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Evaluation of new Electricity Meters

Communication protocol

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“What you read, without any effort, it has been written many times with great effort.”

(Enrique Jardiel Poncela)

Abstract

New technologies developed (new ways of energy generation and consumption) are promoting the introduction of improvements at electricity networks. Currently, European legislation is promoting changes in electricity networks of member states. These changes include new technologies to facilitate the introduction of renewable energy sources to the grid and have a more efficient use of energy. Smart grids are able to achieve these objectives.
One of the important issues at smart grids is the requirement of having good measures (to be able to control the power grid) and good communication between all the electricity market participants. Smart meters are part of the smart grid technologies and are actually useful to solve this task
Smart meters have a lot of features, but the most important is the two-way communication. This really differentiates this meter and electronic meters.

This Master Thesis is going to study deeply this communication to understand how it works, by developing an own program able to read the measurements taken by the meter.

Acknowledgements

I would like to thank my supervisor Ingmar Leiβe for accept me to developing his idea in my Master Thesis. He has contributed with guidance and ideas. Thanks for the confidence and freedom to develop the project.

I am grateful to E.ON because of provisioning with the smart meters used along the project.

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Last but not least I would like to dedicate this thesis to all the nice people around me: old friends and new friends that I have met during my Erasmus period. With special regard to my family, I cannot thank enough the support received these months.

Lund, March 2012
Víctor de la Fuente García

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Chapter 1: Introduction

The focus of this work is to increase the knowledge about the new electricity meters and the potential of using their available functions in combination with more active distribution networks. One main aspect is to study the feasibility to use the measurement values at the customer side. New electricity meters, installed in all Swedish households and at other customers, are capable to measure the voltage at the customer side. These measures can be used for the voltage control. With complete knowledge of the network we can control it and this can be translated into more efficient use of the electricity.

This chapter introduces the work presented in this thesis. The motivation for the work is described and the contributions obtained are summarized.

1.1 Motivation

The electrical network is suffering an evolution as long as society is evolving. New ways of generating energy, as a greater presence of renewable energies, and the presence of new types of consumption, such as electrification of the transportation sector, require a number of changes in the electrical network.

· Facilitate the use of renewable energies.
· Make more efficient use of energy.
· Be more flexible with future changes.
· More active electricity consumers.

These changes could only be carried out with the development of new technologies. The concept includes Smart Grid [Figure 1] technologies that make it possible by controlling the electrical network. For this control, to know the consumption and energy generation is essential.

Figure 1: Smart Grid concept [5]

Since July 2009 monthly measurement readings of all electricity meters installed at private customers in Sweden are required. Therefore new electrical electricity meters have been installed during the last years.

The new electricity meters are equipped with some additional functions, beside the measurement of consumed energy. To provide the possibility of effective measurement readings, the electricity meters are provided with bidirectional communication which today is mainly used for remote meter readings. Furthermore voltage limit violations are reported to the system operator.

Notwithstanding several additional functions as voltage measurements and controllable outputs are normally not used today. However, some of these functions can be used for active distribution networks (Smart Grids). The new electricity meters with two-way communication can therefore be seen as a central unit for future active distribution networks.

Therefore, a better understanding of how the meter takes measurements and how to communicate is critical to know the strengths and weaknesses of the new meters and to improve its functions and thus the operation of the Smart Grid.

In this research, the communication of smart meters will be studied in detail. The master thesis project aims to increase the knowledge about the new electricity meters and the potential of using their available functions in combination with more active distribution networks.

1.2 Objectives

The purpose of this work is to obtain a better knowledge of the feasibilities which are provided by the new electricity meters and their communication, an investigation of the functions and their communication protocol is needed. Moreover the benefit they add to active distribution networks is needed to be studied.

The aim of the master thesis project is to be able to read measurement values, e.g. voltage measurements from the electricity meters at the customers.

Another objective is to identifying the limitations caused by the transfer rate of the communication used today. An increased transfer rate would offer the possibility of real time measurements of the voltage at the customer side for voltage control and also simplify the fault diagnostics in case of disturbances.

The master thesis shall increase the understanding for the communication protocol used by the electricity meters.

1.3 Outline of the thesis

In *Chapter 2: Electricity meters in smart grids* an overview of electricity meters in smart grids is given. It starts with a short explanation of the different electricity market participants. Once this is known, smart grid, as evolution of electricity network, is explained. How smart grids can facilitate the addition of renewable energy sources or how smart grids can achieve an efficient energy use. These are some of the questions that will be answered among others. At this stage, the current situation of smart grids and smart metering in Europe is going to be studied, focusing on Spain and Sweden.

At the end of the chapter, the reader will notice that smart meter technology is needed at smart grids. In

Chapter 3: Smart meter types, different types of meters and how they work will be explained.

Chapter 4: Smart meter communication and setup is going to present the meters used, the software provided by the manufacturer and how to get the sequence of the commands to follow the communication protocol. First of all, the equipment that will be connected and the software provided by the manufacturer are analyzed, specially, the parts used along the thesis. Before starting with the communication code program, the communication protocol and how it was taken will be explained.

The laboratory work to develop a program that communicates with the meters will be detailed in *Chapter 5: Test performance*. The chapter structure coincides with the step by step that has been taken place in the laboratory. Finally, how the final program has been reached is written. It starts from a simple serial communication program and continues with the improvements implemented until the program that communicates over GSM with three counters connected simultaneously is made.

To conclude with one of the objectives of this work, the times needed to read the measurements with the different options that the tool developed can manage and EMH software will be compared. This will take place at *Chapter 6: Evaluation. Time needed for reading measurements.*

A short summary of this thesis and the conclusions obtained by this work are presented in *Chapter 7: Conclusions*.

An outlook on further work that could be done within this area is given in the last *Chapter 8: Future work*.

Chapter 2: Electricity meters in smart grids

This chapter[1] is going to be about the smart grids and the benefits that this new technology offers. To understand it well, it is necessary to know the components of the electric grid. Also Smart meters are going to be carefully studied. How they work, the different parts of an Smart Meter or how the signal is processed are some of the questions answered. Furthermore, the current situation of this technology and how it is being developed in Europe (Sweden and Spain especially) is studied in this chapter.

2.1 Electricity market participants

The first thing that is necessary to know is the different participants that are involved from the electricity generation to the consumption.

2.1.1. Electricity producers

An electrical machine is a device that transforms electrical energy to mechanical energy and also mechanical energy into electrical energy. When the electrical machine is working at the second option is called generator. The source from what the mechanical energy comes can be very diverse. Nowadays the renewable energy sources as for example wind power [Figure 2], hydropower or solar energy are being developed to substitute other ones more pollutants as nuclear energy.

The electricity companies have one or more electric power plants, selling electricity to electricity suppliers. These companies must measure the electricity that they are injecting to their networks. These measurements stored on an hourly basis are used by companies to bill delivered energy to suppliers.

Figure 2: Windmills. Generator that transforms wind energy into electrical energy [28]

[1] Chapter 2 is based on Bollen, M. (2011). *Adapting Electricity Networks to a Sustainable Energy System - Smart metering and smart grids.* Sweden.

Nowadays, renewable energy sources (solar panels, windmills…) allow consumers to be at the same time energy suppliers as long as they have some energy sources.

2.1.2. Grid operators

The electrical network [Figure 3] is the way whereby electrical energy is transported from generation to consumers. It is the meeting point between all electricity market participants.

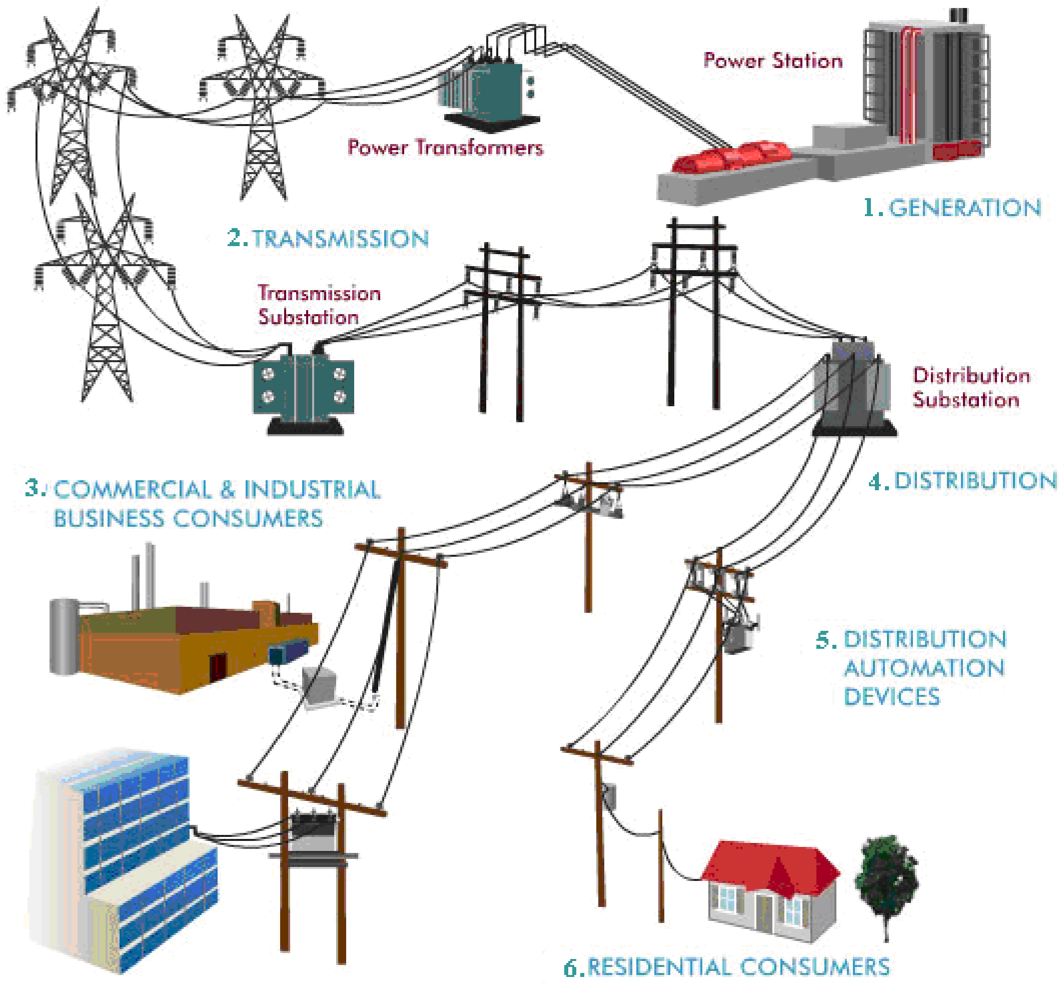


Figure 3: Electric network scheme [11]

Network companies are responsible for the maintenance of electrical networks. Their task is not only to keep them in good condition, but also they should ensure proper operation in the future. Since power generation is evolving to a greater presence of renewable energies and new consumers, as the appearance of electric cars, it is the responsibility of electricity network companies to adjust the grid at the same time that new technologies appear. To achieve that, they should carry out the necessary changes to the evolution of the electric network.

Electric network companies have rights and obligations. Electricity producers, grid operators and suppliers are different parts of the electricity market. Grid operators can transport energy, but they are not allowed to produce or sell it. In addition, these companies should measure input and output electricity flow to the network. On these measures, necessary calculations for trade in energy are executed. Therefore, it is important to have reliable measures to have also good calculations. Smart meters, included in the technologies associated to smart grids, are devices that provide reliable measures.

Moving from the electric network as we know it today to a smart grid is the most efficient way to prepare the network for future changes.

2.1.3 Consumers

Everyone who needs to use electricity and take it from the electricity network is considered as consumer. As expected after studying participants in the electricity market before, there exists a commercial relationship between consumers, electric supply companies and electricity network companies.

Households as well as large or small companies are considered as consumers as long as they are using the electricity supplied and transported along the grid.

2.1.4. Suppliers

Electricity suppliers are responsible of selling electricity to consumers. These companies are responsible party for balancing supply and consumption. Electricity price is fixed in a contract between supplier and consumer.

2.2 Smart Grid

As it has been described in a previous section, it is very important to have a correct measurement of the grid energy and also some developments on it are needed. One of some technological developments are the smart grids and the smart metering, let see what does it mean and what is considered as smart grid and smart metering.

2.2.1. What are smart grids?

Looking for a definition of what a smart grid is, this could be a good one: *"A smart grid is a digitally enabled electrical grid that gathers, distributes, and acts on information about the behavior of all participants (suppliers and consumers) in order to* *improve the efficiency, importance, reliability, economics, and sustainability of electricity services"*[2].

The electrical network is not an isolated entity, it is the set of different networks. The power generation can come from different companies, even from consumers who are also generating energy. The electrical network maintenance and supply of electricity is competence of more than one company. Therefore, coordination between all parties that coexist is needed to have a grid working efficiently. Smart grids improve the performance thanks to better communication, and therefore, better coordination between the different parts which form the grid [Figure 4], moving from a manual control to a more automated control.

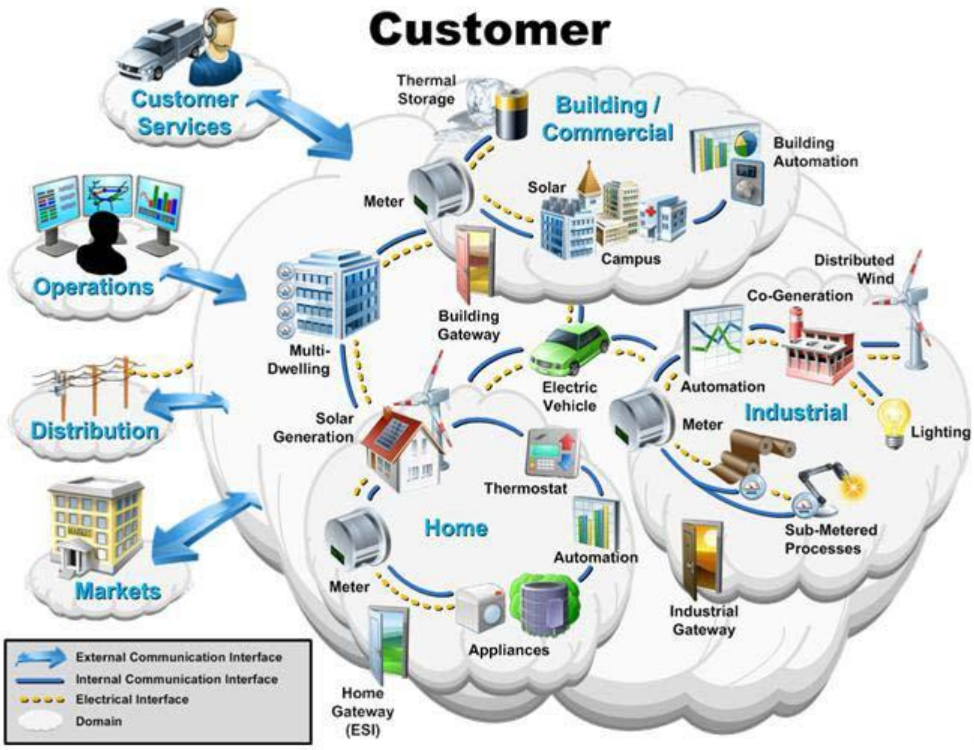


Figure 4: Relation between the different parts of a Smart Grid [7]

Smart grids, also known as intelligent grids or active grids, combine control technologies with bidirectional communication systems, allowing automated coordination between the different parts that make up the network, as it was mentioned above. This allows connecting to the network: electricity producers, electricity suppliers and those who act in both ways, by an efficiently economic way and getting a sustainable power network with less loss and greater quality.

