figure out their activity. Great efforts are being made to gains users' trust; worldwide investment in security will reach $1.6 billion by 2015 [6] developing meter worm prevention, and End-to-End data encryption
- Real-time outage management and restoration: building a self-healing network, reducing blackout times and improving QoS
- Bi-directional metering: in a network which dominates the DG, this feature is essential because there is a need to measure in two directions, not just in a business as usual. Users will have small electric generating sources, and in case of energy surplus, they can sell it to the grid

- Alerts that inform utilities when a customer deviates from his profile or also to inform users about changes in the prices
- Configurable reading intervals: according to the regulations of each country, measurement intervals vary from 15 minutes to some others longer. This gives a detailed statistical analysis of consumption, specifying each appliance
- Enable ToU tariffs: through measurement ranges nearly in real time, users can benefit from this mode of dynamic pricing
- Demand control management: the company will be able to limit load in cases of power supply shortfall and also switch on/off demand remotely
- Tamper detection: have the ability to detect and record manipulations in the meter. By using a piezoelectric sensor [7] it can be detected if the device has been moved from their original position, informing of under-report abuse consumption
- Status Display: customers can consult their current consumption by using an ancillary device that shows data in their homes
- Automated Meter Registration: reducing and avoiding unnecessary operating costs, like an employee travelling to customer's home in order to record measurements
- Export billing data: ability to download daily or monthly use in different formats so that customers can analyze their data in their familiar platform
- Remote firmware upgrade: over-the-air software upgrades to implement new functionalities or troubleshooting

3.1 - Smart Meters Types

Speaking about meters, we can make a distinction between different devices due to its features:

Conventional meter reader: only able to read monthly consumption. Employees of the utility company must go to customer's house to get the data. Many inaccuracies and also possibility sometimes of estimating, making bills sometimes not correct. If something wrong happens to the reader there is no way of remote fixing, maintenance tasks are required.

Automated Meter Reading (AMR): refers to the technology used for automating collection of water and energy (electricity or gas) consumption data for the purposes of real-time billing and consumption analysis. At any given time, the AMR system gathers real-time data and transfers the information gathered to the central database through networking technology.

Automated Meter Management (AMM) / Automated Meter Infrastructure (AMI): they make usage data accessible for utilities so that billing can be more accurate and precisely. With the possibility of remote connect/disconnect loads and with alerts for instances of meter tampering. They also analyze data that flows to and from customer's locations. Some other important features are the following ones:

- Read automatically, as frequently as every fifteen minutes
- Enable remote monitoring of the wholes service area to determine when a customer is out of power and when power has been restored
- Make possible remote disconnect and reconnect services for faster, more certain customer service
- Real-Time Outage Management and Restoration: to make sure that as soon as power is interrupted, the communication between provider-customer will be able to provide a real time view of grid's status.
- Conservation Voltage Reduction: minimizes energy losses on the system
- Integrated Volt/Var Control: calculate settings for capacitor banks
- Phase Load Balancing

The next table remarks the different features of the smart meters and also compares functionalities with the conventional ones. Summarizing:

Table 2: *Feature comparison between different kinds of meters*

	Conventional meter reader	AMR	AMI	SMART METER
Monthly kWh reading	✓	✓	✓	✓
Two way comunication		✓	✓	✓
Theft detection		✓	✓	✓
Outage/Restoring detection		✓	✓	✓
On-demand reads			✓	✓
Programmable load intervals			✓	✓
TOU			✓	✓
Demand respones			✓	✓
Integrated disconnect switch				✓
Power quality data				✓
Remote programmable				✓
Remotely upgradeable				✓

Many other features are expected to come in the near future, such as prepayment by the customer or automatic load control, but at this moment with the current technology this is not possible yet. Also the telecommunication issue is quite sensitive, many options can be chosen at this moment as Wifi or Zigbee; both have its own advantages and the regulators will decide which one should be developed.

4 - Ancillary devices

The implementation of smart meters entails the development of technologies that, working all together, transform the whole system into a complex structure. Not only in the measuring device is based on the system, but also of various elements that make possible the communication and data flow in both directions. The integration with the user is also a key issue; therefore we need a platform to help clients to track their information collected.

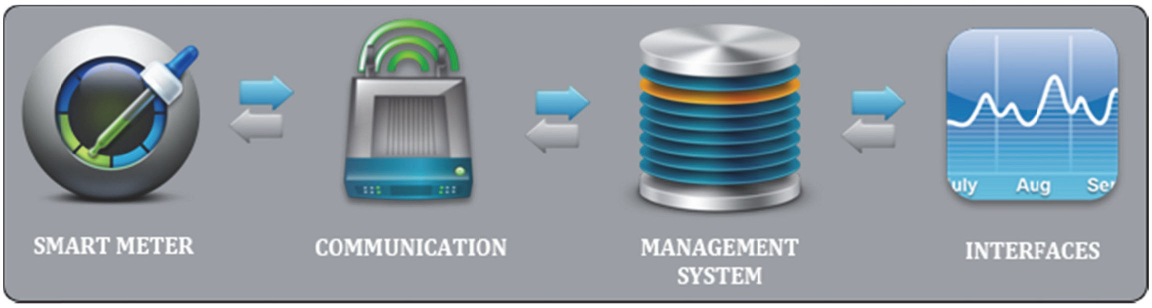


Figure 9: *The Smart Meter infrastructure*

The essential elements that accompany the operation of smart meters, which form part of its structure, are:

- Communication system
- Data management system
- Interfaces for interacting with the customer

They all have the same importance to the ultimate goal and need to be fully integrated for proper operation. Much of the technology required is still developing at this time, therefore the importance of creating global standards.

All these components are manufactured by companies from various sectors, due to the different engineering process required. To try to reduce costs, it is necessary to encourage the interoperability of these devices, thus being able to choose the cheaper alternative. For example, in the case of graphical interfaces, which can be the closest element to consumers, the company supplying electrical energy, when performing the installation, sells all the equipment in a pack to its customer. Later, the user may want to change his notification screen, and if there are different brands in the market, competition will be ensured; and thus lower prices.

Before starting the implementation of the smart grids on a widespread basis, ensuring total acceptance of smart meters and all the associated technology is needed. This is a great opportunity for many technology companies, which can diversify their production activities into a new emerging market, where large investments will be made during the next few years.

4.1 - Communication

Bidirectional communication is a fundamental feature for smart meters. At the present moment, this technology is still in a process of development and maturation and there are several proposals to carry out this two-ways data flow. Various solutions are emerging from the companies involved using different technologies, which helps in the advance of the development and implementation process, but at the same time, generates great diversification.

The lack of interoperability standards is one of the biggest challenges that smart meters must overcome, reaching an agreement among developers after a trial period.

Until now, companies had their own communication networks between the control offices and substations. The information flow was internal, never left the company itself. Thus LAN and WAN controlled data flow required to carry out operations and it was only in one direction. It was a missing link to connect utilities with customers, the required link to interact with the final user. Now with the deployment of smart meters, a new element appears in the communication layer to solve this problem, the FAN networks.

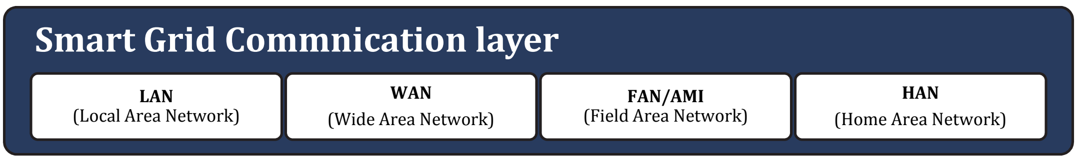


Figure 10: *Smart Grids communication layer [8]*

The FAN will be the connection between the utility and the consumer, the smart link that will enable the bi-directional flow between both parts involved. Smart meters are responsible of bringing this feature to the network, replacing the old equipment that could only measure, by some other electronics that provide a great variety of opportunities.

Once there is no communication gap until the final user, a new layer is needed to collect and analyze all required data, the HAN network. Not only information from appliances and other electronic devices is sent to the supplier company, but also the status of the small generation plants located at user's home.

The communication architectures proposed and developed at this time, in order to carry out the task of communication are [8]:

Table 3: *Diversity Architecture for Smart Meter Networks*

LAN	WAN	FAN/AMI	HAN
Ethernet	Wireless / WiMAX / BPL / Satellite	WiMAX / PLC / Fiber	Wifi / ZigBee / GSM

4.2 - Meter Data Management Systems

A MDMS collects and performs data from AMR/AMI solutions into information that can be treated by utilities for several purposes, such as power management, billing, on demand read and network status control. It is the operation core of smart meters, it brings the opportunity of create applications that simplifies the data analyzing process.

When talking about that the new meters can collect data in real time, we are talking of millions of data to be processed. This task would require huge time to companies, but thanks to this solution, it can be done instantly. This is a very sensitive issue, in which companies must invest to ensure the security and confidentiality of the information, as it reveals the user's profile.

This platform is the gateway to the development of applications by the company. There is no point in collecting a large amount of information if this is not interpreted and read as it should, thus it is said is one of the elements that brings more value to the company [9]. Applications such as web-portal, consumption statistics or data-backup are some assets that can be performed with this system.

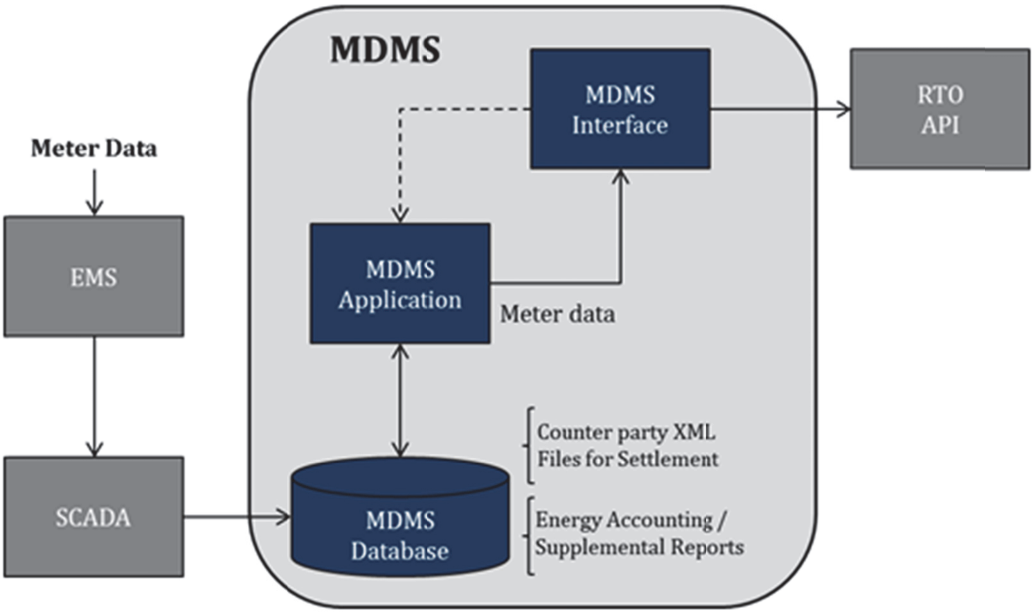


Figure 11: *MDMS architecture [10]*

Not only benefit utilities, but also users since they will have precise control and real-time consumption. Its key features are:

- Real-time operation
- Flexible Data Management
- Intuitive user information

4.3 - Interfaces

Smart meters will be based on an interface with the intention of helping the communication between the supplier and user, being a friendly and intuitive process. Its main functions are:

- Bi-directional information flow

- Consumption monitoring and power price display
- ToU tariffs notification
- Appliances management
- Choice between manual or automatic control

Following a performance model similar to the Internet, via a web-portal, the user controls and manages its electronic devices. Through a real time system operation, the company sends packets of information about the price of fares and its possible variations. Not only is it responsible for registering and storing data, but also it brings the possibility to export the information to some other platforms so that the user can analyze on their own way.