[2] 97*Wikipedia*, *Smart grid*. (2010). Retrieved from http://en.wikipedia.org/wiki/Smart_grid

The smart grid concept can be understood by knowing the requirements that has to achieve. These would be some of them:

1. - Autonomous maintenance.

Use the measurement and control systems to anticipate, detect and respond to possible system problems. Thus, if the system suffers some type of error (such as network congestion) the grid detects the problem, isolate and fix it by itself.

2. - To encourage consumers to be more active.

Consumers can be an active part at the control of consumption and energy demand. Reporting consumer about the price of electricity in real time can cause that user will decide at what moment grab power from the network. By this way, if electricity consumption increases, increasing also the electricity price would induce to slow down the consumption. To achieve this, it is necessary to educate consumers and provide them with the needed devices.

3. - To be reliable.

A good and fast response to a disturbance from human or natural causes is one of the requirements that a smart grid has to achieve. Continuous monitoring with real time information of network status is part of the management and control to avoid potential errors.

4. - Efficient use of the grid.

There are some ways to make a more efficient use of the grid. Prevent peaks in electricity networks. Match consumption and generation by controlling power flows.

5. - To facilitate the integration of different forms of energy generation.

A stronger presence of renewable energy calls for a modernization of the grid, since a real time power flow control and provide bi-directional metering is necessary to regulate the consumption and production of electricity.

To understand the concept of smart grid better, the different improvements provided by these networks, the usual problems of the current use and the requirements commented before will be studied in detail below.

2.2.2. Renewable energy sources in smart grids

The production of more energy by renewable energy sources means the necessity of realizing more changes in the electrical grid. The problem caused by this type of power generation is going to be studied with focus on wind energy. The problems that occur with the other renewable energies [Figure 5] are practically the same, but wind power is one of the most used in countries like Sweden or Spain and it is a clear and easy example to understand these problems.

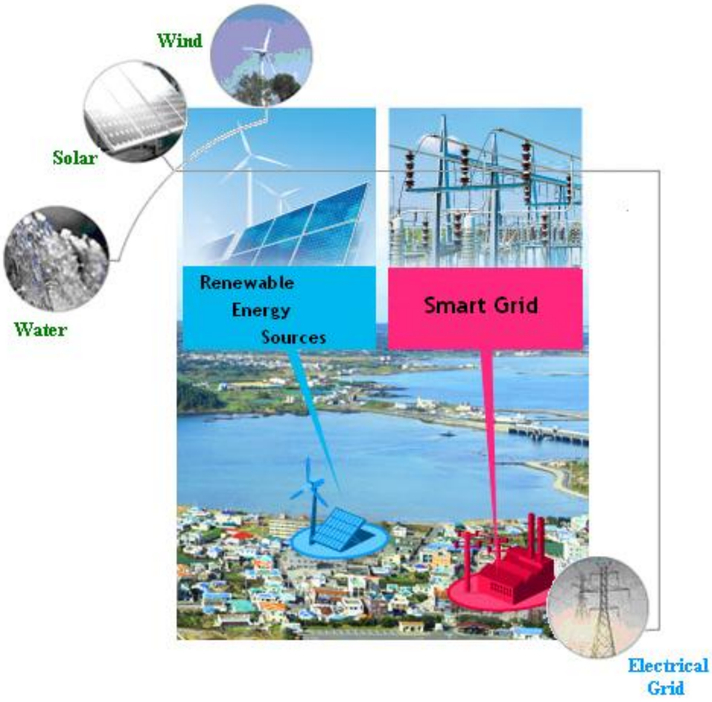


Figure 5: Renewable energy sources and Smart Grid [18]

The effect of using wind power depends of the quantity used. For a small amount the effect is contemptible, but for large amounts that exceed a threshold level these effects have to be considered. This threshold level known as hosting capacity indicates the quantity of new source that can be connected to the grid without violating the performance index limit [Figure 6].

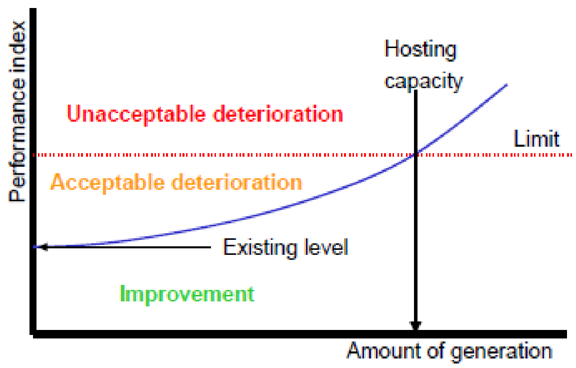


Figure 6: Hosting capacity concept [3]

The main problem is that in low voltage networks, the maximum voltage magnitude is high during periods of low load. Those networks present a huge range between maximum and minimum voltage levels. For fluctuating energy sources (such as renewable energy sources) the increase in minimum voltage is small, therefore the result is an increase in maximum voltage that is not proportional to the rise in minimum voltage [3]. This problem becomes more problematic as amounts of this fluctuating energy augment.

Using smart grids makes it possible to increase this threshold level by a more efficient way than using conventional technologies. For example, there is an innovative solution so-called Active Network Management (ANM) that controls the output of fluctuant energy generators to match the available network capacity in real time and, hence, improving the grid hosting capacity.

Two effects are distinguished when impact of wind power on the electrical network is considered: effects on distribution networks and effects on the transmission grid.

2.2.2.1. Distribution and transmission networks

As it is represented in the Figure 7[3], the transmission (power) network transports the electricity from the generating station to the substation where the step down transformer is located. After that, the distribution network carries the electricity from substation to the customer.

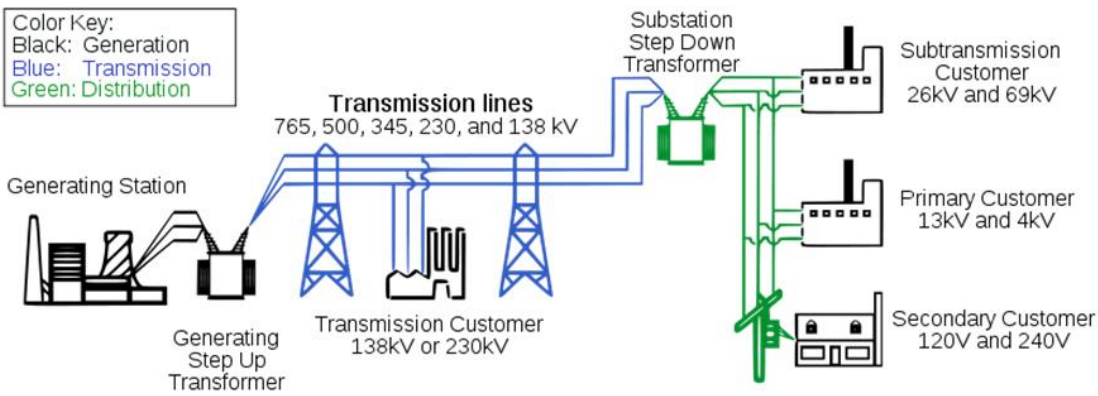


Figure 7: Distribution and transmission networks [6]

The main differences between both networks are:

1 - The level of the voltage that handles the network.
2 - The amount of the power transported
3 - The purpose of the Network.

[3] This figure is an example to show the difference between distribution and transmission network, it does not represent the normal voltages of distribution and transmission network in Sweden.

After the short description about the distribution network and transmission network, it seems clear that the purpose of each one is different. Focusing on the values of voltage that are handled and the amount of the power transported, we see that the transmission lines have to manage higher values of voltage and power. The ones used in transmission networks are so-called high voltage lines (typically from 138 kV up to 765 kV and these lines can transfer power higher than 75 Megawatts), while the ones used in distribution networks are known as medium voltage lines (in the range of 1000 V to 69 kV and these lines can conduct a power belong 75 Megawatts).

2.2.2.2. Effects in distribution networks

Nowadays, wind farms are connected to the grid by regional networks or directly to the transmission grid. First plants connected will not create problems. But, as long as the number of plants increases, this turns into a problem because many local distribution networks are not prepared to accommodate so many.
These are some of the problems that can arise from the connection of high levels of wind powers [Figure 8]:

· Overvoltages can be caused because during high generation periods when the consumption is low, the injection of active power increases the voltage levels. If the energy generation exceeds the sum of the demand, the grid can be overloaded. Regions with weak grids, lots of wind power and not too many consumers can suffer easily this problem.

· The presence of consumption bigger than the limit that can be supplied with power generation causes that there would be more power demand than can be generated. The system will start to be unstable, which could induce into a fault that causes the disconnection of consumers. If there are more consumers than necessary this can cause a disconnection due to a fault.

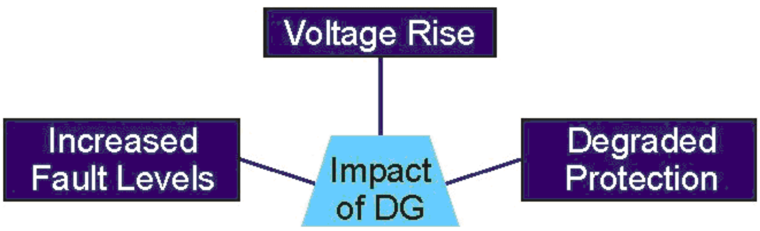


Figure 8: Effects of renewable energy sources on the distribution network [8]

Measurements at different parts of the grid and communication infrastructure of smart grids permit the control of local loads and generation (i.e. energy producers can be disconnected if the energy generated can produce overvoltages due to a low consumption). This control, as a method for grid protection, can manage a larger amount of local generation than current methods used for increase hosting capacity.

When demand and generation mismatch as in the case of high demand and low generation or vice versa, overload and overvoltage can occur respectively. Therefore, if it is possible to control local load (demand) and generation, reducing and/or increasing them depending of the situation, the problem will be solved.

2.2.2.3. Effects on transmission grids

One of the important effects of increasing electricity from renewable energy sources is he additional power flow in the grid. This problem is not specific to this type of energies, it appears whenever new production capacity is connected.

Figure 9: Example of a graphic where it is shown the intermittence of wind power signal during a day. [27]

This is not the only problem. Electricity produced by non-renewable energy sources, the amount of energy generated and the moment when it is generated is controlled, thus two not desired possibilities: both, production and consumption are high or low. The energy produced by wind farms is not constant, it is intermittent and it does not depend on the consumption [Figure 9]. For this reason, in a situation where there are large amounts of wind power, two more extreme scenarios appear, when consumption and production do not match: production is low while consumption is high or high production and low consumption.
It is usual that the renewable energy generation point are spread across the country and in the same country different places could suffer the situations discussed above. Increased communication and improved energy flow that allows electricity transportation from one point with more production than needed to another with deficit are some of the changes that transmission network has to face.

There is another reason why this improvement of the electricity flow has to be developed. One of the consequences of making renewable energies the main source is that the maintenance of conventional power plants will be economically unviable. That means that, as these new energies are not able to be stored, reserve energy will be lost and it would not be possible to ensure security of supply when there is little wind.

To face the challenges needed in electricity networks, it is also needed by the electricity network companies to find the best solution to them, choosing between conventional technologies (transformers, lines and cables…) or smart technologies. Conventional solutions are expensive and take a long time from the project of improving the network starts until it ends. Besides, smart technologies are more flexible and have the technologies needed to balanced short-term intermittent generating by controlling the demands and with technologies to save electricity. Also economically the option of smart technologies is more interesting because after making an initial investment the addition of new improvements will not be as expensive as with the nowadays technologies.

2.2.3. Reducing peak network load

Peak load can be defined as "*the maximum power required to supply customers at times when need is greatest*"[4]. The capacity requirements of the network is determined, among others, by the maximum load that it components like cables, transformers or generating plants can hold. One way to reduce peak network load is to increase the capacity of the different components of the network. These investments could be reduced developing technology to smooth peaks in network load [Figure 10].

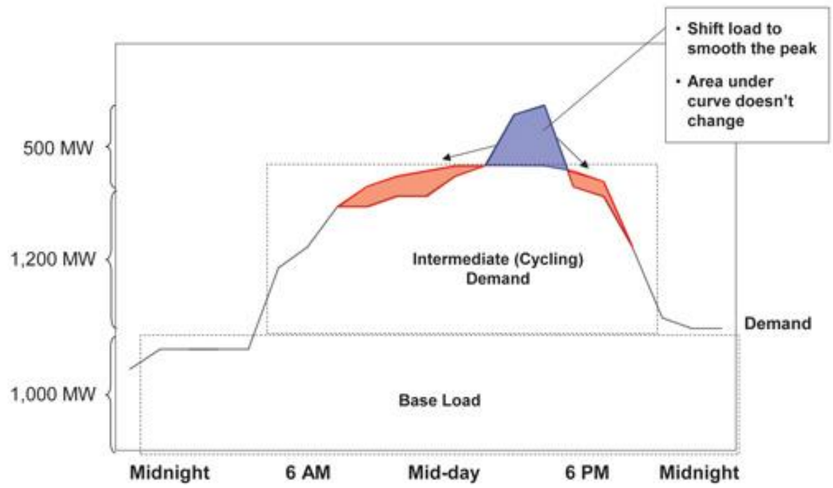


Figure 10: Smoothing a peak load [16]

Before understanding how new technologies can decrease load peaks it is important to understand what determines the need for transport capacity. The maximum amount of electricity that can flow through a grid is limited by the maximum operating temperature that this component can handle. Some features as: the amount of current, ambient temperature and also the waveform of the current, determine a component's operating temperature. Therefore, a way to improve the transport capacity would be improving the thermal features of the grid components. But there are also other ways to have the same solution:

[4] Definition extracted from *Energy Vortex*
http://www.energyvortex.com/energydictionary/peak_load__peak_demand.html

· Filtering the distortion of the current waveform, compensating the distortion caused by equipment installed at consumers facilities.

· Adding capacitor banks is possible to compensate reactive power. By this way, reducing reactive power, the power flow is reduced. As the required power is the active power, with this upgrade the way the network works is more efficient.

· Demand suffers greatly variations along the time. These variations are more perceptible at the distribution network than in transmission network because variations at higher voltage levels occurred as a result of a large number of consumers tend to cancel each other out to certain extent. The use of the electricity grid will be more efficient if smoothing the demand over time is possible. This “time shifting” of demand is one of the important possibilities that brings the smart grids. Demand can be managed, smoothing peaks by spreading out the demand over time. To achieve that, some methods are available: change the signal prices depending on the peaks, grid operators controlling the consumption or the use of energy storage capacity to meet demand on the grid when required.

· Fit the protective algorithms that describe the maximum electrical energy that can flow through the components, will increase the amount of electrical energy that can be broadcasted. For example, monitoring line temperature and using wind cooling.

The solutions to peak load problems, which are used until now, are increasing the generation capacity and reinforce the transmission grid. Thereby, if at some place appears a peak demand it can be met by augmenting production in another region. This solution, to reinforce the transmission grid, is expensive and needs a lot of time to be arranged. Another option to reduce the size of peaks is giving more importance to storage and demand measures.

Another tool that can be used is the network tariffs. Nowadays network tariffs give no incentives to customers to participate as active consumers in a more efficient use of the grid. To achieve that, it is important to show to consumers tariffs that change the price as soon as the load on the grid changes. For example, when power flow is low, the price would be low. On the other hand, when power flow is higher, the price would increase. The communication that exists in smart technologies makes it possible, a better communication between consumers, the grid and the generation. With this information and the correct communication flow, the consumer would be able to shift load to smooth the peak. Generation, and therefore the energy flow, is depending more and more on renewable energy sources and these depends on the weather, among others, making the power flow less predictable. For this reason, continuous feedback on cost is needed to give consumers real information. Smart meters can provide this information.

These incentives and the participation of the consumers would facilitate the introduction of renewable electricity production. This participation is not only to have users consuming energy in a more efficient way due to these incentives. Users can participate adding energy to the grid, if during peak load periods the price of the energy generated rises.

2.2.4. Energy efficiency

Electrical losses are part of the energy transportation through the grid but it is possible to reduce these losses. To do that it is important to know where the losses come from. Electrical losses can be defined as the product of resistance by the square of the current flowing through.

As it was explained before, one possible solution to have a more efficient use of energy is reducing the current (reducing reactive power), because network losses are proportional to the square of the current. Thanks to the relation that exists between current and voltage, it is also possible to reduce losses by controlling the voltage. To transport the same quantity of energy, it is possible to transport it at higher voltages, as at higher voltages a lower current is needed the current is being reduced and then losses are reduced.

Another solution is to reduce the resistance in the lines, cables and transformers, by this way the losses are reduced keeping the current at the same level. For lines and cables the way to reduce the resistance goes increasing their cross-sectional area, on the other hand, to reduce the resistance in transformers it is necessary reduce the losses that occur in the core, as iron losses.

To support consumers with the detailed information of their consumption can induce a reaction in consumers that make them react in a more efficient use of the energy. Monthly bills are a way to make consumers aware about the consumption that they are having, but real time information it is better to make consumers more conscious of their consumption.

2.2.4.1. Active consumers

Active consumers are the consumers that can take part on the network situation choosing between suppliers, services, contracts or any possibility with which they can reduce their electricity invoice by other ways than only reducing their consumption.

To achieve active consumer’s objective it is necessary to support them with tariffs information. It is also important to give this information as soon as possible and have information as similar as possible to real time information. That is important because as the information given is in real time the decision of the active consumers will also be in real time, solving the problems at the moment they are caused. Some network companies already support hourly meter readings. These are some tariff examples:

· Price based on the higher consumption per hour for period of time (year or month).

· Price based on the higher consumption per hour during peak hours for a period of time.

· Price based on the load in local distribution network.

These tariffs interest to distribution companies because by this way they can reduce maximum load without grid reinforcements in addition to the communication and measurement reinforcements, which are included in smart grids.

2.2.4.2. Controlling power flows

Control power flows, demand and generation in the grid, is important for several reasons:

· It is possible to reduce production deficits by just increasing production and/or decreasing consumption.

· It is possible to reduce a local generation of renewable energy if the consumption is curtailed.

· Reduce or increase the consumption by incentives commented below. When generation is low, the price of the electricity rises, this incentives customers to reduce their consumption, and vice versa.

In case that it is desired to reduce the demand, there are some ways to achieved that:

· Reduce or switch off loads under an agreement between consumers and the system operator. For example, offering different contracts which reduce prices if it is needed to disconnect the user to control consumption.

· Rise electricity price depending on the load.

Nowadays is not an option for small customers to buy electricity at different prices in real time. With the development of new technologies as smart meters it is possible to offer this option. To support consumers with this, it is needed:

· Devices that respond according to the price of electricity by controlling the connection or disconnection of the equipment or the energy level required for its operation, according to the case.

· Electric tariffs that change depending on the state of the network: generation, loads connected...

· A good communications network to enable dialogue between the different parts that have to be communicated.

· Keep the consumer informed about their consumption by measure sampling periods as short as possible.

Manage the demand during periods of surpluses of renewable electricity is not always possible and sometimes it is necessary to reduce the generation level. Thanks to a good communication network and reliable information it is possible, for instance, control the output of, each day more common, small-scale energy generation units that most of the times are located at consumer's premises.

2.3. Current Situation[5]

The development of Smart meters in the European Union is not homogeneous, each country evolves differently. Thanks to the pressure carried out by the European Union's Third Energy Market Package, most of the EU countries have established or will implement all appropriate measures to install the new technologies so-called Smart meter. Some countries as Sweden or Italy, the most developed in this technology, have already put into practice the use of electronic meters with two-way communication for economic reasons.

Considering the regulation and enforcement implemented or planned, the EU countries and Norway can be classified as follows [Figure 11]:

- "***Dynamic movers***": This group includes countries that have channeled the way that has to be followed through plans or projects that are being conducted for the full deployment of Smart metering. The countries that can be included in this group are: Sweden, Spain, Denmark, Italy, Malta, United Kingdom, France, Finland, Ireland, The Netherlands and Norway.

- "***Market drivers***": In this group are the countries that do not have the legal framework for the implementation of these meters. The implementation is possible thanks to companies who follow with the installation of electronic meters, either by self-interest or by customer demand. The countries classified in this group are Germany, Estonia, Czech Republic, Slovenia and Romania.

- "***Ambiguous movers***": Despite the existence of a legal framework and rules, these are not clear enough for the complete, or at least as developed as other

[5] This section is based in the information find at Renner, S., Albu, M., van Elburg, H., Heinemann, C., Lazicki, A., Penttinen, L., et al. (2011). *European Smart Metering Landscape Report.* Vienna.

countries, installation of smart meters. Austria, Belgium and Portugal are part of this group.

- "***Waverers and laggards***": The waverer countries (Bulgaria, Cyprus, Greece, Hungary and Poland) seem interested, but initiatives are not enough. On the other hand, the laggards (Latvia, Lithuania, Luxembourg, and Slovak Republic) are not taking action and maybe they will have to start adopting them soon, because of European regulations.

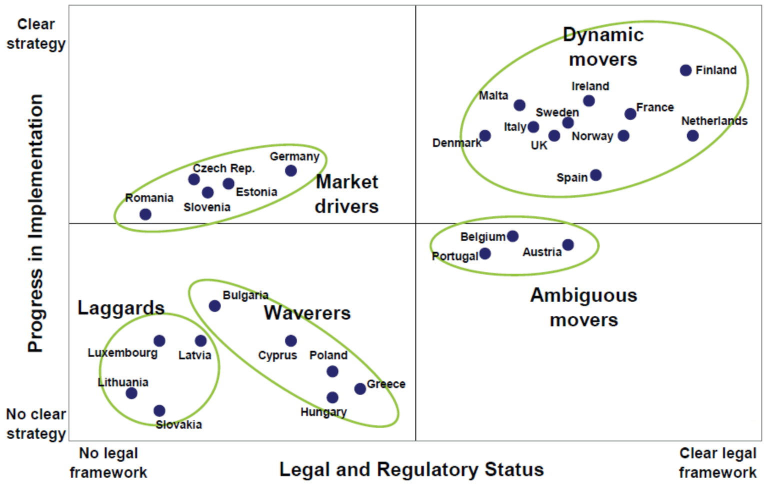


Figure 11: Graphic to classify countries depending on the Smart meter development [19]

Not only smart meters are necessary to achieve the energy savings, there are a lot of tools available for consumers to interact with the smart meters such as software programs, websites, mobile applications etc. These tools are a good way to exploit the possibilities of the meter.

These tools for feedback information from the meter are a direct benefit to the consumer. It is important to convince consumers of the added value provided by new technologies such as smart meters and the modernization of the grid, since it is necessary their intervention (not just economically but also in other complaints as may be installation, maintenance, etc). Therefore, in addition to the operational benefits brought about by these changes (reduction of peak loads, more energy efficient use, easy increase of energy produced by renewable sources ...), it is necessary to show and make known the direct benefits for the consumer.
Inform and educate ordinary users so they accept and participate in the changes that should be made, it is also one of the tasks that the countries have to do for the development of new technologies.

The table below [Table 1] describes, without going into detail, the situation of various European countries and Norway regarding to the current application, the regulatory and legal situation of smart meters. The study is not only limited to European countries, Norway is also added due to the energetic relations between this country and other Nordic countries like Sweden, Denmark and Finland.

Country	Legal and regulatory status	Implementation status
Austria	The Austrian Parliament has approved the new edition of the law that governs the electricity sector, EIWOG 2010, which defines functionalities and data requirements of a smart metering system.	The installed meters have been installed by some network operators despite not having a legal framework.
Belgium	There is no legislation for the introduction of smart metering. Nevertheless, cost-benefit studies are being done since there is a high interest in its incorporation.	Belgium is developing pilot project to test the meters and its communication technology.
Bulgaria	No plans, initiatives, studies planned or performed to regulate the smart metering.	Some electronic meters have been installed to reduce non-technical losses and the complaints about erroneous invoices.
Cyprus	There is legal or regulator framework about smart metering but it is hoped an amendment to the power law in late March 2011.	A cost-benefit report from a pilot project is being done from whose results should set the strategy for full deployment of the meters.
Czech Republic	As other countries there is no legal regulator framework. In 2006 a cost-benefit report was done obtaining a bad result.	Cost-benefits analyses are being developed by some companies (ČEZ or E.ON Ceska).
Denmark	Minimum functional requirement to smart meters are defined (Energistyrelsen, 2009).	Electronic meters were installed without legal requirements by distribution system operators what permits that more or less the 50% of the meters in Denmark will have remote reading.
Estonia	No legal obligations for a rollout for smart metering yet.	Around 2% customers have an electronic meter. Distribution networks have plans to invest into smart metering infrastructure.
Finland	Electricity Market Act (66/2009) demands 80% smart meter penetration by 2014. The regulator defined minimum functional requirements for the metering system.	All network operators have started their rollout. 50% of district heating meters can be remotely read.
France	Legislation is in preparation for a mandatory rollout. Some guidelines and minimum functional requirements for	Currently smart meters are being installed.

		electricity meters. A cost-benefit report with a positive result was presented in 2007.	
	Germany	A mandatory rollout is not planned. The national legislature (EnWG 2009) only demands to install smart meters in new buildings. Minimum functional requirements are not available. A cost-benefit report has not been carried out yet.	Some pilot projects are in progress. However, due to the unclear legal situation, the majority of the energy suppliers waits and sees.
	Greece	Greece is proceeding to a rollout of electricity smart meters and has adopted a legal framework (Article 15 of law 3855/2010).	Currently smart meters are being installed to consumers of low voltage connections.
	Hungary	There is no legal framework, minimum functional requirements are proposed and a cost-benefit report was carried out in 2010.	Pilot projects are expected to start in 2011.
	Ireland	A National Smart Metering Plan is in place, the regulator (CER) started consultation process on a rollout strategy and functional requirements for electricity	The regulator (CER) initiated a major pilot project with network operators to acquire technical experience and test customers on how they react to additional feedback
	Italy	The installation of remotely readable electronic meters is mandatory. Minimum functional requirements are available.	Rollout started in 2008 and by the en of 2011 95% of customers have received electronic meters.
	Latvia	No strategy, legal framework or cost-benefit report.	The dominant distribution system operator prepares a concept for rollout. Conventional meters are step by step replaced by electronic meters.
	Lithuania	No strategy, legal framework or cost-benefit report.	No activities.
	Luxemburg	No strategy, legal framework or cost-benefit report.	Some distribution system operators testing displays, internet portals, etc.
	Malta	A complete rollout of smart meters started in 2010. Functional requirements are available.	In 2010 a rollout plan to replace all electricity and water meters of customers by the end of 2012.
	Netherlands	Dutch Parliament adopted legal framework for voluntary installation of smart metering in November 2010. An updated cost-	Multitude of pilot projects has been performed. A 6-year rollout phase could start in 2013.

		benefit-analysis and functional requirements are available.	
	Norway	Currently, hourly metering is required for large customers only.	Some distribution system operators have installed AMR technology to all customers for weekly meter readings. Some power retailers offer contracts at the spot price on an hourly basis.
	Poland	No legal framework is available but is expected there will be legislation ready for decision in 2012.	National energy platform and smart grid consortium were founded in November 2010 to support the implementation.
	Portugal	A substitution plan for the actual meters has been done coordinated with Spain.	The project InovCity for the city of Évora with 30,000 meters was presented in 2010. Customers receive near real-time consumption information.
	Romania	A decision on a rollout is expected in 2012. By now there is no official plan and cost-benefit report has not been done.	Some distribution system operators started with pilot projects.
	Slovakia	No strategy, legal framework or cost-benefit report.	Distribution system operators install some smart meters.
	Spain	A substitution plan for the actual meters has been done. Functional requirements are available. Cost-benefit report has not been done.	"Smart city" projects have been developed in Andalucia and Castellon.
	Sweden	It was the first country to apply a complete rollout of smart meters. Since 2009 monthly meter reading is been done. Functional requirements are available.	Despite all customers had remotely readable meters it is being invest to increase reading frequencies.
	United Kingdom	In July 2010, the government published the smart metering prospectus outlining the rollout strategy. Minimum requirements for meters not yet available.	Some suppliers (British Gas, First Utility, nPower) have already begun installing smart meters including customer response trials.