By giving to each appliance and electronic device its own IP address, the two-way communication brings a great possibility of control and monitoring the domestic grid. The way of connecting the HAN technology is the following one:

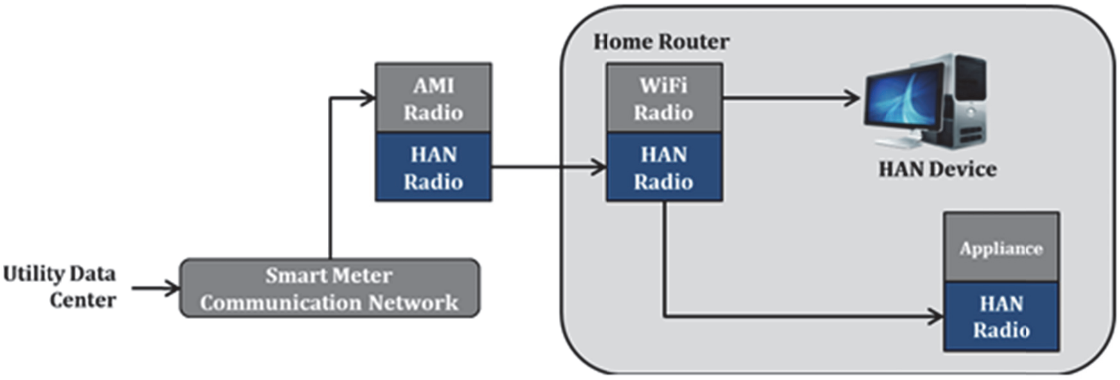


Figure 12: *HAN connections [11]*

To make users take advantage of this solutions, it is needed some ancillary devices that eliminate the gap between the MDMS and customers; devices such as a touch screen, SCADA, web-portal or mobile phones applications. If the client is informed of its consumption, by receiving constant information and feedback, they would be able to save between 5% up to 15% on their energy bills [12].

It is very important to create an attractive UI, so that the user gets engaged with the system and feels comfortable when using it. It can be a great failure if they quit using it after an initial period, the result would not be satisfactory because if they do not follow the solution, the architecture deployment is senseless. The company will require a great feedback from user's experience to try to set the application according to his preferences.

There are different ways to display all this information, but all of them must have a minimum functions such as:

- Show instantaneous current consumption in a short interval time
- Show historical consumption
- Consumption of each appliance with a representative load curve
- Monthly average consumption comparison
- Comparison between users, anonymously, to encourage them to improve their savings performance
- Information about the ToU tariff with attached explanation of its possible changes
- Appliances planning programmer

4.3.1 Touch screen

Using a touch screen provides an opportunity to show information clearly, and at the same time, interact with the interface. It is useful to situate it in a common place, where it can be seen frequently, so that warnings are reported in a satisfactory manner.

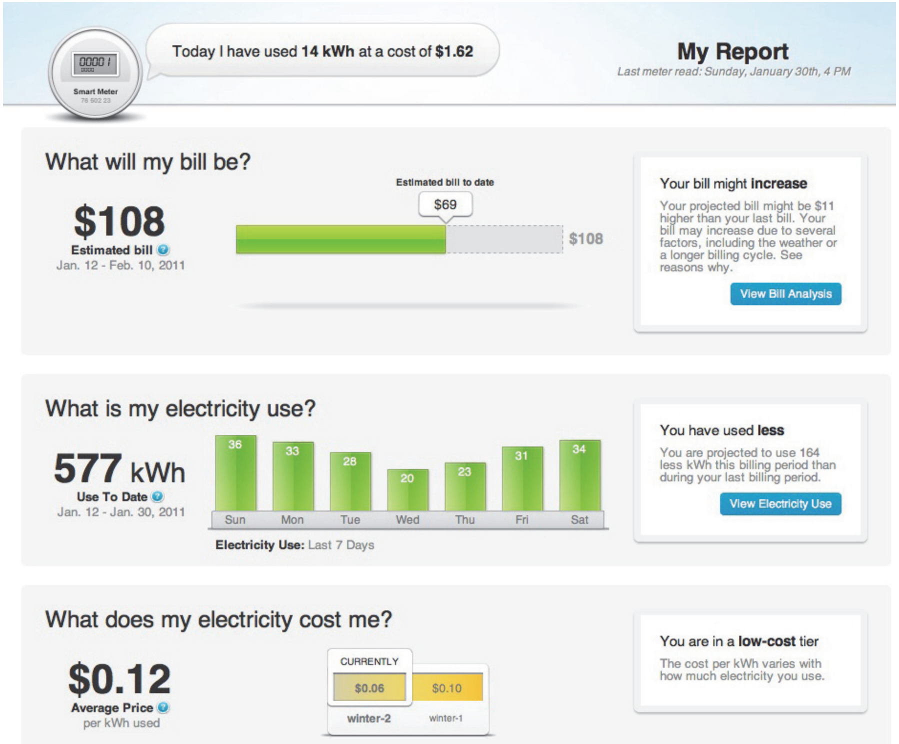


Figure 13: *Example of a Smart Meter Interface [13]*

4.3.2 Web portal

A simple change of the current billing system by a new one, in which customers can consult all the information in a detailed and updated way, it involves a breakthrough in user's experience. Currently a large majority of people have access to a computer with Internet connection, so offering this option benefits the company by saving on sending letters to each customer's postbox, and also the user by obtaining more interesting information by accessing the database represented with graphics.

4.3.3 Smartphone applications

A system that can become very interesting, due to the high implementation of smartphones in the current society, it is the development of applications that send real-time alerts to costumer's mobile phone. It might be the most effective way to make the user feel "engaged" in monitoring their consumption, but also requires the compatibility to work in the different mobile operative systems.

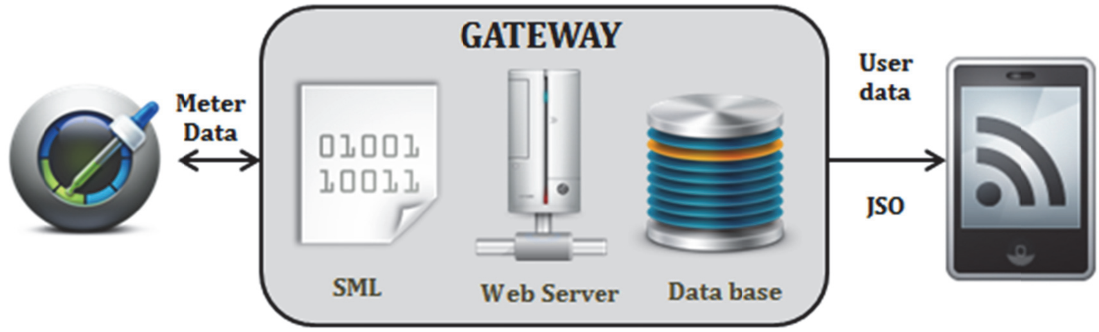


Figure 14: *Smart Meter communication architecture with a mobile phone [14]*

The communication between the smart meter and user's mobile phone is made through a gateway compound by three elements:

- SML parser: receives data from the smart meter and stores it in a database
- Web server: a small web server provides access to the mobile phone through wireless connection in a web browser
- Database: stores data and sends it to the mobile phone in JSO format, a light-weight data interchange platform

For those users who do not have one the latest generation mobile phones, they may be offered the option of a warning system via SMS. They would receive a message notifying them of any changes in pricing and to confirm/refuse to carry out an action, for example, validate the operation of appliances.

5 - Possibilities for the client

Energy users benefit from smart meters as they can have direct control and review possibility of their energy consumption. Thanks to these new opportunities, they will be able to self-manage their energy bills, taking more responsibilities and options to increase their monthly savings.

The current system of monthly, or even in some cases bimonthly readings, seems to be totally unfair related to the client's rights. Estimating is a provisional solution admissible in case of breakdowns or any other kind of problems, but as a normal habit it does not provide any benefit or accuracy. With the existing technology, it is obvious that an evolution in how this process is taken is not unreasonable, if not a necessary requirement by users.

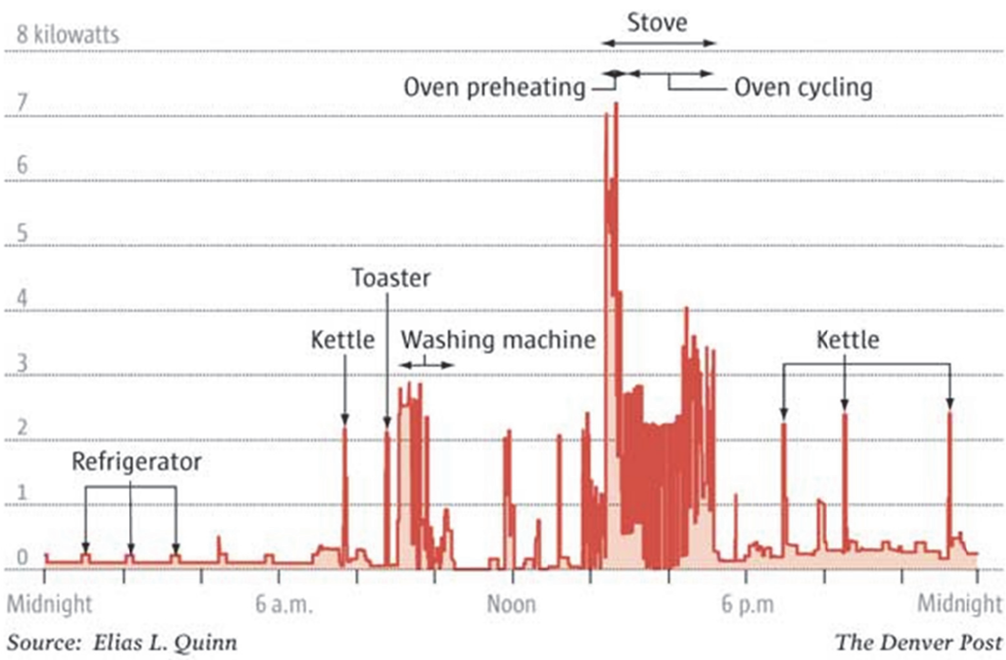


Figure 15: *Meters keep track [15]*

The possibility of tracking the consumption during the day, extracting down by appliances and other electronic devices brings a new chance to customers to control and guide their consumption. If they try to avoid using their devices in the periods of the day when energy is more expensive, they will be able to safe up to 10% in their energy bills and reduce up to 15% their peak consumption [16]. The consequences are real and represent a great benefit for the client, but for make this new system working, users may take an active role in their energy consumption management and feel engaged with this platform.

5.1 - The client as a main actor

So far, the electrical system was based on a one-way communication data flow, in the direction from companies to users. But the challenge is to change this out-of-date method of communication, by developing one where the client can also decide, choose and report their incidents to electrical energy suppliers in real time. Consumer participation will play a key role.

5.1.1 Feedback

One of the main goals of smart meters is to try to change the behavior of consumers, according to a new way of Electric Tariffs, where prices are dynamic and vary according to the time when we meet during the day, called ToU Tariffs.

Figure 16: *Representation of a ToU Tariff [17]*

By creating a continuous information loop, linking a customer with his provider, it is being created a chain that is very satisfactory for both parties. Thanks to this, the client has the possibility to report any incidence in an easy way, interacting and forming part of the system. In the other side, companies will have instant control and knowledge of his network status.