Table 1: Table extracted from of the project [19]Renner, S., Albu, M., van Elburg, H., Heinemann, C., Lazicki, A., Penttinen, L., et al. (2011). ***European Smart Metering Landscape Report.*** **Vienna.**

Below, a graphic representation [Figure 12] of the Table 1 is showed:

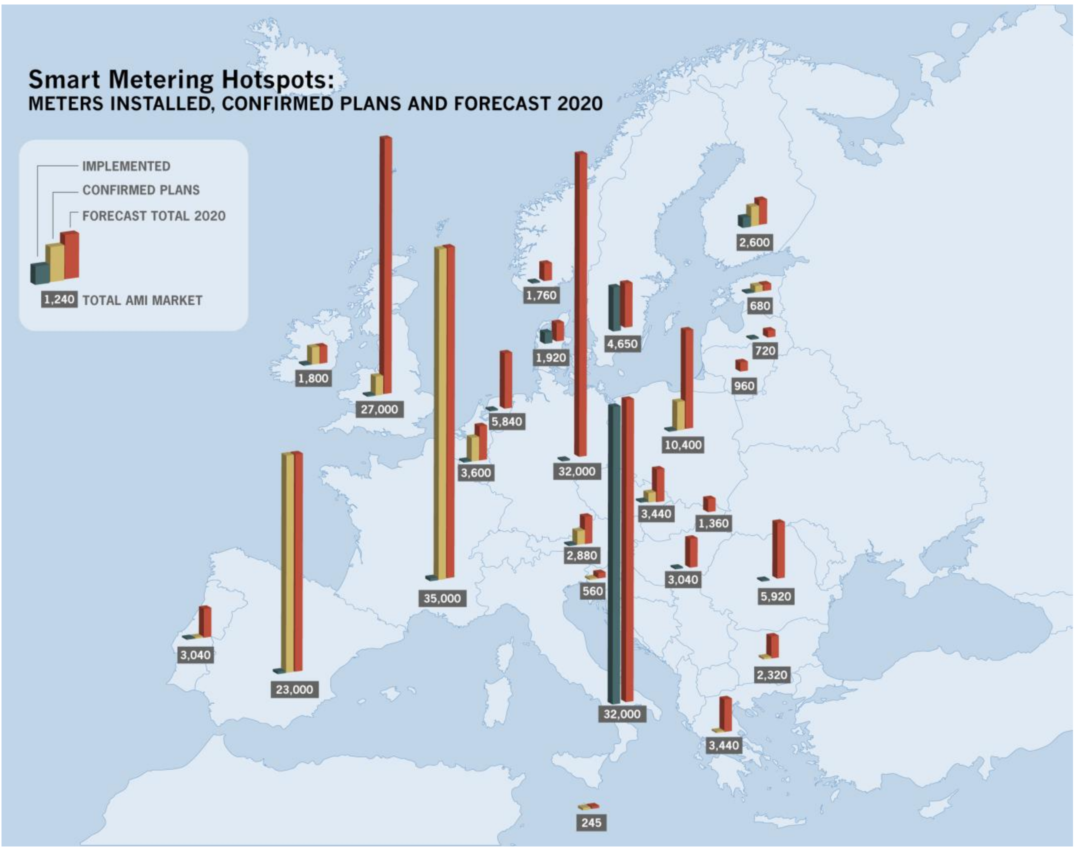


Figure 12: Graphic to show Smart metering European landscape. [29]

2.3.1 Legislation promoting change in Europe

Specially, two European legislations are pushing for the implementation of Smart meters and Smart grids. Art.13 of the so-called Energy Services Directive (2006/32/ED, ESD) and the Directive on the international electricity market (2009/72/EC).

The first of them, Art.13(2006/32/ED, ESD), requires that in situations where it is technically possible and economically efficient due to the energy savings, European member states have to supply customer with competitive priced that reflect consumption and information of the time use, and also that bills has to be based on actual energy consumption provided frequently enough to allow consumers to regulate their consumption.

The second one, the Directive on the international electricity market (2009/72/EC), is part of the Third Energy Package mentioned before. Art.3 of this Directive requires that, to promote efficient energy use, the European member countries or regulatory authorities should encourage electricity companies to optimize the use of electricity by introducing, for example, smart metering systems or smart grids. This metering system "*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 meter is economically reasonable and cost-effective and which timeframe is* *feasible for their distribution*". The Directive forces European countries to carry out cost-benefit reports before the rollout of smart metering. Deadline is placed for the 3 September 2012.

There are two directives that drive the introduction of smart metering: Energy Services Directives (2006/32/EC, ESD) and Energy Performance of Buildings Directive (2010/31/EU, EPBD).

Directly related with smart meters, the recast of the Energy Performance of Buildings directive (2010/31/EU, EPBD) includes develops on the introduction of intelligent metering systems. Art.8(2) of this Directive specifies that intelligent metering systems shall be installed at new constructions or buildings that needs major renovation. Apart from this, member states may promote the installation of control systems such as automation, control and monitoring systems to save energy.

The European Commission (2010) offers more information to guide the implementation of measures in the new Electricity and Gas Directives. For customers billing, the Commission believes that it is positive the introduction of smart meters because thanks them it is possible to create a bidirectional communication between the consumer and supplier, in addition to the energy efficiency at home. The Commission also considers the implementation of smart metering as a key to implement smart grids. With respect to the frequency of meter reading, the Commission's services (2010,8) established that monthly readings are sufficient to regulate the consumer consumption. However, it is clear that the presence of most often readings would increase the control that the consumer can do on their consumption.

The new legislative at European level is pressing the Member States to the introduction of smart technologies for electrical purposes. The mix of new technologies and the active participation on their development by part of the different countries to adjust to the new legislations is making of the smart metering landscape in Europe a highly dynamic landscape. The countries that are part of European Union are going on modernizing the electric grid, developing electronic metering system as a key for integration of volatile sources of electricity as wind.

Next, the current situation in Sweden and Spain is going to be studied in greater depth. The reasons why, as the author of the thesis, I focus on the study of the current situation in Spain and Sweden is because they are my home country (Spain) and the country where the thesis is being developed (Sweden).

2.3.2 Current situation in Spain

Before explaining the current situation in Spain, measures that are taken and development plans, it must be said, to know the magnitude of the project, that Spain has 46.772.000 inhabitants.

2.3.2.1 Policy measures for the introduction of smart metering

The policy measures taken for the incorporation of smart meters in the country are compliance with European directives (2006/32/EC, 2099/72/EC, 2010/31/EC), plan replacement of consumer meters below 15 kW by 2018, hourly frequency telemetry and control schedule for achieving efficient use of energy through active consumers by providing them with knowledge about their consumption.

2.3.2.2 Legal foundation of smart metering services

Energy Law sets the replacement plan for electricity meter consumers below 15 kW before December 31, 2018 [Figure 13]. The purpose of this change is to enable telemetry.

Spanish regulation about smart meter implementation:

- Real Decreto 1634/2006: Additional disposition twenty-second. Installation plan of measuring equipment. In the above plan will set out the criteria for the replacement of metering equipment as well as the number of equipment to be installed annually, understood as a percentage of total national metering systems.

- Orden ITC/3860/2007: This order establishes the plan of replacing meters measuring power supplies up to 15 kW of contracted power to promote the establishment of remote management systems. Distribution companies are responsible for the meters replacement. The percentages by which the replacement plan is governed are presented in the following graphic:

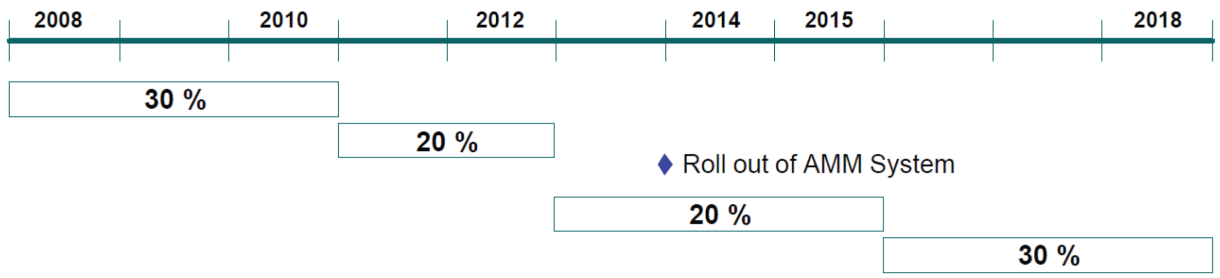


Figure 13: Metering replacement plan in Spain. [19]

Minimum functional requirements for the metering system:

- Remote control and tariffs with time-rates per hour. That means hourly metering and tariffs able to change depending on this hourly metering.

- Remote management system. That means the possibility, thanks to the bidirectional communication between controllers and distribution company, to make remote readings and managing energy, also by distance, with the connection and disconnection of the equipment, among others.

- The measuring equipment must be able to measure active and reactive energy, maximum power every 15 minutes, hourly measurements with data storage for 3 months and must be able to handle flexible tariffs.

2.3.2.3 Status of implementation in Spain

To have a view of the situation in Spain it is a good view to see what happens with the five main electric companies that operates in Spain:

- **Endesa**: The timetable for implementation of Endesa to its customers is adapted to that established by the Order ITC/3860/2007. The smart metering system which will be applied is called "Meters and more". This is an open protocol communication for automatic measurement solutions. Endesa has installed 22.000 units during 2010 in several main cities of Spanish regions (e.g. Málaga Smart City project), while the target is to install 1.5 million meters by 2011 and 13 million units by the end of 2015. In October 2010, the company opened the Center for Management and remote management operation in Seville, with the presence of the Minister of Industry.

- **Iberdrola**: Iberdrola says that a study of viable alternatives to meet with legal regulatory requirements has been conducted since 2006. Among the different alternatives, Iberdrola has chosen the PRIME standard because of some features as low cost, high performance, open, public specification, standard medium-term international and, especially, because it is currently available. Iberdrola is a founding member of the PRIME Alliance (Powerline Intelligent Metering Evolution) in Spain, which have subsequently added other operators such as Gas Natural Fenosa and EDP.

The company has started carrying out a project that will turn Castellón into the first Spanish city with a smart power.

- **Gas Natural Fenosa**: The company has developed three pilot projects in the period 2007-2010 in Madrid, Barajas (Madrid) and Molina de Aragón (Guadalajara), installing a total of 1,000 measurement equipment.

In 2010, because of supply difficulties, Gas Natural has installed only 5,000 of the planned total of 80,000 meters.

In late 2011, the company's plan is the total installation of 580,000 meters. The company has to recover the backlog to achieve the legal deadline and deploy 100% smart metering equipment before the end of 2018.

To highlight the Project SCALA (Smarts Cities Alcala and Aranjuez) of remote management and remote control

- **E.ON**: In 2004, E.ON began the first experience of deployment of the smart metering company in Spain. It was developed in the period June 2004-July 2005 in Torrelavega (Cantabria). 950 smart meters were installed.

Until December 2010, a total of 180,000 smart meters have been installed. It is expected that Eon Spain has installed a total of 708,000 meters by the end of 2014.

Moreover, the company expects to meet legal deadlines required integration of remote management system, to have it set right before the end of 2013.

Among the advantages of their smart devices include:

- Minimize errors.
- Access to consumer data instantly and universally.
- Working with real data.
- Adjust the billing periods.

- **HC Energy**: HC Energy states that there are still large technological and logistical risks for the start of a massive deployment for the following reasons:

- Innovative Solutions in continuous improvement involves modification of versions.
- Reliability of the equipment.
- Communications Technology.
- Availability actual equipment in large quantities.
- Living for a period of old equipment with new ones.

The company finds the necessity to continue working with pilot projects of increasing extend.

2.3.3 Current situation in Sweden

As it has been made in case of Spain, to understand the situation in Sweden and know the magnitude of the project is necessary to know that Sweden has 9.495.000 inhabitants. That means that the changes and therefore the magnitude of the project is going to be smaller.

2.3.3.1 Policy measures for the introduction of smart metering

Swedish Energy Agency approved, based on studies, that a higher frequency of meter readings generates economic benefits due to a energy reduction and an energy effective use. From these studies, the Swedish parliament approved, the July 1, 2009, for the start of monthly reading of electric meters.

The policy with respect to smart meters in Sweden is based on improving the services of the meters (more accurate consumption information, greater flexibility in contracts ...) to facilitate the policies related to energy efficiency and emissions of the country.

2.3.3.2 Legal foundation of smart metering services

Energy Law: Due to legislation on new regulation for electric meters, in 2003 Sweden was the first country in European Union to mandate indirect automatic electricity meters reading. On July 1, 2006 was lowered from 200 A to 63 A the limit at which the hourly metering reading has to be done. These regulations have enabled the deployment of smart meters to the point that in 2009 all users in Sweden had accountants, which permitted the remote reading, installed. Although, by legislation, it is only needed monthly reading, the distribution system operators prefer an hourly reading.

Swedish electricity market model has about 5,2 Mill. final customers, 170 distribution system operators, 100 power retailers and 35 companies responsible of the maintenance. The client has a contract with one of the distribution system operators to which he pays a fee for getting connected and using the electricity network. Distribution system operators are the owners of the meters, so that the user pays metering fees or tariffs because of using electricity network.

Minimum functional requirements for the metering system for customers over 63A (commercial and industrial customers):

- Must be measured active energy generated and consumed on a daily basis and at a frequency of one hour. Data collection will be done as soon as possible after 00:00 on day pass following at which measurements have been made.

The DSO has to deliver preliminary data to the national settlement daily at 08:00.

Minimum functional requirements for the metering system for customers up to 63A (household customers):

- Readings, as active energy consumption, must be saved on a monthly data base. Data collection has to be registered exactly at 00:00 of the first day of the month and collected as soon as possible, else the registration will be estimated instead of being calculated. Also the supply cuts or interruptions should be registered by the distribution company because the user can apply for an economic compensation.

2.3.3.3 Status of implementation in Sweden

Sweden has performed full-scale deployment during the last years, and by 1 July 2009 all customers had got installed technology for automatic meter reading. The requirements are hourly metering of the consumption for larger customers with a fuse rating larger than 63 A (commercial and industrial customers), and monthly metering of the consumption for smaller customers (households) with a fuse rating smaller than 63 A.

The deployment of smart metering technology allows Sweden to have a wide range smart metering services. The next step is to increase the frequency at which measurements are made. Although the distribution system operators are read per hour instead of reading per month, a regulation for a higher reading frequency than the current (per month) would be better.

If the situation between countries more deeply studied (Spain and Sweden) is compared, it is possible differentiate the situation and the evolution of each one, one that it is starting to deploy the smart technologies (Spain) and the other one that is one step advanced (Sweden) that nowadays is improving the technology installed before. This advantage has some economical and environmental benefits, among others.