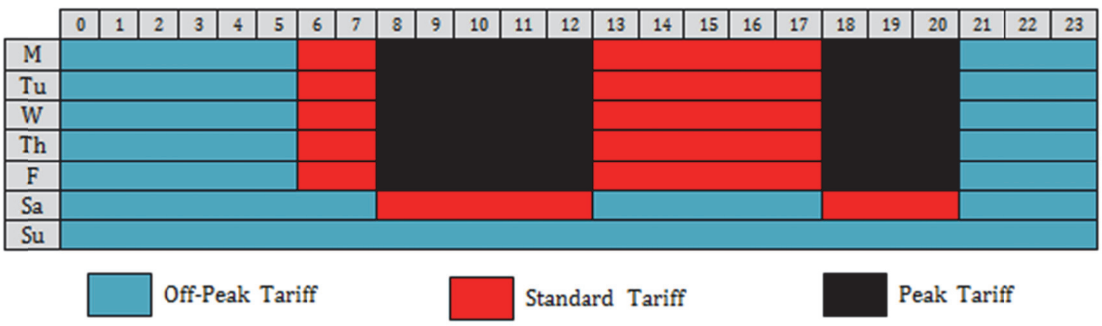
The real-time two-way communication opportunity that smart meters offer will ensure that all users make efforts to save on their bills and also cleaner energy consumption will be rewarded. By enabling DG resources in user's buildings such as solar cells, micro turbines or small wind power systems, the client will get the opportunity to sell all surplus energy.

5.2 - ToU Tariffs

These kinds of tariffs incentivize clients to reduce their energy bills by rewarding them with cheaper prices during off-peak periods. Peak demand can be handled better by giving incentives to consumers to turn off high voltage appliances. Both sides are benefiting; customers save on monthly consumption and power utilities meet their objective of reducing peak loads.

The periods of day are divided into peak, off-peak and standard demand tariff rates. In peak periods, consumption will be penalized by a price increase of up to 300% of the standard one; but also be reduced up to 20% during off-peak times [18].

Table 4: *Example of a daily ToU Tariff*



This dynamic pricing is not the same throughout the year; it will have different characteristics depending on the season and moreover during the week, being the weekend characterized by off-peak consumption. Energy demand fluctuates throughout the day, being mornings and evenings the periods of higher consumption. These variations in prices are mainly due to two reasons:

- Electric power generation
- Electricity consumption

This variable pricing system needs to be associated with two basic applications to ensure user interaction; RTP and TOU pricing tools [19]. The variation of price's magnitude needs to be modeled in advance, according to each user, and it can mainly be two models with the aim of covering most cases; domestic and industrial users. Model parameters depend of consumption variation across the time, degree of consumer economic rationality and on the price of the KWh.

This pricing system pretends to be a revolution compared with the current one; the user is going to be charge in a more legitimate way according to their energy consumption. They will have the opportunity of shifting the operation time of his devices according to the more convenient price.

5.3 - Ways of control

To facilitate user's work, different ways of control can be provided to manage household appliances. The idea is to convert the home into a smart home, in which the operation of electronic devices is controlled by their inhabitants so as to achieve the maximum savings.

By installing the necessary infrastructure, users can control the management of its appliances such as dishwashers, washing machines and, more importantly, the heating. All these appliances are characterized for being the ones with higher consumption within the range of non-continuous use appliances. This type of solution may not apply to some other items such as refrigerator, because its running time is continuous throughout the day.

The idea is to adjust the operating times into the periods when the price of electric energy is the lowest in the day. In order to satisfy user's needs, two ways of controlling home's electronic devices can be arise; manual or automatically.

5.3.1 Manual control

The client will be responsible of adapting the time of use of his appliances at all times. Using the information provided by any ancillary services, such as the touch screen or a web application, they decide when the proper time to launch their devices is.

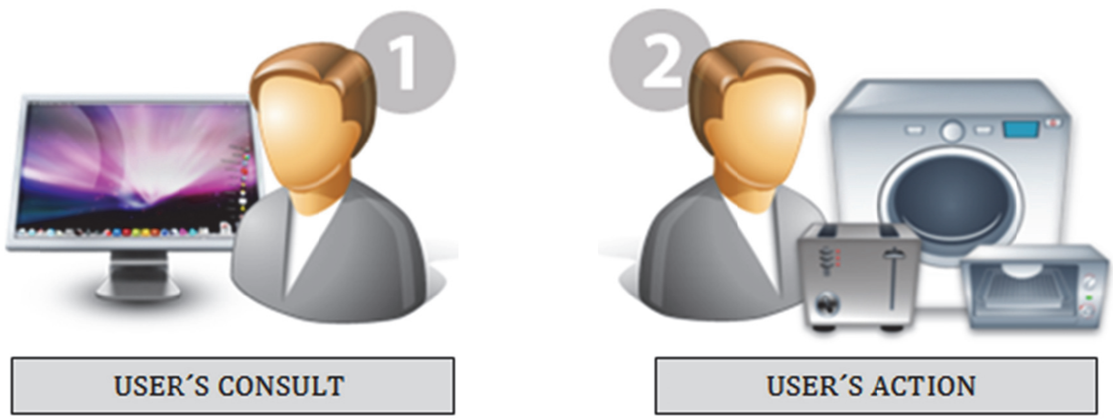


Figure 17: *Operation mode of Manual Control in a Smart House*

In this situation, the ToU Tariffs acquire a high profile, being a fundamental issue how to inform the user about all these data so as to making him aware. More attention by the inhabitants of the house will be required, but they will also have total control of their consumption.

5.3.2 Automatic control

By choosing this control option, the client can plan and decide in advance when his appliances will work by setting some parameters. The main point is not to select the working hours, if not to start it according to some user priorities, such as:

– Lowest price during the day
– Minimum temperature in a room
– Use of renewable energy sources
– Excess of stored energy

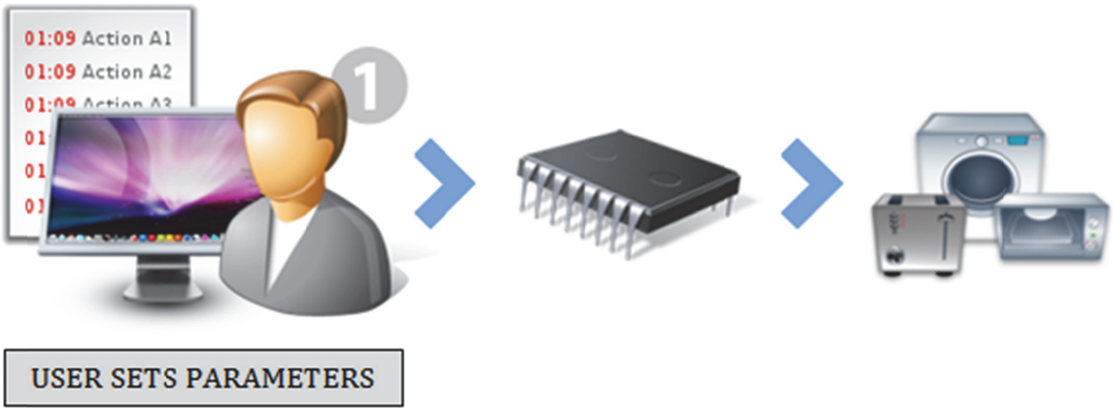


Figure 18: *Operation mode of Automatic Control in a Smart House*

No doubt this new method is a breakthrough and brings comfort to the occupants of the house. By simply choosing between different parameters, their electronic devices will work according to their criteria, insouciance of this task. But this system also has some disadvantages, for example a working period can be started when it is not really desired, during the relaxing hours.

That is the reason of why both control systems should be deployed, not always one solution is the optimal one. Offering customers the capability of switching from one mode to the other one brings greater flexibility, while meeting the demands made by the user.

6 - Benefits for utilities

The current electrical grid construction began in the late 19th century [20], and most probably it is one of the most important engineering achievements of the 20th century. Since that time, the worldwide energy consumption has increased an average of 2% each year [21], and not so many changes in the system were done.

Energy supply is maybe one of the pillars supporting the current world we live in. From a kitchen to an airport, all basic elements that we normally use rely on a good power supply. The current network is out-dated and supply security is, therefore, threatened.

The recent survey by Pacific Crest Mosaic among the largest utilities around the world concludes that the main concern of companies, nowadays, is getting improvements in the reliability of their network. Their second major concern is to fix the problems of peak consumption and demand response.

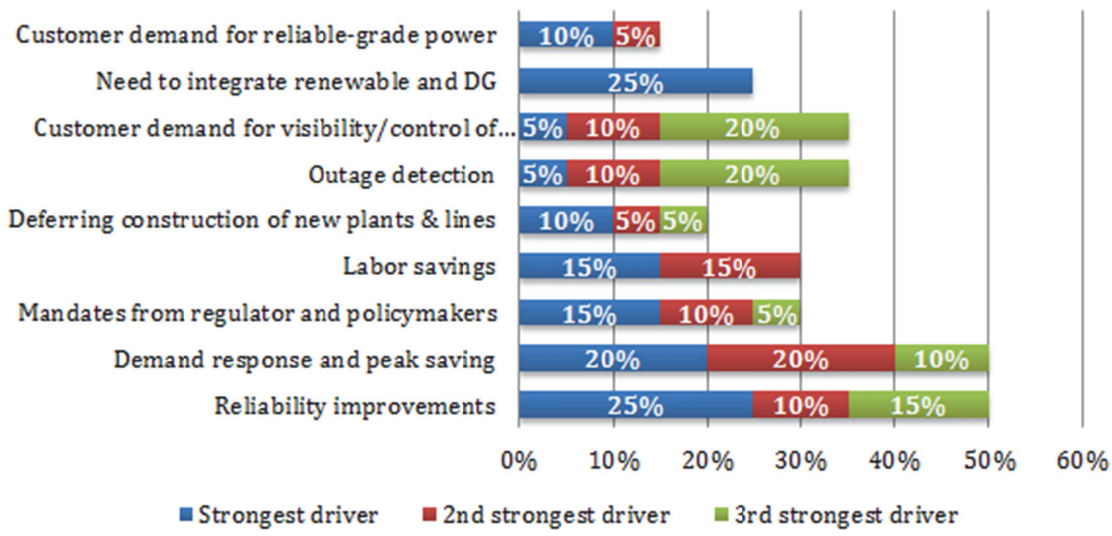


Figure 19: *Top 10 utilities' reasons for moving to Smart Grids [5]*

These are some of the main reasons of why supplier companies are seeking a revolution in their grids. Through the use of smart meters, electric power companies will have real time tools that will inform about the status of all elements within the system, an automatic and instantaneous manner that facilitates and streamlines all the processes of maintenance.

In some countries and in many isolated areas, the only way that a company can notice of any kind of incidence is by costumers´ phone calls. This notification method is totally out-dated, and represents great loss of money for the utilities, due to a long period of time elapses between the beginning of the breakdown and its repair.

The main possibilities that smart meters can offer to utilities are the following ones:

- Total integration of renewable and traditional energy sources, reducing the dependence of bulk generation
- Higher system security, with data encryption and tamper-detection technology
- Continuous monitoring of network status, using databases and more intuitive graphical interfaces
- Increased reliability and reaction time
- Outage detection
- Self-healing capability
- Increase workforce productivity and safety by automating tasks and limiting the amount of onsite work required
- More accurate demand forecasting
- Encourage users to reduce consumption through energy expenditure detailed information
- Expand ToU tariffs to help reduce peak consumption, reducing waste and maximizing use of lowest-cost generation resources
- Improve communication between users and suppliers through a more interactive system
- Accurate load profiles for better resource planning, helping to manage the available resources

- Better integration of DG into the grid, facilitating the development of small generation sources in buildings and integrating energy storage systems
- Bidirectional energy flow, facilitating customers with the task of selling the energy excess
- Ability to supply energy to new developments in society, such as electric vehicles
- Decrease human activities in network operations; avoiding travel costs and reducing the possibility of errors
- Greater respect for the environment, giving customers the option of deciding whether to consume energy from renewable sources
- Reduction in carbon dioxide emission through cutting down transmission losses
- Remote firmware updates of smart meters, integrating new functions without changing the device
- Reduction of unnecessary costs by increasing efficiency and reliability

6.1 - Quality of service

QoS of electric power is a set of features; technical and commercial, inherent to power supply required by customers, subjects and bodies of the Administration. The three aspects that the CEER has established to define it are: continuity of supply, voltage quality and commercial quality.

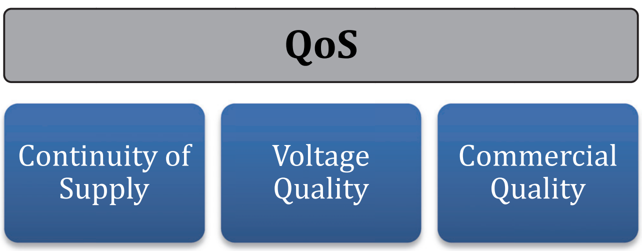


Figure 20: *Aspects of service quality*

Continuity of supply is basically called "reliability" when we talk about the following topics: number of interruption and their duration. To measure these data we can use several indicators such as SAIFI or SAIDI. The table below reflects the cost that would entail the loss of electric power for an hour, in different industry sectors.

Table 5: *Average cost for 1 hour of Power interruption [22]*

INDUSTRY	AMOUNT
Cellular communications	$41,000
Airline reservation system	$90,000
Semiconductor manufacturer	$2,000,000
Credit card operation	$2,580,000
Brokerage operation	$6,480,000

Voltage quality is a term used to describe the relative number of disturbances or variation in voltage; particularly referred to: harmonics, voltage fluctuations, transients and power factor. The last element as part of the aspects to measure the QoS is the commercial quality, dealing with the quality of attention and relation between the provider and consumers, related to billing, consumption measure and contract.

In most cases, utilities are penalized for not meeting the minimum QoS required values, and must pay great rewards to those affected; causing their public image clearly damaged. By developing smart meters in their infrastructure, the ability of tracking their network status improves; in the way they can know, in real time, what is happening all around their network and act instantly in case of trouble.

6.1.1 Outages management

Incidents with electric power blackouts can be solved by implementing self-healing applications in the electric grid, with technology that is continually making assessments to detect, analyze, respond and, where necessary, restore components or network sections. This target can be achieved by developing and installing sensors, software, wireless communication and several electrical components as though reclosers and switches.

Using algorithms, the engineering application is able to detect, in real time, what kind and exactly where the impact is occurring. Next state is to isolate the affected area, so that the closest regions avoid the effect of the outage, maintaining the power. While seeking for a definitive solution, DG plays a key role; working as a Microgrid, through small sources of electric power generation and UPS attempting to minimize the lack of power flow.

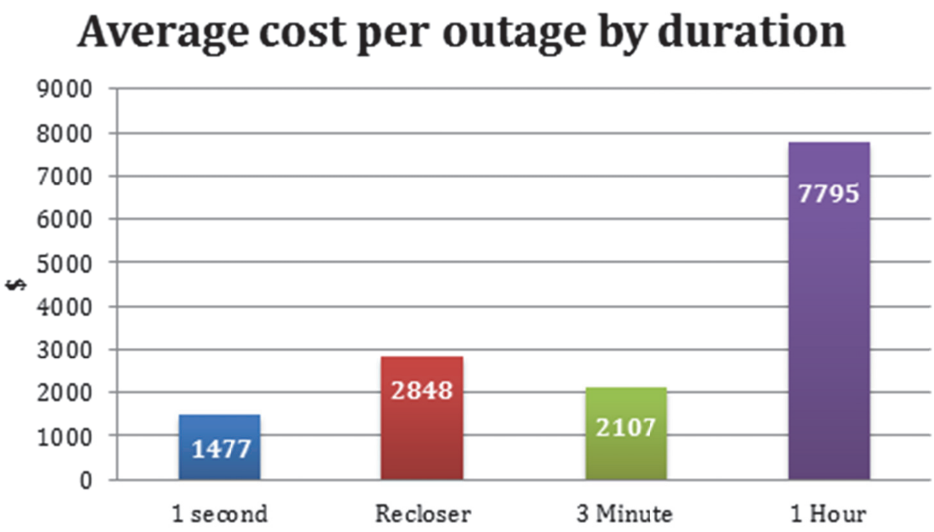


Figure 21: *Average cost per outage by duration [23]*

The above figure represents the cost per blackout and duration. It is critical when the time is extended for a long period, assuming a huge cost. In Apendix A is also explained the effects of various electrical faults. Therefore, through the use of smart meters all these operations of maintenance may be performed in an automatic manner, providing greater reliability and stability to the network.

7 - Current situation

Within the European Union has been established several special plan for helping the development of smart grids, with the corresponding installation of smart meters in the different member countries. A new electricity network scenario is coming with new challenges, and for fulfilling it, the European Electricity Grid Initiative (EEGI) was founded. The aim of this organization under the Strategic Energy Technologies Plan (SET-PLAN) is a 9-year period of European research, development and demonstration (RD&D) to accelerate the change from the current situation to the future one. Its deployment will be continuous over the period from 2010 to 2030.

Figure 22: *Countries involved in the EEGI project [24]*

Objectives sought with this project, besides starting to research and build the infrastructure of smart grids, also promote the deployment of intelligent metering for electricity all around customer's consumption points, defining some rules such as [25]:

- "…Member States should encourage the modernization of distribution networks, e.g. through the introduction of smart grids, which should be built in a way that encourages decentralized generation and energy efficiency"…

- "…In order to promote energy efficiency, Member States, or when the Member State has so provided, the regulatory authority shall strongly recommend that electricity undertakings optimize the use of electricity, for example by providing energy management services, developing innovative pricing formulas or introducing intelligent metering systems or smart grids where appropriate"…
- "…Member States shall ensure the implementation of intelligent metering systems that shall assist the active participation of consumers in the electricity supply market. The implementation of those metering systems may be subject to an economic assessment of all the long-term costs and benefits to the market and the individual consumer or which form of intelligent metering is economically reasonable and cost-effective and which timeframe is feasible for their distribution"…

EEGI's programme can be considered one of the most ambitious taken in Europe for the future years, numbers talk by themselves. With 1,5 million customers involved, 50000 kilometers of power lines and around 20000 substations; the budget ascends up to €2 billion [25] to be invested from 2010 until 2018. Apparently a huge amount of money, but the estimated savings according to Smart Energy Demand Coalition ascends up to €52 billion [26].

Many other pilot projects are being taken at European level, but also each country is starting to develop its own programs, trying to reach the goal settled by the European Union of providing 80% customers with intelligent meters.

Below it is showed a survey on the status of implementation and development of smart grids in different countries of the European Union, considering the most relevant ones. It's also showed Singapore, as a particular country where the efforts and progress made in the deployment of smart grids is an example to be followed by the rest of the governments; its success is now a reality.

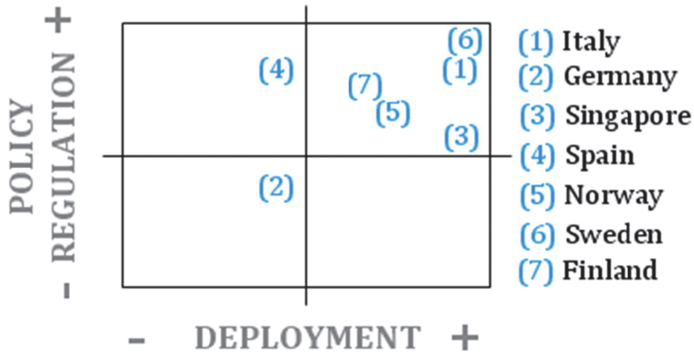


Figure 23: *Status of policy and deployment of Smart Meter in different countries*

It is easy to find many different statuses among the areas, some of them, as Norway, it is in a state of stand-by, waiting to see what is happening and the evolution in some other places. Special mention is required to Italy, due to its conviction in this project since the beginning. Now is upholding the honor of being the first country expanding a firm policy, reaching a quota of 100% of smart meters deployment by the end of 2011.

7.1 - Italy

Italy was the first country in Europe to roll out smart meters on large scale. Digital smart meter have been compulsory for all electricity provider since 2006. The government's timetable is for 65% of customers to be on smart meters by 2009, 90% by 2010 and 95% by 2011 [27]. Enel (the major electricity company in Italy) invested €3 billion with the intention of replacing 27 million standalone electricity meters in their "Telegestore Project" [28].

These smart meters are fully electronic and smart, with integrated bi-directional communications using the power lines, advanced power measurement and management capabilities. They can also be locally and remotely managed. The communication runs over existing low voltage power lines based on the Neuron chip and Echelon's PLT-22 power line transceiver; data concentrator at each utility substation; LNS network operation system software; and gateways to enable communication to indoor services [32], which point they communicate via IP to Enel's enterprise servers.

The main features of Italy's smart meters are the following ones: the ability of allowing power billing in accordance with different tariff profiles on a multi-hour, daily, weekly and seasonal basis. They also provide data on the total energy consumed during the current and the last previous billing period (two months for households, one month for small businesses and free market). Hourly-based tariff system [33], flexible and adaptable to the various needs, allowing customers to select supply contract tailored on their needs and consenting a cost saving.

The meter stores and shows on its display the energy consumption data related to each active tariff rate for the current and the previous billing period [29]. They can detect a service outage and also detect the unauthorized use of electricity [31]. The ability of remotely change the billing plan from credit to prepay as well as from flat-rate to multi-tariff is included in this kind of meters.

Enel's customers can currently read their energy consumption, rates, and contract on the meter display. They are able to monitor and manage their power consumption over the Internet [30] making use of a Web-portal application. Investigations figure that concerned customers have been able to cut their bills by as much as one-half just taking care of energy prices and usage.

Enel had taken an aggressive investment in the initiative and now is saving up to $750 million per year and cutting consumer costs dramatically. The payback will be just in four years. The meters already paid for themselves because the new way of collecting customer's data, managing its energy network and solving breakdowns is remotely, instead of sending out costly technicians. But saving electricity can be sometimes more important than saving money, due to avoid getting close to the power grid capacity, when there is a huge risk of power blackout. Enel estimates a 5% reduction in consumption peaks as a result of increased customer awareness and energy price signals. When a dangerous situation is foresee, utility companies send signals to the smart meters so that the client can realize the current situation and then reduce power consumption in their homes. Customers acquire an active role in the power grid management.

Future projects are being taken by Enel to improve the deployment of smart meters in Europe. Enel and Endesa (an electricity provider in Spain) are working together in an international non-profit association called “METERS AND MORE” under Belgian legislation [34]. The aim of this Association is promote the new generation communication protocol and will be open to third parties. It will be based in Brussels and its legal personality will be granted by means of a Royal Decree. Membership of “METERS AND MORE” will be opened to other industry players, leading research institutes and universities, which will be able to access to and further develop protocol, hence supporting the standardization of communication solutions across Europe.

7.2 - Germany

Germany is considered one of Europe's leading market reformers. Their power market is considered competitive; there are 900 energy companies that work in the German electricity market, although 80% of electricity generation is still controlled by only four huge companies: RWE AG, E.ON Energy AG, Vattenfall Europe AG and EnBW. In 1998 after the Energy Industry Act of April the electricity sector became completely liberalized.