Chapter 3: Smart meter types[6]

Reading real time data is needed by Smart Grids to have a real time control. It is not possible to control an actual situation if the measures that the control system handles have been taken a long time before. The system needs the readings to manage and monitor, whereas users need the tariff information and their bill to control their energy consumption. The difference between bill and automatic control is that with the bill the user can control its consumption while with the automatic control the device is connected, disconnected or changes the consumption depending of some price level, voltage level or load level set up before by itself.

Figure 14: Smart meters [1][24]

Smart meters [Figure 14] are often referred to electricity meter but there are also devices known as smart meters that measure natural gas or water consumption. Focusing in electricity Smart meters, these are electrical meters that measures electric energy consumption and record them in intervals of time (each 15, 30 minutes or each hour, two hours…) and communicates that information to the utility monitoring and billing purposes. This communication between the meter and the central system [Figure 15] is one of the most important differences between the Smart meters and the electronic meters.

[6] This section is based in the information find at Casellas, F., Velasco, G., Guinjoan, F., & Pique, R. *El concepto de Smart Metering en el nuevo escenario de distribución eléctrica.* Barcelona (Spain).

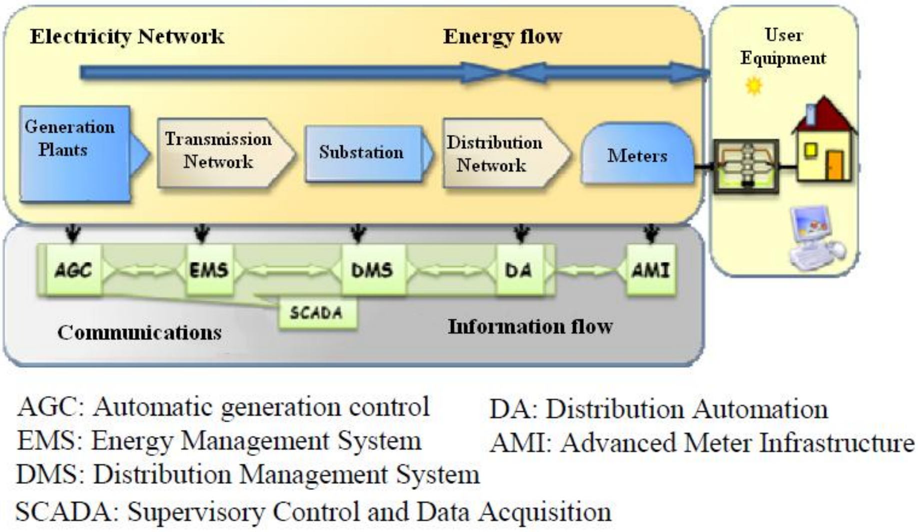


Figure 15: Electric energy flow in parallel with information flow [4]

Smart meter makes easier the introduction of renewable energies, improve energy efficiency, provides the necessary conditions for load reductions and makes possible the active participation of consumers in the electricity market.

3.1. Different types of meters

There are different types of electric meters that can be rated depending on their features:

- Technologically: electromechanical or electronic meters.

- Functionally: single-phase or three-phase.

- According to energy: active meters and / or reactive meters.

- Device or software that enables remote handing.

The recording equipment can come from the two technologies:

· Electromechanical: The ones that can be classified in this technology can only measure one type of energy, kvar accumulated or accumulated kWh. Electromechanical counters are standard induction.

· Electronics: To only measure cumulative energy. They record the energy metering by preset time intervals. This technology counts with two-way communication between the meter and the data server.

Electronic programmable measuring equipment types are:

· Advanced Meter Infrastructure (AMI). These devices allow the reading of the accumulated energy consumption or the instantaneous power. This technology provides differentiate pricing options.

· Smart Meters. The equipment provides through the management center the information and control parameters measured electronically in a telematic way. Smart meters provide network communication between the manager and consumer premises equipment.

3.1.1. Electromechanical meters

The basic idea for the electromechanical meters [Figure 16] induction is the study that Galileo Ferraris made. This study says that with two AC fields out of phase, a metal solid disc can be rotated. This discovery stimulated the development of induction motors and electromechanical induction meters.

Figure 16: Example of electromechanical meters [23]

The different types of electric motors for electric meters can be classified into:

- Commutator type.
- Induction type.
- Faraday disc type.

The most common electric meter is the one known as Thomson or single-phase electromechanical induction meter. Also three-phase electromechanical meters are very common in Europe.

3.1.2. Electronic meters

The first automatic measuring devices are from the pre-internet and pre-microprocessor. It is as electromechanical devices based on existing electric meters with a digital communications based on the emerging digital technologies at early 60's. The patents that are listed below determine the evolution of these devices.

- Reading equipment by detecting the angular position indicator for a binary code of the measured value, the angular position sensors.

- Fully electronic equipment, measuring voltage and current from the average value of the rectified signal with a voltage-frequency converter and a counter that allows the display of the mean value.

- A device that allows communications by telephone to the central station and transmits the code from the meter and the value of the measure.

At the earlier 70's data acquisition, processing and communications were very limited by the computing power of microcontrollers.

In the decade of the 80's hybrid counters based on induction meters started to be produced. The first AMR were measurement devices that incorporated a Microcontroller Unit (MCU), which allowed automating the system and also provided communication with central system.

The fully electronic counters [Figure 17] intends to provide reliability to the data obtained. It is also important for the manager to obtain a real consumer profile, for what frequency programmable measures are needed.

Figure 17: Example of electronic meters [10]

The operation consists of sending information to the *Data Management* (DM) as part of an infrastructure for measurement, data collection and management where a new counter called AMI is needed. The readings are listed to the users in real time so they can change their consumption behavior in terms of tariffs or ecology.

The next evolution of technology is the Smart Meter [Figure 18] which is basically an AMI which includes at least the following supplements: programmable power control set to limit consumption, a communication port and tariff services under demand.

Figure 18: Example of Smart meters [17]

The general structure of the meter maintains the three main elements: the measurement system, the memory and main information device that it is now the communications system. To expand its operational capabilities the following additional elements are added:

- Power supply system.

- Calculation processor.

- Communication processor.

- Actuator and/or control device.

Thanks to these additional elements and the measures taken by the meter the application showed in Figure 19 are possible.

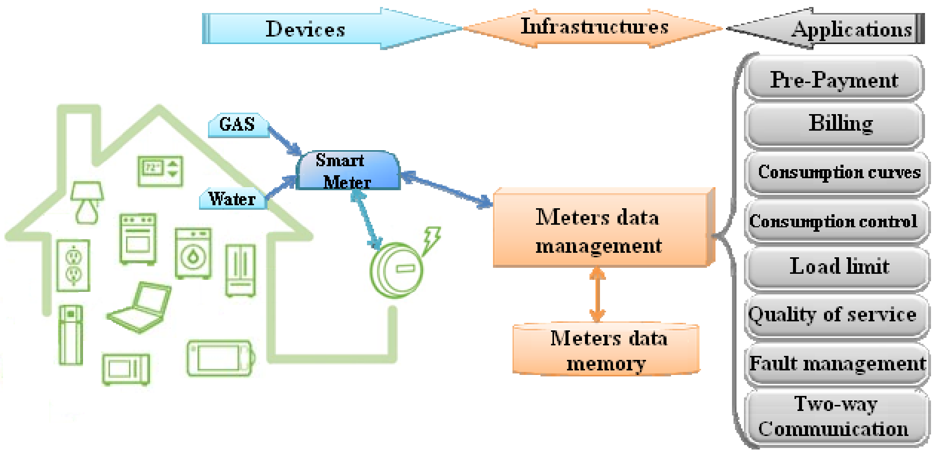


Figure 19: Diagram of the Smart meter improvements [4]

To show the consumption curves, to manage a fault if it occurs, limit the load connected by the user or control the consumption, to have a control of the billing and tariff information and the two-way communication possibilities are some of the applications of the meter that are useful for the Smart grid purposes and also for the consumer that has more information and can intervene as active part.

3.2. How does smart meters work?

The smart meter benefits to the consumer, the different parts that compound the smart meter and the stages that the signal has to pass since it is measured until it is processed and transmitted are going to be studied below to understand how smart meters work.

3.2.1. Smart Meter benefits to the user

There are several types of smart meters at the market, all of them look like the rest of electronic meters, but there is a difference between smart meters and the rest of them, a difference that is at the same time a basic feature of smart meters. All of them are connected to the communication network thanks to their communication port by which send the electricity consumption measured. Not only the electricity consumption is recorded by the meter. Along the years it is being more usual that consumers act also as producers. Smart meter are allowed to record also the energy given to the distribution network from small generators as solar panels or turbines.

One of the facilities that smart meters present to consumers is that with the bidirectional communication permits centralized meter reading, which means that it is not necessary to visit the reader to collect the measurement data the electricity consumption. Nevertheless, at least, some visits are going to be still necessary to test and maintain the devices.
The electricity consumption is also shown at the same meter. Thus it is possible to check it and reduce the bills if it is desired.

3.2.2. Different components of the Smart Meter

The energy value that has to be calculated follows the next processes before being displayed on the LCD of the meter:

- Process digitalization of the instantaneous values of voltage and current by a high resolution converter.

- Product of the variables calculated to get the instantaneous values of power.

- Integration of calculated variables over time providing the values of energies.

The main difference between different manufacturers is the electronic design which implements the counter [Figure 20], where you can find the following:

- Mid-range MCU devices, *Digital Signal Processor* (DSP) or programmable logic device, the three mixed-technology options including *Programmable Gain Amplifier* (PGA) and

Analog Digital Converter (ADC). The three options have in common a serial port for control by an external processor performs other operations. It is the basic model.

- Mid-range MCU with computing capabilities such as hardware multiplication, *Structure Reduced Instruction Set Computer* (RISC) with communications peripherals, memory of various types and analog-mixed elements. Normally MCU devices adapted to a generic design measures.

- Low-end MCU dedicated to the overall management of the system and its programming is more comfortable, surrounded by a number of peripherals similar to the previous case where it has added a DSP-based or programmable logic device technology elements mixed necessary. This dual-core system allows the process of calculating power and energy is developed in a more deterministic and optimized for the DSP.

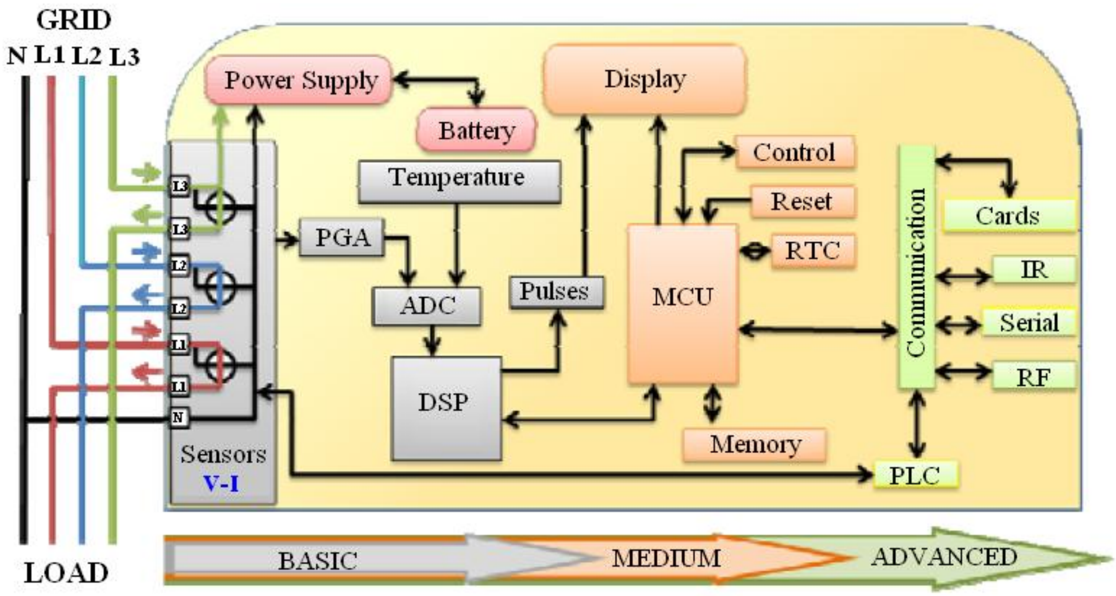


Figure 20: Smart Meter parts. Block diagram [4]

In all these designs have to be added a few extra communication peripherals items that are implemented only to allow local connections of a few meters at most. The connection system must be electrically isolated, included the mass of the system connected to electrical network neutral.

3.2.3. Stages of the signal in the Smart Meter

From the measurement of the electrical signal sent to the display or via the communication port the signal must pass through a number of stages as conditioning, processing and transmission.

3.2.3.1 Stage of sensing and the signal conditioning

The first part of the measurement process is analogical and external to the integrated circuit. It is different how voltage or current is measured:

- To detect the voltage signal it is necessary before attenuate it with a voltage divider or with a transformer to adjust the amplitude to the PGA values. The measurements are made between phases or better between phase and neutral.

- The current measurement is performed using a voltage current transformer, a shunt resistance or a Rogowski coil. The current measurement can be taken in one phase, in two phases, in three phases without neutral or in three phase with neutral, depending on how the meter is going to be implemented and the number of ADC's that the integrated circuit has.

The use of transformers for voltage or current measurements presents a problem. The offset at the phase of the signal introduced with respect to the secondary to the measured signal. That means an error in the measure calculation of the instantaneous power from the DSP that has to be minimized by implementing a digital filter adjusted by the calibration of the meter.

3.2.3.2. Quantify and signal processing

The next stage has to adapt the signals with the PGA and convert them with the ADC sending the values to the DSP to perform the calculations of the powers.

The instantaneous power p (t) is given by the product of the instantaneous voltage v (t) and current i (t). To the result of the operation is applied an averaging filter to obtain the constant term corresponding to the active power, P.

For reactive power, Q, the current phasor is moved 90 degrees. After that, the same calculation performed with the active power is applied. The apparent power, S, is calculated as the square root of the sum of the squares of active power and reactive power.

Other possible computations that can be implemented are those concerning the quality of the signal on the line, such as the peak values of the rms voltage, the reduction of the effective voltage, frequency variations in the signal or aperiodic errors of zero crossing in the voltage wave.

3.2.3.3. System control and data transmission

On devices with dual-core processor, the values calculated by the DSP are saved as variables in the data records available at the MCU, for storage and remote transmission. Alongside, as a designer option, the pulse generator acts over the outputs enabling active and reactive powers, sending pulses to an external counter.