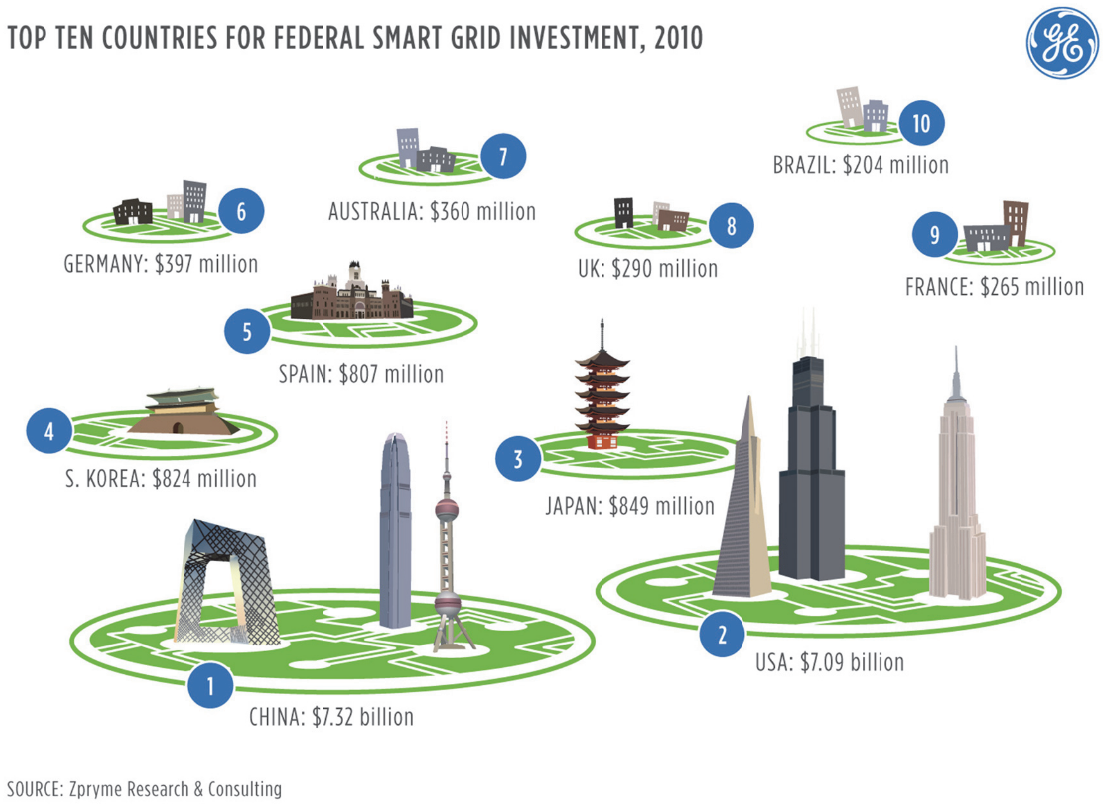


Figure 24: *Top ten countries for federal Smart Grid Investment, 2010 [35]*

Nowadays, meters of standard profile customers have to be read by the metering operator every three years. In between these periods, the measure can be done by the customer or estimate it. To achieve the European Union's goal of providing at least 80% of customers with intelligent meters in 2020, the German Government is starting to act and it is interested in the implementation of "meters that accurately reflect the final customer's actual energy consumption and that provide information on actual time of use” [36]. Currently this kind of meters need to be installed by the metering operator in buildings that are newly connected to the energy grid and in those buildings that are subject to major reconstruction from the 1st of January 2010. The aim is roll-out smart metering in a six year timeframe after consulting several proposals. Load variable tariff must be offered by suppliers by 2010.

Liberalization of metering market started in the fourth quarter of 2008. As at this time there was no legal compulsion for smart meters, customers had the competence of deciding what kind of smart meter they would like to have, by choosing among several models and features (load/time variable tariffs, detailed energy information, special devices) in the market [37]. They were also able to contract their desired metering operator. Relationship between metering operator and DSO is subject to regulatory action to clarified contractual details and minimum technical requirements. The Federal Network Agency is working with market participants to develop this standard contracts and minimum requirements. Privacy law about access to meter values relates only to generic law.

At least 50 pilot projects with a range of 10 to 100000 installed meters per project at being taken in Germany. Starting in 2011, German utility companies will have to provide load-bases or time-of-day-based power saving initiatives. All major energy suppliers are testing smart meters, but only 0,01% are considered smart at this moment. The main barrier for its deployment is that replacing ¼ of the electric meters in Germany would cost €1 billion and manpower of 5000 person per year [38]. Another barrier is the fear of citizens of becoming a “transparent customer”, especially if the data protection laws are not enough strict [40]. These planned pilots are the following ones:

<u>Yellow</u>

They started with the project on mid-2008, and now they are providing and intelligent electricity meter called “Yellow Sparzähler”. The main features that this device gives to customers are [39]:

- Superior control of their consumption
- Monthly online reading of bills

- Identifies off-peak electricity periods
- Increases energy efficiency, provides transparency and electricity cost savings
- Personal Sparzähler accounts on their PCs

The Yellow Sparzähler is available for Yellow Electricity's customers for a not expensive package price. Installation requires a one-time fee of €79.

RheinEnergie Köln

This is a regionally based company, municipally owned, with a strategic partner. They started in 2009 its plan for the deployment of smart metering in the city of Cologne; in 2010 the goal is providing 1 million of users with smart meters. They are working in an intelligent system for retrieving data out of meters via IP-networks, with a totally IT-based presentation [41] able to process and communicate the data to and from all parties, including billing process and invoicing (grid use, energy consumption). Some features of its device are:

- Tamper detection inside the meter
- Outage information at central data access point
- Validation, interpolation in meter data management system
- RTP, ToU-tariffing in the billing system
- Price information in easy customer access

Stadtwerke Schwerte

The project called "NES-System" was developed to reduce costs in meter reading and the evaluation of AMM-scenarios. They implement the smart metering solution "Meterus" based in Echelon Networked Energy Services (NES) Technology [42]. This device measures the total consumption of the substation and delivers information about the power flow and capacity utilization, so that the utility company can detect technical losses and fraud.

In order to carry a meter reading or to check any feature of the system they use an Internet-based access to manage the NES-system. Each meter in the system can be addressed individually and has 4 tariffs in its software, which can be updated dynamically. All information provided by the NES-System can be exported and processes in other software systems [43].

The meters can be reconnected and disconnected remotely and they can also bring the possibility of reducing the load to a certain level. The consumption is measured monthly and the data is exported to further systems.

The next steps of the project are: creation of load profiles for selected households, observation, observation of the power supply network quality and alarms to detect manipulation.

RWE

The German utility RWE will equip with 100,000 smart meters all Mülheim an der Ruhr's customers. The new meters will provide customers more comprehensive and up-to-date information about their energy consumption. The investment will be of €20 million over the next three years. RWE is working in increasing cost transparency for customers; they want to give clients a tool where they can check their energy consumption in order to effectively save on energy and money; a change in consumption behavior will only occur when customers can directly check the success of their energy saving measures.

The aim is to develop a smart meter with an open standard system, which can work with several different billing programs; this technology offers the potential for new tariffs models, like time of day or weekend tariffs.

7.3 - Singapore

In November 2009, during the Smart Grids 2009 Summit, as part of the Singapore International Energy Week, the Energy Market Authority (EMA) of Singapore launched a three-year pilot project, with the objective of testing and evaluating new technologies and applications around smart grids. The project called "Intelligent Energy System" (IES) seeks to develop and deploy new ways and solutions for the next generation Singapore's grid [44].

Singapore already has one of the most reliable and secure grid in the world, with an average interruption time of less than one minute per customer per year [45]; the grid stability is not an issue at this moment. Nevertheless, the necessity of modernize the electricity transmission and distribution networks with new information and communication sensors, makes this project the first step to obtain a smarter system.

Electricity consumption in the Asia-Pacific region is expected to increase almost two times during the next years, from 9385 TWh in 2005 to 16442 by 2030; also currently, 10% of the vehicles in Singapore are electric vehicles that require 1,3 trillion watts of energy [45]. To be able to face this challenge, the Singapore's Government started this project so that they can ensure that their electricity infrastructure will be ready for the future. In addition, EMA seeks facilitate the integration of small and variable sources of power into the grid in a "plug-and-play" manner.

A recent research on the roundtable "Is Singapore Ready for Renewable Energy?" claims that Singapore is not ready for renewable energy [46]. At the present time localized generation sources include photovoltaic systems and small co-generation plants. There have been several plans to support the renewable energy industry since the government decided to focus on clean-tech in 2005.

The main barrier is the lack of renewable targets by the government due to specify how much energy should be generated by renewable sources in time period. Also a big problem in the deployment of this technology is that the government thinks that giving subsidies to this kind of energy it's no fare, and without subsidies the use of this electricity is not viable; renewable solutions are not competitive as compared to current electricity tariffs. As it is expected a big increase of electric vehicle's use, new cars can be used as an energy storage system to feed power back to the grid during peak periods, technology also known as V2G (vehicle-to-grid) [47]. With all this new, it becomes obvious that grids must change to avoid energy rationing and power outages.

The IES pilot will be conducted it two major phases [48]:

Phase 1 (2010-2011): the goal is to roll-out the infrastructure elements for the IES. The actual infrastructure will be transformed into an advanced metering infrastructure that will allow the communication from one smart meter to another. The most important components are both the advanced metering infrastructure and the communication system. They will bring the two-way data communication; and also will enable demand response and outage management [49]. Integration of distributed energy resources and testing behavior of electric vehicles in the grid will also be investigated in this stage. The pilot project will install over 4500 smart devices in residential, industrial and commercial locations with the aim of testing and evaluating workable solutions.

Accenture Pte Ltd has been appointed to design and implement the $30 million pilot project towards developing a smart power grid. They will be working together with industry heavyweights such as ST Electronics (Info-Comm Systems), Greenwave, Hewlett Packard, Oracle and Power Automation.

Phase 2 (2012-2013): the pilot will focus on smart grid applications; the emphasis will shift to engagement between customers and EMA. The aim is involve the participation of clients, industrial consumers and commercials. Selected customers will be located in several areas of Singapore, as the CleanTech Park, the University of Singapore and housing estates such the Punggol Eco-Precinct. Pulau Ubin, a small island of the northeast coast of Singapore, has been chosen by EMA for researching the ongoing of an intelligent microgrid. In this unique location is being installed a microgrid infrastructure using only clean and renewable energy technologies to displace the current diesel generators. This important project is expected to provide significant information about the integration of renewable energies into the smart grid network.

The pilot project also involves several agencies from the Singapore Government such as the Infocomm Development Agency (IDA), which will be the responsible of installing the Next Generation National Broadband Network (a high speed fibre optic network to all addresses); and the Agency for Science, Technology and Research (A*STAR). Also the Housing & Development Board (HDB) will have an active work, delivering smart meters to all households. Singapore Power will have an essential role at the level of infrastructure, facilitating applications for customers. The main point of the project will be at the Nanyang University (NTU) [50], which has the research and technical resources to test the various smart grid applications and solutions.

The target of the IES project is to help homes and business to conserve energy and save in their bills. After the installation of smart meters in 400 homes, the results were evident: they could reduce overall consumption by 2% and peak load consumption by 10% as consumers changed demand to cheaper periods. The new system is like using mobile phone plans, volunteers are allowed to buy “electricity credits” at peak and off-peak periods, getting more control over their energy bill; instead of the currently flat plan of paying S$ 0,25 per kWh, which is sold exclusively from SP Services [46]. Participant will be able to buy electricity online, or in several machines located in Marine Parade and West Coast. They can also monitor their hourly usage with the help of smart meters.

The role of customers managing their electricity consumption will be a very important element in this new way of understanding electricity management. The trial indicated the scope for incentivizing clients to optimize consumption by shifting their consumption in line with time-related tariffs. By reducing peak consumption, not only households get benefits, but also power companies will save money because they will not need to build extra power plants to cope with such high demands and also they would be able to reduce the spare generation capacity that companies are required to maintain. All these achievements will be possible by installing an advanced metering and communications infrastructure, with fiber-optic cables, Wi-Fi and radio frequency, so both parts involved can make more informed decisions about electricity use.

Singapore is also being part of another pilot project besides IES, the Singapore-Israel Industrial Development and Research Foundation (SIIRD) is supporting an 18-month project with a total budget of $10.6 million; to develop a smart metering system to create new standards, construct an open architecture and enabling real-time monitoring of smart metering devices. Companies involved are an Israel-based fables semiconductor company, Yitran Communications Ltd and the Singapore smart meter developer BBS Telecommunications Pte Ltd. The goal is to develop a new generation smart metering system, work under the latest smart grid end-to-end TC57 and ANSI C12.22 standards and allow connectivity with no new wires.

7.4 - Spain

The Spanish electricity market started to change in 2007, when the Regulator forced distribution companies to implement smart metering projects in a specific time frame, establishing also a set of minimum functionalities that the implemented solution must cover. The ORDEN ITC/3860/2007 law established compulsory for DNOs to implement smart metering solution replacing all the meters before 2018. The smart meter roll-out started in January 2008 and will be completed by 2018 taking several steps (30% of substitution by 2011, 50% by 2013, 70% by 2015 and finally 100% by the end of 2018) [51].

The current law approved by the Spanish Ministry of Industry sets that smart meters will be compulsory for all those residential customers called metering point "type 5", which are customer with contracted power up to 15 kW (24 million of households) [52], making public the features and technical specifications for electricity metering. The main requirements for the new meters are the following ones [51]:

- AMR: remote reading of energy and power for billing
- Remote parameterization including time of use
- Precision: class "A" for active energy and "3" for reactive energy
- Capability of activation power control mode: maximum demand meter or cut off element
- Show different information to users in a display
- Storage of the last 3 months load curve
- Power supply remote control: cut off and reconnection supply
- Time discrimination with capacity of managing 6 programmable periods of active and reactive energy and consumption each 15 minutes
- Storing measures during 6 months without power supply
- Available load management, to reduce demand response at critical moments. Power contracted or available can be programmed
- Remote reading of quality parameters

The CNE (National Energy Commission) is worried about the lack of fulfillment of the deployment plan. The present situation of the reading service, with mechanical meters and reading recordings each two months [53], was totally optimized for companies. The proper development of the project implies a strong economic effort, the total budget is up to €5500 million in order to invest in innovation and technology. At this moment, there are no economic aids from the government side to try to help utilities during the huge initial investment. Companies will be only allowed to increase the monthly rental charge of the meter to the customer from 0.54€/month to 0.81€/month. A study of benefits concluded that smart metering is not economically reasonable for a yearly consumption lower than 5000000 kWh, and is inefficient in terms of costs [54]. By the way, many benefits will be achieved with the use of these new devices such as saving in electricity bills for consumers, mare accurate calculation of network losses for DSOs and more and better information to design pricing options to retailers.

There are several pilot projects trying the deployment of smart meters and they are held by the three of the major Spanish Utilities:

Iberdrola

Iberdrola is Spain's number one energy group and one of the largest utilities in the world. Its services reach 16 million customers, over nine million in Spain. Its operations include generation, transmission, distribution and marketing of electricity and natural gas.

The Spanish utility has achieved during the year 2008, the approval of the European commission, within the 7th Framework Programme for the promotion of RDI, the project called Open Meter (Open and Public Extended Network METERing), it has begun in February 2009 and last 30 months. The main objective of the project is to develop a standard technology for remote meter management, internationally accepted. The budget is more than €4 million, 60% of which will be subsidized, foresees the large-scale implementation of remote electricity meters. The consortium is made up of 19 partners from seven European countries (Spain, France, Italy, Germany, Holland Belgium and Switzerland), electricity companies, meter manufacturers and universities will work to achieve open telecommunication standards able to ensure interconnectivity between the equipment and devices of different companies.

Iberdrola is leading the PRIME project (PoweRline Intelligent Metering Evolution), which objective is the development of a new open, public and non-proprietary telecommunication solution for the AMI infrastructure. It will support automatic meter management functionalities and also the progress towards the smart grid. PRIME is based on the OFDM (orthogonal frequency-division multiplexing) application in CENELEC-A band [55], achieving a new generation of high-speed and low cost PLC using low and medium voltage networks as a telecommunication media.

The main objective of the project is to create a Physical and Mac layer standard definition based on up-to-date technologies, in order to guarantee the interoperability among equipments and systems from different manufacturers, ensuring that all components of this architecture will not belong to Intellectual Property Rights [57]. Itron has been selected for the first phase on its smart metering program, which is expected to run from July 2010 until the end of the year. Its task will be develop and integrate an advanced metering management system, including head-end and meter data management (MDM) software. The project will roll out an initial 100000 smart meters in the city of Castellon [56] and could expand to 10 million meters across the country, allowing optimizing network management, reducing operational costs and enhance quality of service for the benefit of consumers.

Based on the PRIME standard, the “STAR PROJECT” is the revolutionary metering infrastructure program, based on a budget of €22 million, starting in April 2010. STMicroelectronics will provide the equipment that employs ST’s STarGRID ST7590 Soc [58], which offers a flexible, scalable and future-proof power-line communication platform, allowing the integration of an optimized DSP engine for different modulation schemes and physical layer services management. A digital 8-bit industrial microcontroller core is used for system supervising and protocol stack management. The STarGRID platform also includes the ST758x family, which performs the innovative dual-channel suitable for different protocol implementations, such as the 'Meters & More' specification, which has been adopted by the ENEL group. The most innovative aspects to be developed are:

- Interoperable meters with advanced features
- Active management of demand
- Recharge of electric vehicles

<u>Endesa</u>

The utility company Endesa forms part of the international non-profit association "METERS AND MORE", which main objective is managing the new generation communication technology and protocol applied to smart meters. The protocol enables bidirectional data transfer between smart meters and central billing systems in an advanced smart metering environment.

Under the name of "SMART CITY", Endesa has started the deployment of its remote management plan, which seeks the installation of 13 million of smart meters by 2015, planning to have installed 150000 by the end of 2010. It pretends to be the first Spanish utility to complete installation for all customers under 15kW, including residential and most small commercial customers [59]. The company will invest over €1600 million, creating more than 2000 direct jobs and making the path towards the creation of a new electricity system.

This new project is the result of the cooperation with its parent company Enel. It will use intelligent power metering so as to reduce the cost of the consumer's bill, cut energy consumption by 20%, cut 6000 tons of CO_2 emissions every year [60] and also increase the efficiency of the electricity network. The starting location is the city of Málaga, Andalucía; where 900 businesses, 300 industrial customers and 1000 households are receiving smart meters, advanced telecommunications and remote control systems. The meter will be installed without disturbing customers because it does not require any work. In addition, a concentrator system will be laid in all its low voltage transformer centres. This concentrator will control meters automatically and remotely, communicating via the electricity grid using PLC communication protocol.

ST is the selected provider to complete the smart metering solution, which includes a powerline communication System-on-Chip (ST758x), a powerful 32 bit microcontroller (STM32) and an innovative power supply device, as well as MOSFET and EEPROM memory devices. The powerline communication protocol (SITRED) will be applied in this new generation of remote meter management solutions [61].

Some of the benefits obtained from this research are [62]:

- Two-way communication between the customer and the company: helps how to manage loads and energy consumption, saving money and improving efficiency
- Precise reading of consumption, on site and remote
- Better information on energy consumption, resulting in savings and improved efficiency
- Better commercial service: real-time remote operations (connections, disconnections, modifications and reconnections)
- More flexible rates
- Smart management of peaks in demand
- More reliable information on grid performance
- Improved flexibility to deal with regulatory changes
- Easier fraud detection

Otherwise, Endesa is leading the project called INTREGRIS (INTelligent Electrical Grid Sensor), with the intention of design and develop the telecommunication infrastructure of smart grids [63]. Its duration is estimated in 30 months, and it will analyze distributed energy system technologies, studying also the viability of using cognitive systems; which permit an improvement of electricity supply, providing a simple and low cost communication system. The budget ascends to €5 million, and 60% will be provided by the European Commission as part of the 7th Framework Programme.

The future frame in the electricity market for Spanish customers would be benefit from applications, such as eMeter's Energy Engage, that allows them to manage data, monitor and control their energy consumption.

7.5 - Norway

The energy authority of Norway is taking a very careful behavior about the deployment of smart meters in its country. Attitude will be to wait and study other countries' standardisation works and projects [66], especially the Swedish roll-out, to figure out the results. In June 2007, the Government recommended some legislation requiring smart meters for final customers installed by the end of 2013 [64] and the Norwegian Electricity Industry Association is analyzing, in collaboration with several DSOs, what elementary requirements smart meters should have. At this moment, they have further postponed the implementation until 2016, in order to check the results of the projects arranged within EU. The regulator will make the decision of the roll-out plan and the minimum requirements for functions during the autumn 2010.

In Norway instead of using the definition of smart meter as "intelligent meter", they use the phrase "Advanced Metering and Management System" (AMS), which is based in three main components:

- An advanced meter
- Data collection/front end system
- Two way communication between the meter and the data collection architecture

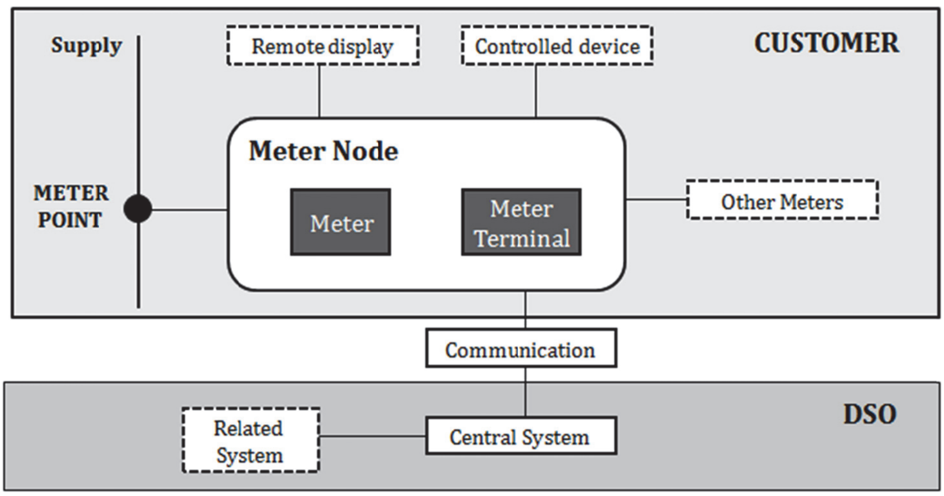


Figure 25: *Principal structure of smart meter system [67]*

By the way, it could be possible to install supplementary equipment in the device, e.g. a display, but the customer will have to carry with the costs. Regarding to privacy laws, the protection of clients' data is ensured by another establishment, the Data Inspectorate.

NVE (Norwegian Water and Energy Directorate) settled that from the 1st of January 2005, all points that consume over 100000 kWh/year have to be hourly metered. It also suggested that all customers should have hourly metering within 2016, with the possibility to the change the metering frequency up to 15 minutes; in order to improve the information flow between customers, grid companies and suppliers. The entire roll-out of this new way of metering to all customers in Norway will cost around €550 million [65]. Several cost & benefits studies have concluded that, currently, the implementation of smart metering is not profitable for DSOs; but it will be really useful for the entire society. To achieve the objective the objective of complete the implementation by 2013, householders will have to pay a charge of €5 per year.

Lyse Energi AS, a power company which head office is located in Stavanger, engages in the production and sale of energy and telecommunication in Norway. Since 2003, when the price of electricity was extremely high due to low rainfall, it established monthly self-reading by customers. This data can be reported either by Internet, SMS or meter cards. At this moment, Lyse Energi is working in a pilot project about the deployment of 20000 smart meters linked by fiber optic wire. The communication structure will be based on WIFI for the communication from the meter to the Home Access Gateway, and IP-based fiber optic to communicate with the central system. Lyse Energi focuses on the cost of communication, taking into account also the cost of system's installation. They think that in the future, when measurements will be able to be done hourly, the cost will become an important issue, that's why they are looking for cheaper solutions.

A new and very interesting project is being developed thanks to the collaboration between the city of Bergen, Bellona, Bergen Chamber of Commerce and Siemens. The idea is to converti the city of Bergen in the first Norwegian Smart City in terms of energy use and management.