Communications are implemented using the serial ports MCU peripherals available. It is a local communication *Machine to Machine* (M2M) with other specialized devices on networks that could wish to been deployed. This modularity allows the design to adapt to the circumstances of each application.

As complementary elements typical devices include an internal temperature sensor, real time clock, power management system, the supervisor of the system configuration memories and firmware or current leak detection.

Chapter 4: Smart meter communication and setup

This chapter will explain the steps that have been followed until run the final program. This program will be capable of communicating via GSM, send and receive the commands to collect the desired measures, which will be saved in a file. In addition, more than a meter will be connected at the same time.

4.1 EMH metering. LZQJ smart meter

First of all, it is necessary to make a short description of the meter that is going to be used. The meters that are going to be used in the thesis are manufactured by EMH. The smart meters have been provided to Industrial Electrical Engineering and Automation, department at Lund University, by the energy company E.ON.

Figure 21: E.ON and EMH logotypes

On the website of EMH it is possible to find a catalogue of the products that they have. The classification that the company does on the website is:

1. - Special meters

2. - Residential meters

3. - Industrial meters

The differences between them are not defined at the website, but technical specifications of the different meters are provided. In these technical documents, an overview of the principal features of each meter is given.

Industrial meters and residential meters are very similar, but the manufacturer indicates which are the ones used for industry and billing purposes. Both of them record at least positive active energy and only some, as ITZ (industrial meter) and ED300 (residential meter), add the possibility of more measures (negative active energy, positive reactive energy or negative reactive energy). One highlighted difference between industrial meters and residential meters is that, in most of the cases, residential meters can register more tariffs. The normal for industrial meters is to register one tariff, whereas residential meters register four tariffs.

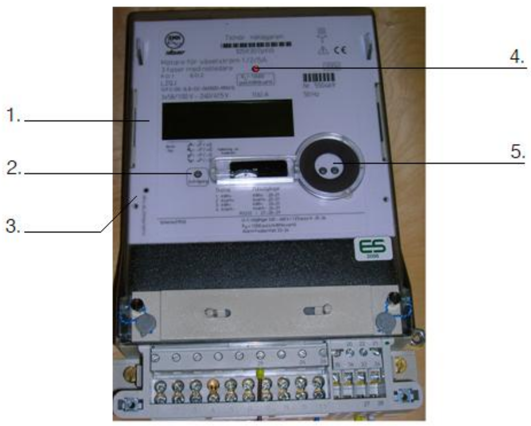
The meter provided by E.ON is the model LZQJ, classified by EMH as special meter. These meters, LZQJ model, use current transformers for measuring the current. Comparing special meters with the rest, special meters are more complete. These differences can be appreciated in the next table [Table 2]. More complete meters are better for this work, due to they are going to be deeply studied and further researches will be carried out.

	EIZ-FEWF7393	ITZ	LZQJ
			
	Electronic Single Phase Meter	Digital Impulse Meter/Tariff Meter	4-Quadrant-/Combi Meter
Measuring of			
Active energy	yes	yes	yes
Reactive energy	---	---	yes
2 directions/4-Quadrants	--- / ---	yes / ---	yes / yes
Type of connection	2-wire	4-wire	3- and 4-wire
Voltage (+15%, -20%)	1x230 V	3x230/400 V	4-wire-version: 3x58/100 V ... 3x240/410 V 3-wire-version: 3x100 V ... 3x415 V further voltages by enquiry
Current			
direct connection	5(25) A	10(65) A / 0.5 - 10(65) A	10(100) A
transformer connection	---	5 A	5II1 A (double area)
Frequency	50 Hz	50 Hz (± 2%)	50 Hz, 60 Hz (± 2%)
Accuracy			
Active energy	Cl 1	Cl 2 / Cl. B, Option: Cl 1 / Cl. A 1)	Cl 1, Option: Cl 0.5S or 0.2S
Reactive energy	---	---	Cl 2, Option: 1% or 0.5%
Energy measurement/Tariff design	1 tariff	2 tariff registers + 1 tarifless register	2 tariff registers + 1 tariffless (for every energy type
Maximum measurements	---	---	2 maximum registers (for every energy type)
Measuring period	---	---	15 minutes
Tariff control	---	external control	external control
Further measuring variables	---	---	Apparent energy, current, voltage, power, line frequency, power factor
Data retention time	permanent	> 20 years	> 20 years

Meter constant-LED (Imp./kWh)			
direct connection	2 000	1 000	500
transformer connection	---	10 000	10 000 (3x230/400 V, 5II1 A)
Meter constant-output (Imp./kWh)			
direct connection	2 000	1 000	250
transformer connection	---	5 000	5 000 (3x230/400 V, 5II1 A)
Control inputs	---	Option: 1 control input (system voltage)	3 control inputs (system voltage) for tariff- and maximum switching and clock synch
Outputs	S0 (DIN 43 864) for transmission of impulses	OptoMOSFET (250V AC/DC, 100 mA), fulfils S0-specification	OptoMOSFET (250V AC/DC, 100 mA), fulfils S0-specification
Interfaces			
D0	---	yes	yes
CL0	---	Option	Option
M-Bus	---	---	---
LON-Bus	---	---	---
Further interfaces	---	RS485	RS485
Display version	mechanical register	LC-display with	LC-display acc. to VDEW with
direct connection	6.1 digits	6.0 digits	8.0 digits
transformer connection	---	5.1 digits	5.3 digits
Power consumption (per phase)			
Voltage path	< 2 VA	< 2.0 VA	< 2.0 VA
Current path	---	< 2.5 VA (direct), < 0.5 VA (transformer)	dependent on the meter version
Temperature range			
Operate/ Limit	-10°C...+45°C	-25°C...+60°C / -40°C...+70°C	-25°C...+55°C / -40°C...+70°C
Storage	---	-40°C...+70°C	-40°C...+70°C
Class of protection			
Housing	IP 50	IP 51	IP 51
Connection	IP 20	IP 20	IP 20
Dimensions	1 pitch = 18 mm (DIN 43 880)	178 x 328 x 60 (W x H x D) mm	178 x 328 x 60 (W x H x D) mm
Weight	approx. 0.1 kg	approx. 1.35 kg	approx. 1.6 kg
Installation	DIN-rail	Meter cross	Meter cross
PTB-Approval	☑	☑	☑
EC type-examination certificate acc. to directive 2004/22/EC	☐	☑	☐

Table 2: Features of some EMH meters [13]

The meter showed at Figure 22 is the one that has been used along the report.



1. LC-Display
2. Optical call-up sensor
3. Parametering key (under meter cover)
4. Impulse LED
5. Optical data interface D0 with magnetic fixing for the optical communication head

Figure 22: LZQJ. Smart meter aspect

The main features [Table 4: LZQJ. Smart meter RS232 features [17]] for the smart meter model LZQJ are described in the product manual. Among all the features, as the thesis is focused on communication protocol, the most important is that the meter is able to manage serial communication by RS232, the data protocol (IEC

62056.21 or DLMS) and the maximum baud rate that the meter can achieve (9600 Baud).

		Direct connection version 5(60) A or 10(100) A
Voltage	4-wire	58/100 V...3x240/415 V, optional up to 3x400/690 V
	3-wire	3x100 V...3x415 V, optional up to 3x690 V
	2-wire	1x58 V...1x240V
Current		5 (60) A or 10 (100) A
Frequency		50 Hz, 60 Hz, 16 2/3 Hz
Accuracy	Active energy	Cl.1
	Reactive energy	Cl.2
Measutring system	designation	Compensated current transfromer
Measuring types	Active energy	P+, P-
	Reactive energy	Q+, Q-, Q1, Q2, Q3, Q4
	others	S, Ah, U2h, I2h
Meter constants	LED (Imp./kWh[Kvarh])	10 000...40 000 (depending on meter type)
	outpu (Imp./kWh[karh])	5 000...20 000 (depending on meter type)
	configuration ability	after certification by means of the certification relevant logbook
Energy registers	Maximum number	32 tariff registers + tariffless register, each with 15 historical values
Maximum registers	Maximum number	32 tariff registers + tariffless register, each with 15 historical values
	Measuring period	1, 5, 10, 15, 30, 60 min, adjustable
Load profile	Maximum number of chanels	32
	Typical memory depth at 1 channel	317 days
	Registering period	1, 5, 10, 15, 30, 60 min, adjustable
	Registering type	power, energy, energy feed
Real Time Clock	Accuracy	within 5 ppm
	Synchronization	via data interfaces, control input or DCF-module
	Running reserve battery / capacitors	> 20 years / > 10 days
Ripple control receiver	Number of channels / telegrams	6 / all common telegrams

Control inputs	S0-input/system voltage	max. 1 / max. 6
Data retention time		without voltage in the FLASH-ROM, at least 10 years
Display	Display version Alternative display version	VDEW-display 84 mm x 24 mm, height of digits 8 mm alphanumerical display 4 x 20 characters
Operation	Optical sensor	for operation of display
Data interfaces	Optical data interface Electrical data interface Data protocols Maximum transmission rate	Optical data interface D0 RS485, CL0 or RS232 IEC 62056.21 or DLMS 9600 Baud (fixed or Mode C)
Outputs	Number Opto-MOSFET S0-output relays	Max. 7 max. 250 V AC/DC, 100 mA, make contact and break contact max. 27 V DC, 27 mA max. 250 V AC/DC, 100 mA (max. 2 relays)
Energy supply	Switched-mode power supply Mains buffering time	3-phase > 500 ms
Auciliary voltage supply	Longe-range	48...300 V AC/DC
Power consumption perphase (basic meter)	voltage path with auxiliary voltage without auxiliary voltage current path auxiliary voltage	 < 0.02 VA / < 0.01 W (3x58/100 V) < 1.3 VA / < 0.8 W < 0.004 VA < 1.8 VA...< 2.9 VA
Electrical parameters	isolation resistance surge voltage resistance against HF-fields	isolation: 4 kV AC, 50 Hz, 1 min. surge voltage: 8 kV, impulse 1.2/50 !s, 2 " (measuring path, auxiliary voltage) 6 kV, impulse 1.2/50 !s, 500 " (outputs: Opto-MOSFET, relay) 30 V/m (with load)
Temperature range	operating / limit and storage	-25°C...+55°C / -40°C...+70°C
Relative humidity		90% at 40°C, non-condensing
Housing	Dimensions class of protection degree of protection: housing/terminal block housing material fire characteristics weight	accord. to DIN 43857 class of protection 2 IP 51 / IP 31 polycarbonate glass-fibre-reinforced, recyclable flame-inhibiting (without halogen) 1.35 kg

Table 3: LZQJ. Smart meter specifications [17]

Focusing in the RS232, the shown information [Table 4] is going to be needed later. Only one meter can be connected to the computer. The length of the cable is not going to be a problem, because the meter is always going to be close to the computer. The data transmission rate goes from 300 to 9600 baud. Voltages for “high” logic level and “low” logic level are also determined. This voltage will be important along the thesis [5.5 Communication with three meters by GSM.].

	RS232 balanced two-wire-interface	
No. of connected meters	1	
Max. cable length	up to 15 m	
Data transmission rate	300 ... 9600 baud	
Signal accord. to ITU-T V.28	logical “1” - 3 V to - 15 V	logical “0” + 3 V to + 15 V

Table 4: LZQJ. Smart meter RS232 features [17]

4.2 Connection and setup of the meter

Before start working with the meter, it is necessary to connect it and set it up. The purpose of this project is to study how communication with different meters connected at the same time works. First step is to communicate with one of them [Figure 23]. To achieve this, RS232 serial communication is going to be used. Furthermore, as the main objective is not to check the measures obtained or to look for the different possibilities that the meter provides to the user but developing software to receive the wanted electric values, a simple load is going to be used, a bulb directly connected to the meter is going to be the load.

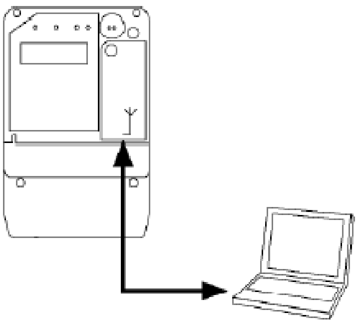


Figure 23: First step. Communication between PC and smart meter.

Along the thesis, three special meters model LZQJ [Figure 24] of the manufacturer, EMH, are going to be used.

Figure 24: LZQJ EMH smart meter. [17]

According to the manual user, RS232 is a symmetrical two-wire interface designed according to ITU-T V.24 and ITU-T V.28. The RS232 protocol communication determines that it is a point to point connection, what means that the connection, without any change, is going to be able to handle only the communication between two devices. In this case the PC and one of the meters.

Following the interface specification of the RS232 protocol for the serial communication as described in the user manual, the maximum cable length, up to 15m, is not going to be a problem to develop the thesis, because the distance between the meter and the PC is going to be short.

With respect to the data transmission rate which is from 300 to 9600 Baud. To communicate with the meter a baud rate of 4800 is going to be used, the choice of this value will be explain later.

The digital logical levels are “1” if the voltage is within the range of [-3,-15] V and “0” if it is between [+3, +15] V. This is not a problem at the beginning because the serial communication is managed by the communication module of the serial port in the PC.

The electrical interface RS232 (galvanically de-coupled) is found at the three additional terminals (RxD, TxD, and GND) under the sealable terminal cover [Figure 25].

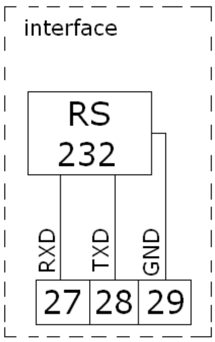
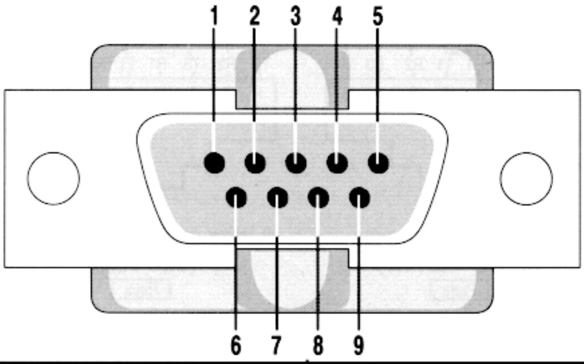


Figure 25: RS232 meter connection pin at the terminal cover. RS232

When talking about RS232 there are two optional connectors, DE-9 and DB-25. As the meter is going to be connected to the computer and it has a DE-9 connector [Figure 26] this is the one that is going to be used.



Pin	Signal	Pin	Signal
1	Data Carrier Detect	6	Data Set Ready
2	Received Data	7	Request to Send
3	Transmitted Data	8	Clear to Send
4	Data Terminal Ready	9	Ring Indicator
5	Signal Ground		

Figure 26: RS232 female connector. [20]

Once the connections are known, the RS232 wire [Figure 27] can be built up and the meter can be connected to the serial port of the PC.

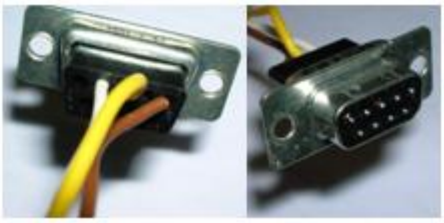


Figure 27: RS232 wire

After having prepared the connections needed for the communication, the electrical supply and the load are going to be connected.

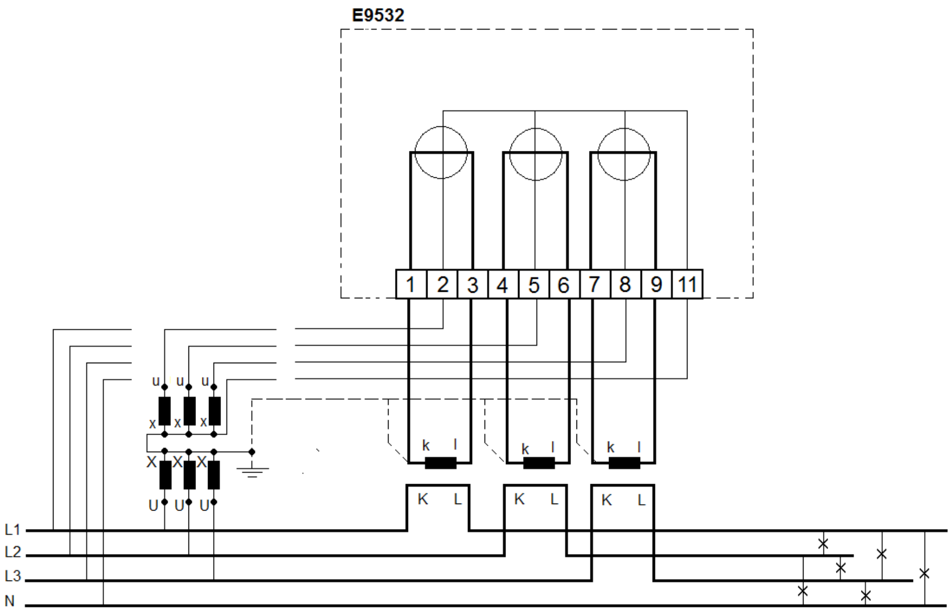


Figure 28: RS232 meter connection pin at the terminal cover. Load and power supply.

As mentioned above, only a bulb is going to be connected as a load. Also without the bulb connected it is possible to send and receive commands, the result of the measure will show that no load is connected. There will be voltage but not current measured. The terminals where the load is going to be connected are terminal 3 and 11. On the other hand, the power supply of the meter is going to be connected to terminals 1, 2 and 11. The connection scheme is showed in Figure 28, whereas the connection performed is showed in Figure 29. Observing the scheme showed in Figure 28, between terminals 1 and 3 there is a current transformer. The current of line 1 is going to be measured in terminal 1. Thorough terminals 1 and 3 there is a closed circuit where the transformed current from line 1 flows. This current is used to supply the load (the bulb), which is connected between terminals 3 and 11 (neutral terminal). Also in the same figure, can be noticed that terminal 2 is connected to a voltage transformer. It is in this terminal where the voltage is measured.

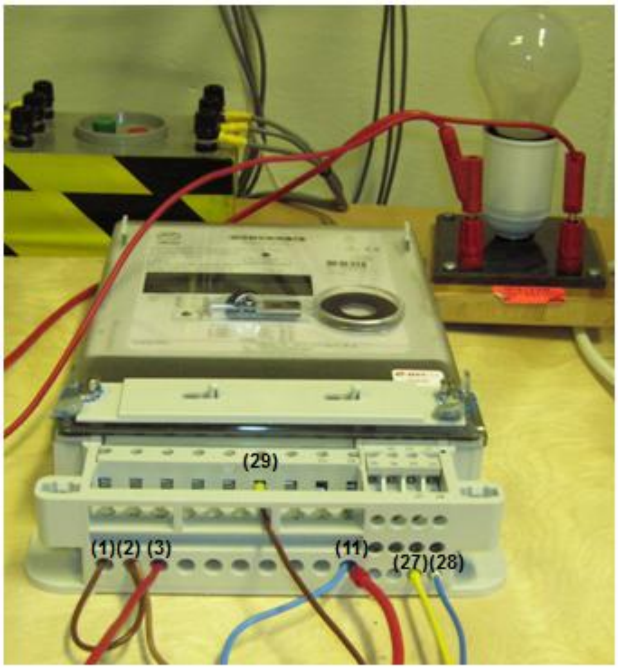


Figure 29: Meter connection: RS232 serial communication, load and power supply.

The meter manufacturer provides the user with “EMH-COMBI-MASTER”, this software is going to be explained later but in this step it is possible to check if the connection has been done correctly by using this tool. Once the program is opened there are two ways of check the installation: clicking the direct icon or going through ‘Readout’->’Installation check’ [Figure 30].

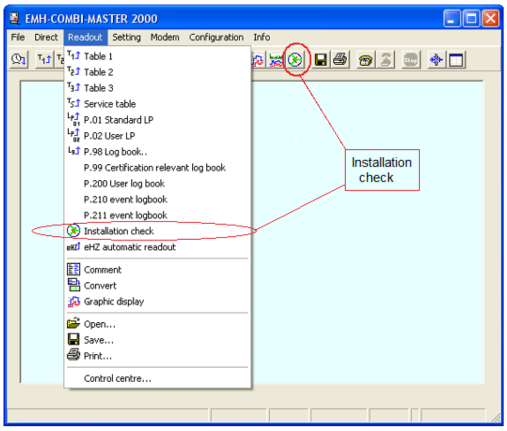
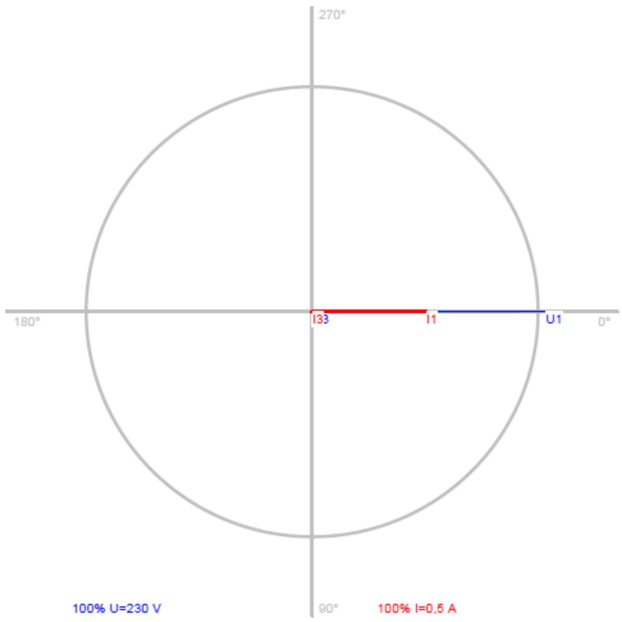


Figure 30: Installation check with EMH-COMBI-MASTER

For a load as a bulb, the results of measuring with the meter are showed in Table 5.



Installation check

Meter : 01059307
Readout : 2011-11-23 16:28
Montuer :
Customer :
Comment :

	L1	L2	L3	Sum
U	237,2 V	0,62 V	0,61 V	
I	0,2516 A	0,0005 A	0,0005 A	
P	0,059 kW	0 kW	0 kW	0,059 kW
Q	0 kvar	0 kvar	0 kvar	0 kvar
S	0,059 kVA	0 kVA	0 kVA	0,059 kVA
P/S	0,99	0	0	0,99
degrees	0,0 °	0,0 °	0,0 °	0,0 °
f	50,11 Hz	50,11 Hz	50,11 Hz	50,11 Hz

Table 5: Installation check results. EMH-COMBI-MASTER

Once the connection is verified, the next step is to take a look at the possibilities of the software (representation of the values, the possibility of changing the tariffs, etc.).

4.3 EMH Software

At this section, EMH software is going to be overviewed, especially the options related to the measures because they are the ones used in the thesis.
The first thing that has to be done to run the software with the meter, once it is connected, is to setup the communication settings [Figure 31].

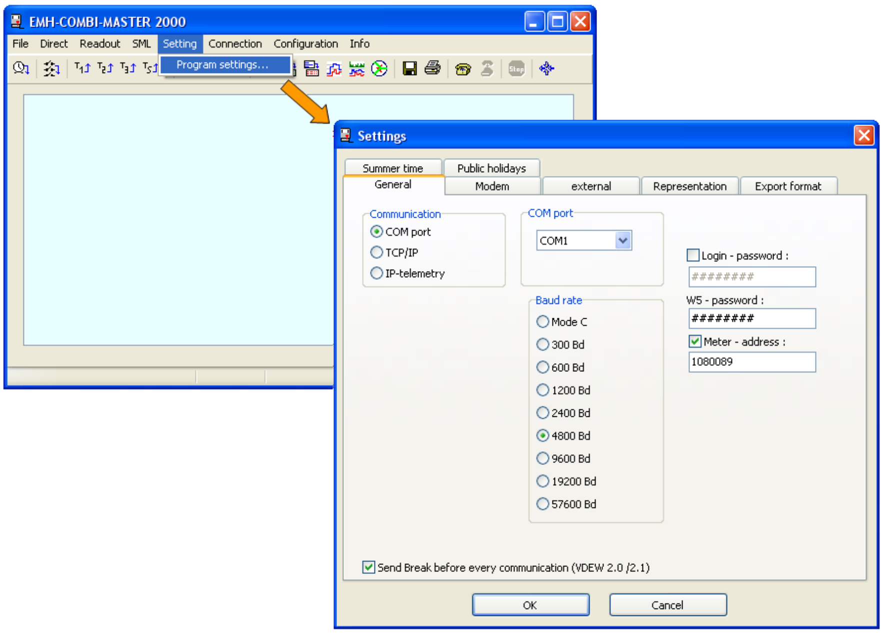


Figure 31: EMH-COMBI-MASTER. Settings

Here the COM port and baud rate are selected. It is also necessary (depending on the meter configuration) to insert the ID of the meter which is going to be used. Now with the meter connected, the rest of the options of the program can be viewed.

Going one by one thorough the menu bar, the first option is File [Figure 32].

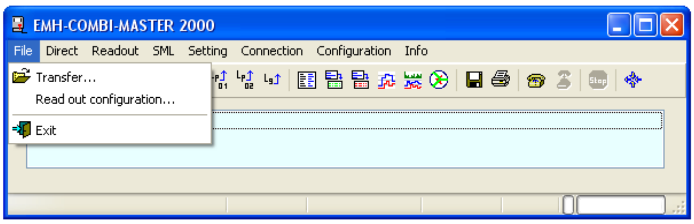


Figure 32: EMH-COMBI-MASTER. File

Menu file transfers saved set-files, parameter-files, tariff-files and ripple control files, reads out configurations and ends the program, nothing related to reading measurements.

The next option at menu bar is Direct [Figure 33].

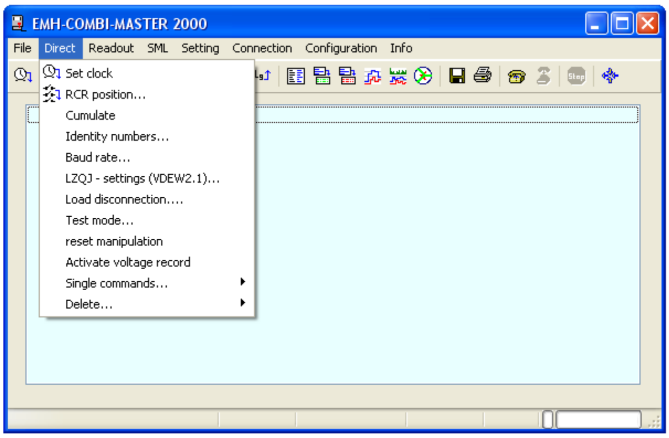


Figure 33: EMH-COMBI-MASTER. Direct

This menu is used to send direct commands to the meter. Read out the time and date from the meter or send the current PC time or PC date to the meter, read out the identity numbers from the meter or send the identity numbers to the meter, read out the start- and data baud rates of the meter or send them to the meter, read out the relay cumulation of the ripple control receiver, etc. are some of the possibilities of this menu. The most important for the developing of this thesis is the possibility to send a single command [Figure 34]. That is used to read or write some variable like time, meter identity or electric measurements.

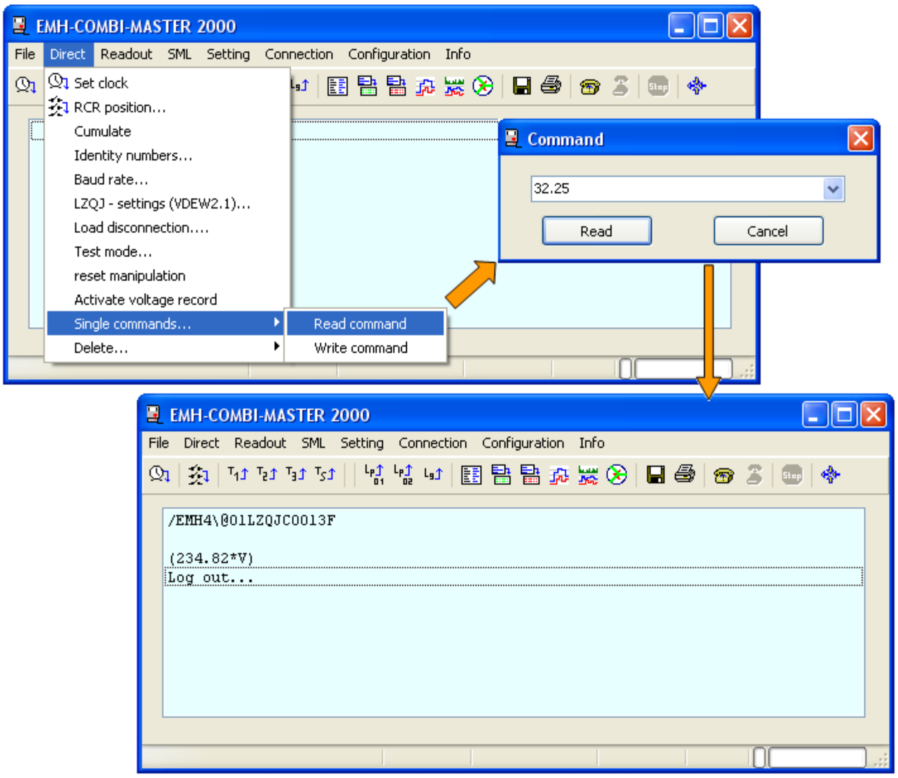


Figure 34: EMH-COMBI-MASTER. Direct command to read voltage at line 1

Proceeding with the option of the menu bar, the next option is Readout [Figure 35].