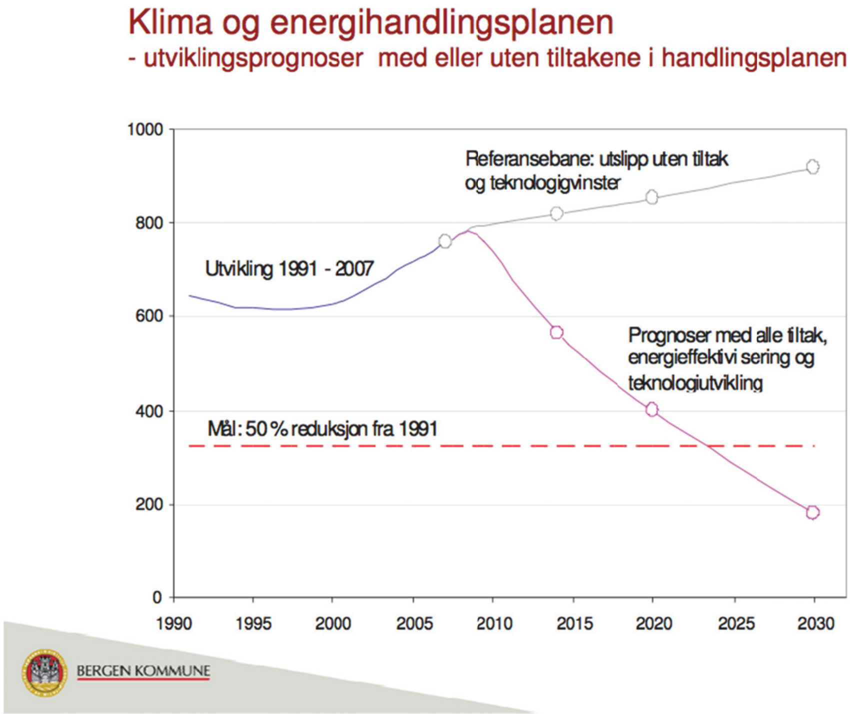


Figure 26: *Forecast of greenhouse gas emissions [68]*

A recent report [68] shows that if the city of Bergen deploys a smart grid network in its neighborhoods, the power consumption can be reduced in average up to 29 percent; reaching 35 percent in case of households. If this reduction of GWh is translated to money, it represents 1,3 Bkr.

The main idea of this plan is to expand a district heating network. It is estimated that around 14% of gas emissions are caused by oil-based heating in houses and industrial buildings of the cities. By creating a smart heating network in Bergen, pollution gasses can be cut up to 50% in 2025 comparing with the value in 1991. This can be achieved by increasing the thermal efficiency of the houses (isolation, ventilation, exposure to the sun...) but also using renewable and clean energies, instead of burning coal for heating water, such as:

- Geothermal Energy
- Solar energy
- Corn, rye and wheat
- Biomass

7.6 - Sweden

The first studies of smart metering started in 2001, and since then, Sweden has made a great effort of research on this topic, being now the first country to achieve totally penetration of smart meters. It was the 1st July 2009 when monthly collection meter values became mandatory by DSOs [69], trying to avoid the high costs they would have incurred with monthly manual meter reads. This milestone put Sweden at the forefront of demand response potential. Counting both households and companies, there are more than 5 million utility customers in Sweden [70], being one of the most intense electricity users in the world.

This step on the electricity scope was initiated by consumers' organizations, demanding a better billing from providers and more frequent measures. The legislation requires monthly reading, but several DSOs have already indicated their intention of using hourly metering and reading, but only if it is profitable. Sweco, a Swedish consulting group, has been selected by Energy Markets Inspectorate [71], the country's energy market, to study the benefits of hourly meter reading and the upgrades that may be necessary. Utilities selected simpler technologies at the beginning, so about 15% of these meters installed are not really smart, they are only capable of monthly reading. This will be fixed in the coming years by being replaced by new ones.

In 2002, a cost-benefit analysis was done to check the necessary investment in both cases of hourly and monthly reading. The overall costs per user for an hourly based system were €18 per year, and it is also in addition a cost of €5 for maintaining the systems. In the case of monthly reading systems, the cost was just €18 per year in total, so due to the small difference in costs and the big benefits that can be achieved with more accurate bills, hourly reading systems should be developed to help Swedish consumers to better understand how energy demand causes prices to fluctuate and engaged them. This is going to happen because regulators support it, retailers would benefit from reduced risk of price and consumers would save energy and money. New requirements, recommendations and a timelines were expected by late 2010 [72].

Swedish utilities have been totally involved in this new market scope and several projects have been taken so they could achieve the requirements of the European Union.

Vattenfall

Vattenfall is Europe's fourth [73] largest generator of electricity and the largest generator of heat. It operates in Sweden, Finland, Germany and Poland and in 2002 decided to begin the project "Number one for the customer" to get the goal of being a leader company in energy services for their customers; the target was to install Automated Meter Reading for all 850000 distribution customers in Sweden [74]. The AMR Project roll-out was completed in June 2008, and it improved their services reaching the following objectives [75]:

- Power outage reporting
- Power quality monitoring and reporting (voltage, current, frequency)
- Remote switching
- Power/peak control for demand/respond
- Real time operations
- Reduction in billing error

With the deployment of this plan, Vattenfall also got several business opportunities, like operation planning based on meter values, network planning based on PQ-data and finally outage data handling based in real time alarms and statistics. The roll-out scheduled was segmented in three subprojects under the name "AMRELVA Project", with the purpose of replacing old meters by AMR, detailed below:

1. AMRELVA 1 (June 2003): the supplier is the French company Actaris. The communication is based on radio and it is developed by the Swedish company Senea. The installation structure is usually connected to a concentrator, but if the location is far for the concentrator it can also be point-to-point, in this case the meter communicates via GSM with the collection system. In terms of storage capacity, the meter values are sent daily, and it's able to store data during one year.

2. <u>AMRELVA 2 (July 2004):</u> in this case the chosen supplier was the Slovenian company called Iskraemeco. A new way of communication was installed in this kind of meters, PLC to link meter and concentrator, but also GSM/GPRS is used for point-to-point situations. The meter values are sent on a daily basis and the storage capacity is only half a year.
3. <u>AMRELVA 3 (December 2005):</u> the main supplier is the Spanish company Telvent Energia SA, that delivers their system platform Titanium with meters of Echelon, with a total budget of €15 million [78]. An external operator is responsible of collecting data and Vattenfall acts as a customer and buys the information. Their system is based on a set of intelligent communicating electricity meters, powerful IP connected data concentrator and system software based on Echelon's Panoramix enterprise software platform [76]. The NES platform (Networked Energy Services) from Echelon is used as the backbone of the smart metering solution [77]. GSM/GPRS is used to communicate the concentrator and the data collecting system, PCL is used to link the meter with the concentrator. New features compared to previous versions were installed in this last generation meters, such as remotely upgradeable firmware, immediate access to meter values for the customer services and also remotely disconnect (connection still needs a manual switch on by the customer). Remote change of tariff can be done automatically and scheduled by customer service and clients are able to check their consumptions values by using a web interface. In order to detect outages, the concentrator works in a cycle; pinging all the meters using a technique to check for the presence of another party in an Internet Protocol (IP) by sending messages from the originating host to a destination device. In the near future the ability to isolate fault and restoring power for customer is expected to be supported in AMR3.

To guarantee the success of this new system, several rules should be instilled and they have to be clear since the beginning. Also it has to be some kind of incentive for the DSO's for doing it.

E.ON Sverige AS

E.ON, the largest utility in Sweden with more than 1 million customers, has selected Echelon's NES System for the deployment of 370000 smart meters [78] in Malmo, Orebro and Stockholm. The NES System was elected after the evaluation of the results gathered in Italy, where 27 million of smart meters where successfully deployed. The expected revenue for this project is approximately $30 million [80]. This system provides an open, bidirectional and extensible infrastructure that bring benefits to both utilities and customers. The objectives that E.ON wants to achieve with this election are having better control over energy usage, saving money in monthly readings and, at the same time, providing improved customer service. In the near future, next steps are being taken such as remote connect/disconnect customers and also integrate SCADA with AMI/AMM [81].

Göthenburg Energi

The Western Sweden's leading Energy Company Göthenburg Energi is installing 270000 General Electric's smart meters [82] in the city of Gothenburg [83], due to fulfill the government's mandate. The new meters will benefit customers allowing them to be better informed about their actual consumption and then adapt their energy usage accordingly and also the utility, providing real-time data access.

They will be installed by NURI Telecom, and the chosen technology for communications will be Ember's ZigBee infrastructure to support and AMI system for electricity. ZigBee is an economical wireless mesh networking. It provides highly efficient connectivity between small packet devices. The low cost allows this technology, as a result of its simplified operations, to be easily deployed [84]. Due to its low power output, ZigBee devices can sustain themselves by using smaller batteries to have a longer life. With the system in place, Göthenburg Energi will be able to provide accurate monthly bills, even down to daily consumption. The future plans are, for example, expanding the AMI system to include district heating, gas and water meters.

Staffasntorps Energi AB

The South-Western Sweden utility company signed a five-year full service contract with Landis+Gyr Enermet (LGE) to deploy an automatic metering management (AMM) solution to all its clients. The communication methods of the infrastructure are based on low voltage PLC and GPRS [85], so that a cost-efficient solution with high performance is reached. Company officials will use handled PDAs integrated with the application AIM Site Manager. LGE will provide the solutions for metering data, to manage real-time readings and reports.

Växjö Energi AB

The Swedish electricity, gas, steam and hot water supplier has launched a project called "EnergiKollen" to help consumers to better understand their energy use and consumption. The main goal of the company is to reduce electricity usage by 5% [86]. EnergiKollen is a web-based graphics solution using Microsot.NET and Oracle databases, being easy to follow by clients. Customers can log on to the service over the Internet, free of charge, in order to analyze their usage of electricity, water and heating. Their innovation respect to other solutions is system able to compare the energy consumption of different households to motivate customers to lower their usage.

7.7 - Finland

Finland is a Nordic country with a population of 5.3 million people [87], which distribution network was built during the 1960' and the 1970'; that is the main reason of why there is a necessity of investing in a new and more efficient infrastructure. The peak consumption in the Finnish electricity network is usually covered by using fossil fuels, so in 1990 Finland became the first country to fine carbon emissions. In 2009, the government launched a plan so that utilities have to install smart meters for 80% of the approximately 3.3 million households by the end of 2013 [88]. Late studies, by the research organization VTT, found that one half of Finland's electricity meters will be read remotely by 2010 [94].

The deployment of AMR solutions is the solution for Finnish companies to have monthly billing, hourly data collection, remote switching and support to network planning. The development of this new technology also seeks an annual electricity savings in the range of 0,5-1,5 TWh, corresponding to 0,1-0,4 million ton CO_2 [89], but authorities are convinced that for making this project successful, it is vital customer's participation providing utilities with tailored feedback. A report from the VaasaETT Global Energy Think-Tank declares that just by using smart meters, Finnish customers will reduce their energy consumption by 10,3%, more or less the same the result as of an European Commission's report that concludes that the energy savings can be of 10% in case of businesses and 7% for residences [91].

The minimum features required [90] in AMR by the new legislation of 1st March 2009 are:

- Hourly interval measurement data available next day to market actors and customers
- One load control signal to customer
- Support for TOU-tariffs and controls
- Registering over 3 minutes outages
- Two way data communication
- Data security

In order to get cheaper, more accurate and time saving devices, spreading functionalities into separate systems can be the solution. In Finland, metering is a task responsibility of the distribution companies. At this moment, DSOs measure from customers only once a year, with non-hourly readable meters. The purpose is that data will be collected from smart meters at least once a month by 2011, and from January 2012, all smart meters must be read once a day. There are some exceptions related with the hourly metering issue, such clients using [36]:

- A main fuse no more than 3x25 A
- A main fuse with over 3x25 A but with a consumption under 5000 kWH/year and electricity supplied by the delivery responsible supplier

The way that authorities are taking this project is very innovative. Social networks are strongly held between people, and can be a good tool for involving customers in the task of saving and using in a responsible way their energy. By being able to access friend's data consumption, clients can compare their activity with what their neighbors are doing, so they can improve their energy use and check, real-time, how much energy they are wasting.

There are some national plans in process such as:

Helsingin Energia

With a total of 400000 customers and covering more than 90% of heat demand of Helsinki [92], Helsingin Energia is one of the largest utilities in Finland. At this moment, the company is working in the deployment of 12000 smart meters around the capital area [93]; working together with some other providers like Smarteq, for developing the wireless transmission technology and taking care of the machine to machine (M2M) communication; Aidon Oy for supplying the smart meters and Tritech to solve the communication platform.

In the first phase of the project, which was finished by the end of 2010, all currently meters will be replaced for the new intelligent ones, so that the employees will not need to move to the houses to make the readings. From that moment they will be able to take usage readings remotely. Aidon's smart meters are based in open-architecture due to meet international standards and for being easily updated. The way of transmitting information can be by using routing cables, or by radio frequency. The communication solution chosen is called MeshNet, provided by Tritech's. MeshNet utilizes small, low-power radio transmitters based on the ZigBee platform, which transfers information from the smart meter to centralized data collection centers. With all these solutions, Helsingin Energia guarantees that by using simplicity, openness and flexibility solutions; their project will cost less than a half what other markets can presently offer.

<u>Vaasan Sähköverkko Oy</u>

The Finnish utility, with a total amount of 62000 customers, has an energy distribution of approximately 1TWh per year [95]. The pilot project of AMM that is running at this moment is one of the largest ever undertaken in Finland, with a cost of €10 million to fulfill the goal of automatic read, control and manage all its metering points [96]. Before taking the decision to undertake such huge investment, the company made a depth survey about the advantages of installing AMM in its network, taking special care of the Italian case.

The deployment started in spring 2008, with a rate of 4000 meters per month. The chosen company for being responsible of the management, schedule installation, system integration and acceptance tests, was Landis+Gyr's Advanced Metering Management. Field device installation was carried out by a partner of Landis+Gyr Oy, and the selected technology for the meters is given by Gridstream AMM, which is able to offer tools to monitor energy consumption. It also benefits the utility, by giving Vaasan the skills of streamline its operations and optimize network management, getting a more efficient system that accelerates cash flow.

About the communication architecture, the selected system is based in a combination of GPRS and low voltage network, as Power Line Communication, that guarantees a cost-effective and high quality solution. The integration between the customer's information system and the energy data management system is covered using an application called AIMIA (Active Information Management Integration Application) [97]. It's a unique integration platform for connecting Enermet AMM system to Energy Company's other IT systems which main features are the following ones:

- Seamless two-way integration for key system functions, such as the Customer Information System (CIS), Energy Data Management System (EDMS) and Network Information System (NIS)
- Standardized interfacing technologies, such as SQL, XML, Web services
- Fast adaptation to different external systems

As the client plays a vital role in this project, it's vital providing them with the essential tools to get informed about their energy consumption and activity, so afterwards they can act accordingly. AIM Dashboard is the technological response from Landys+Gyr to this issue, a Web-based application which offers quick an intuitive access to all the information regarded.

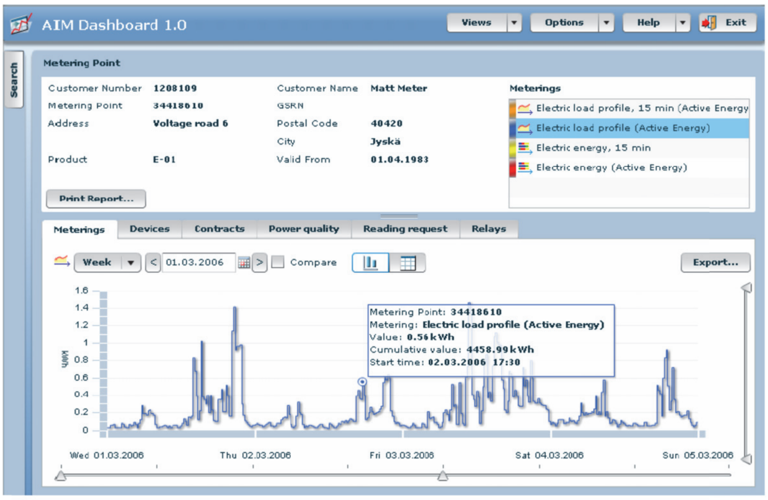


Figure 27: *Example of the AIM Dashboard given by Landis+Gyr [98]*

The main feature of this Web-based technology is that it's easy to interact for customers, providing those services tools for searching, viewing and controlling their energy activity.

Fortum

With a total of 550000 customers in Finland [99], Fortum is a leading energy company focusing on the Nordic countries, Russia and the Baltic Rim area. New challenges have been taken trying to improve services to its clients, that is the reason of the new project with smart meters that is being developed together with the IT company Telvent. With a total budget of €170 million [100] and installations scheduled to begin in 2011, Fortum wants to achieve precise hourly measurements to retail customers and also bi-directional measurement of renewable power generated at home by the end of 2013.

Telvent will play an important role in the success of plan, being in charge of the project design, development and start-up of the smart meter Management System (SMM); Etel Networks will be responsible for the meter installations. By using Telvent Smart Metering Titanium technology integrated with Echelon's Networked Energy Services (NES), customers will be able to access to their power consumption information instantly and afterwards act according to their needs. Fortum will be profited by administering and operating its network more efficiently, reliably and with less cost by managing peak loads during an incident and outage periods.

Meters will compile the essential features to be capable of store, analyze, process and discriminate, in real time, all the information required by the company; also detecting outages for faster power failure resolution. Apart from these basic requirements, they will be also able to report, automatically and via Internet, data consumption with the possibility of access the database with other devices, for example mobile phones, via a local wireless interface. The communication issue is based by an IP network equipped with a secure ZigBee wireless interface [101].

8 - Conclusions

The necessity of a revolution in the electrical system is obvious, and smart meters will be the solution. The development of smart grids will be built over the new electronic measuring devices, which implies a challenge for the next few years in the engineering field.

Since Italy began with the implementation of smart meters in 2006, many other countries have followed in the race for a new electric model. In all these years, a wide variety of configurations have been proposed, increasing diversification in the field of research. It is therefore essential, the creation of a unifying standard in research and development efforts, avoiding duplication and unnecessary expense. International bodies, like the EU, must determine from the wide variety of possible technologies, a range that annotates solutions optimally.

For this reason, some countries prefer to remain in a state of “stand-by”, waiting for the results obtained in other locations, and afterwards, move to action. The financial outlay is very large; the development state is still immature, so the attitude of prudence can be a very intelligent approach in order to avoid wasting efforts. However, institutions cannot be stopped; they should seek partnerships with universities and research centers to get a final model as soon as possible.

The current electrical system is not prepared to support the consumption of today. It was not built to integrate renewable generation systems, or for example, to power electric vehicles. If we want to achieve sustainable development, we must reduce emissions of polluting gases to the atmosphere, and to achieve this, the new generation ecological systems have to be integrated with the electrical network. The solution starts by replacing the current bulk generation systems by others of smaller size and more distributed around the areas of consumption.

The change will not only be performed in terms of infrastructure, but also in the way of operation. Customers are going to move onto a key role, synergy will be created between users and companies, both seeking their benefits. Through an innovative charging system, the ToU Tariffs, users will be able to know in real time how much the electricity costs, so they can plan when to use their appliances in order to save on their bills. In this way, through an economical penalty shaped of higher prices, avoiding peak times, it will be possible to improve the reliability of energy supply.

Facing the future, it is the challenge of enhance user’s experience, ensuring that it is affiliated with the electrical distribution system. For this reason, intuitive applications must be developed, in order to make everyday tasks easier, adding ancillary services to smart meters. There are several barriers that may hinder the change of existing meters by the new "smart" ones, including the rejection by society. In a society in which change into something unknown is not attractive, it is needed to take information and training campaigns so as to ensure that efforts are not vainly.

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Appendix A. Effects of faults [102]

1. Effect of a sudden loss of generation (or import from another part of the system)

Possible result	***Containment actions (in order of preference)***	***Time available to implement action***	***Possible further effects***
Frequency fall	Increase generation Reduce demand	.1 seconds to seconds	Insufficient demand disconnected will lead to cumulative loss of generation and system collapse. Excessive disconnection of demand or poor damping of governors may lead to oscillation of frequency, cumulative loss of generation and system collapse.
Transmission overload	Increase generation Reconfigure network Reduce demand	Seconds to minutes	Sequential tripping of overload circuits, possibly leading to an uncontrolled system split. This implies (possibly large) generator-demand imbalances in each section.
Transient instability	Increase generation Reconfigure network Reduce demand	Milliseconds	System oscillations and tripping of circuits (e.g. on impedance-protection) possibly leading to an uncontrolled system split, as above.
System oscillations	Increase generation Reconfigure network Reduce demand	Seconds to minutes	Build up of oscillations and circuit trippings up to an uncontrolled system split, as above.
Voltage drop	Increase generation (real and / or reactive power) Reconfigure network Reduce demand	Milliseconds or seconds to minutes	Cumulative voltage falls as tap changers operate. Transmission voltages fall and currents increase with circuit trippings and generator excitation systems limiting leading to system voltage collapse and probable system instability.

2. Effect of a sudden loss of demand (or export to another part of the system)

Possible result	***Containment actions (in order of preference)***	***Time available to implement action***	***Possible further effects***
Frequency rise	Reduce generation	.1 seconds to seconds	Over responsive governors may lead to oscillation of frequency. Cumulative loss of generation and demand with possible total loss of system.
Voltage rise	Reduce reactive power on sources Reduce generation	.1 seconds to seconds to minutes	If not halted a severe voltage rise will lead to extensive faults and tripping of circuits possibly resulting in system collapse.
Transmission overload	Reduce generation Reconfigure network	Seconds to minutes	Sequential tripping of overloaded circuits leading to possible uncontrolled system split. This implies (possibly large) generator-demand imbalances in each section.
Transient instability	Reduce generation Reconfigure network	Milliseconds	System oscillations and tripping of circuits (e.g. on impedance-protection) possibly leading to an uncontrolled system split, as above.
System oscillations	Reduce generation	Seconds to minutes	Build up of oscillations and circuit trippings up to an uncontrolled system split, as above.

3. Effect of a sudden loss of transmission (no system split)

Possible result	***Containment actions (in order of preference)***	***Time available to implement action***	***Possible further effects***
Transmission overload	Reconfigure network Adjust generation Adjust generation and demand	Seconds to minutes	Sequential tripping of overloaded circuits leading to possible uncontrolled system split. This implies (possibly large) generator-demand imbalances in each section.
Transient instability	Reconfigure network Adjust generation Adjust generation and demand	Milliseconds	System oscillations and tripping of circuits (e.g. on impedance-protection) possibly leading to an uncontrolled system split, as above.
System oscillation	Reconfigure network Adjust generation Adjust generation and demand	Seconds to minutes	Build up of oscillations and circuit trippings up to an uncontrolled system split, as above.
Voltage fall	Reconfigure network Adjust generation (real and/or reactive power) Adjust generation and demand	Seconds to minutes	Cumulative voltage falls as tap changers operate. Transmission voltages fall and currents increase with circuit trippings and generator excitation systems limiting leading to system voltage collapse and probable system instability.

Appendix B. Potential Reductions in Electricity and CO_2 Emissions in 2030 [103]

Mechanism	Reductions in Electricity Sector Energy and CO2 Emissions[a]	
	Direct (%)	Indirect (%)
Conservation Effect of Consumer Information and Feedback Systems	3	-
Joint Marketing of Energy Efficiency and Demand Response Programs	-	0
Deployment of Diagnostics in Residential and Small/Medium Commercial Buildings	3	-
Measurement & Verification (M&V) for Energy Efficiency Programs	1	0,5
Shifting Load to More Efficient Generation	<0,1	-
Support Additional Electric Vehicles and Plug-In Hybrid Electric Vehicles 3	3	-
Conservation Voltage Reduction and Advanced Voltage Control	2	-
Support Penetration of Renewable Wind and Solar Generation (25% renewable portfolio standard [RPS])	<0,1	5
Total Reduction	**12**	**6**

(a) Assumes 100% penetration of the smart grid technologies.