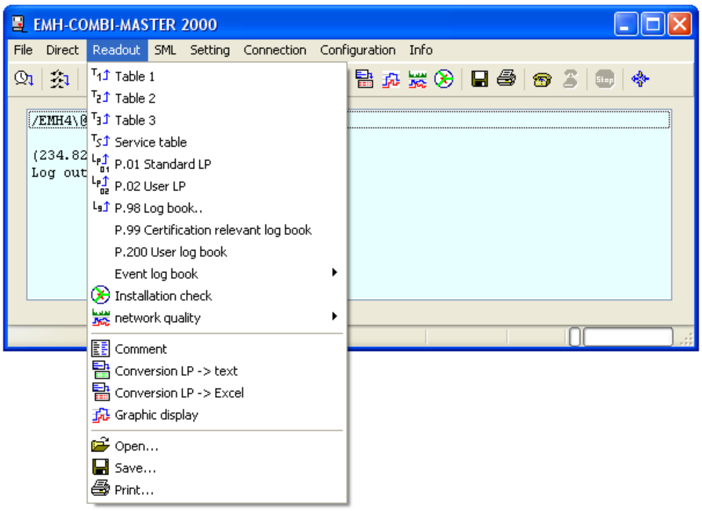


Figure 35: EMH-COMBI-MASTER. Readout

The menu Readout contains menu options for reading out the meter and also for processing the data readouts. From this menu, *Installation check* was used before to verify the connection of the meter. There are other really interesting menu options, like the fourth tables at the beginning: Table1, Table 2, Table 3 and Service table.

- Table 1 [Figure 36]: Displays different electric variables for one tariff: positive and negative active power and positive and negative reactive power. The three first lines (0.0.0, 0.9.1 and 0.9.2) correspond with the meter ID, the date and time when the reading has done.

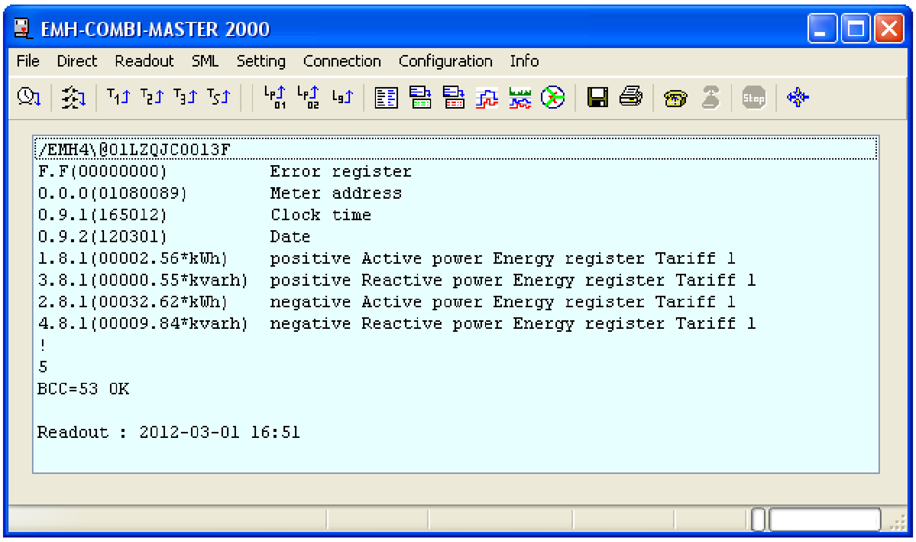


Figure 36: EMH-COMBI-MASTER. Table1

- Table 2 [Figure 37]: Load profile with pre-adjustment of the load x days (standard: last 40 days).

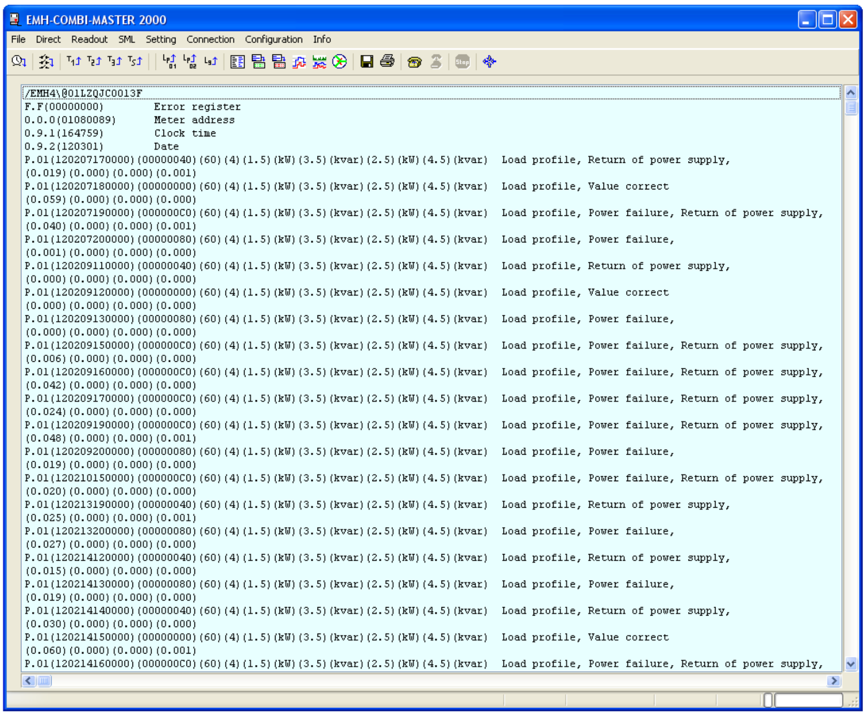


Figure 37: EMH-COMBI-MASTER. Table2

- Table 3 [Figure 38]: This table contains the information shown in Table 1 (in this case the price for two different tariffs), some of the information of Table 2, and also some information in Service table. In addition, internal tests of the EMH software (checksums) are displayed in this table.

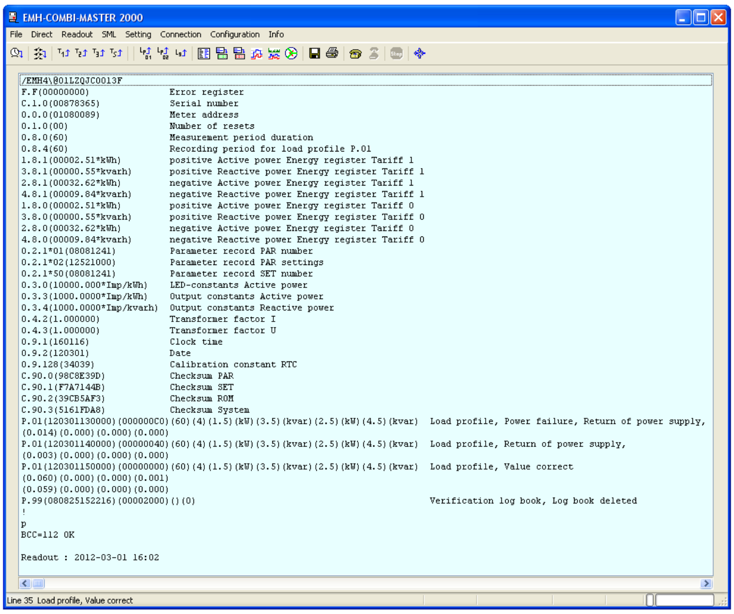


Figure 38: EMH-COMBI-MASTER. Table3

- Service table [Figure 39]: Instantaneous electric measures read from the meter.

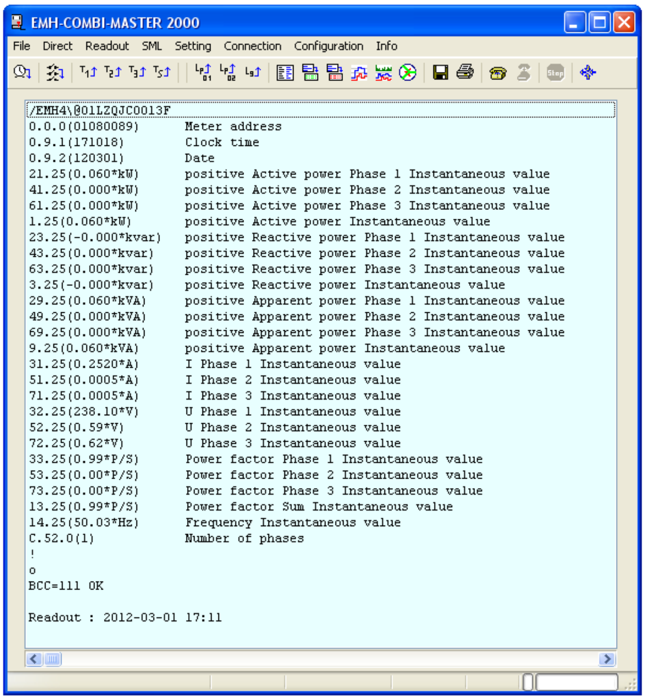


Figure 39: EMH-COMBI-MASTER. Service table

The rest of the menu options are used to read out the load profile data from the meter (P.01 Standard LP), read out the operation log book from the meter (P.98 Log Book), etc. These options are not going to be used for the development of the thesis, but some of them are also interesting.

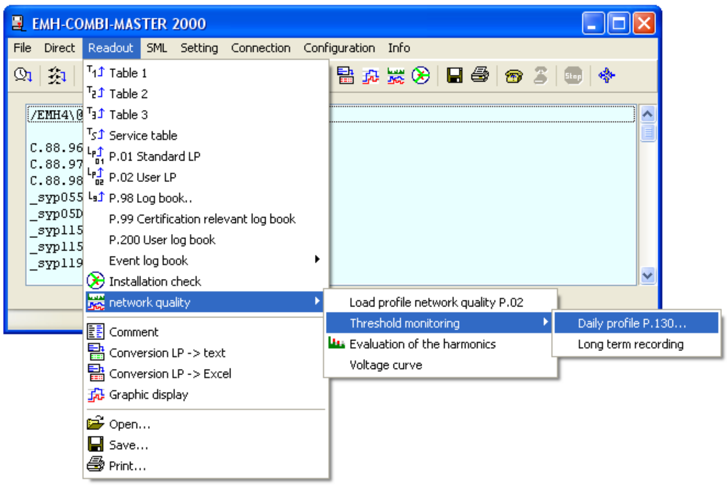


Figure 40: EMH-COMBI-MASTER. Network quality

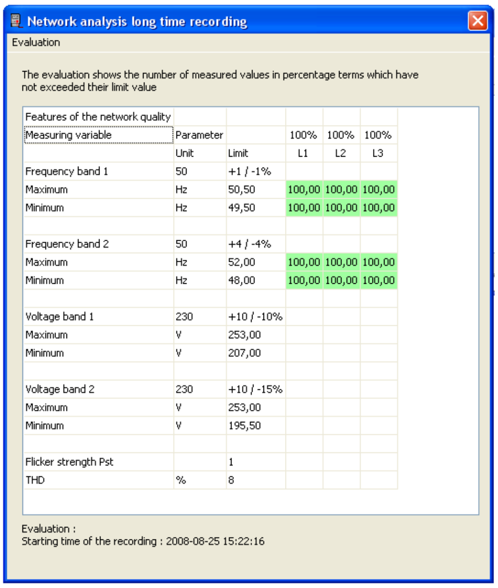
These options are the ones to check the network quality [Figure 40]. The program module network quality contains the read out of data on the network quality and also the instantaneous harmonic values.

Load profile network quality [Figure 41] is going to provide the maximum reached by some variables and also the data and time when it was reached.

```
Total evaluation load profile

Transformer factor U : 1  Transformer factor I : 1

Evaluation of the data from 2011-11-22 00:00 until 2011-11-23 00:00


Channel 1 (1-1:1.5 = Electricity Channel 1 positive Active power last average value ) :
Month                Maximum      Time stamp                             Energy
11/2011              0,058 kW     2011-11-22 14:00-15:00                 0,217 kWh

Channel 2 (1-1:3.5 = Electricity Channel 1 positive Reactive power last average value ) :
Month                Maximum      Time stamp                             Energy
11/2011              0,0 kvar     2011-11-22 00:00-01:00                 0,0 kvarh

Channel 3 (1-1:2.5 = Electricity Channel 1 negative Active power last average value ) :
Month                Maximum      Time stamp                             Energy
11/2011              0,0 kW       2011-11-22 00:00-01:00                 0,0 kWh

Channel 4 (1-1:4.5 = Electricity Channel 1 negative Reactive power last average value ) :
Month                Maximum      Time stamp                             Energy
11/2011              0,001 kvar   2011-11-22 13:00-14:00                 0,003 kvarh
```

Figure 41: EMH-COMBI-MASTER. Load profile network quality

The long timer recording of threshold monitoring is showing the quality of the measurements taken [Figure 42].



Network analysis long time recording

Evaluation

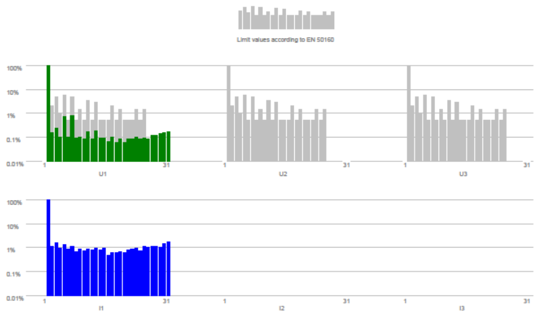
The evaluation shows the number of measured values in percentage terms which have not exceeded their limit value

Features of the network quality					
Measuring variable	Parameter		100%	100%	100%
	Unit	Limit	L1	L2	L3
Frequency band 1	50	+1 / -1%			
Maximum	Hz	50,50	100,00	100,00	100,00
Minimum	Hz	49,50	100,00	100,00	100,00
Frequency band 2	50	+4 / -4%			
Maximum	Hz	52,00	100,00	100,00	100,00
Minimum	Hz	48,00	100,00	100,00	100,00
Voltage band 1	230	+10 / -10%			
Maximum	V	253,00			
Minimum	V	207,00			
Voltage band 2	230	+10 / -15%			
Maximum	V	253,00			
Minimum	V	195,50			
Flicker strength Pst		1			
THD	%	8			

Evaluation :
Starting time of the recording : 2008-08-25 15:22:16

Figure 42: EMH-COMBI-MASTER. Threshold monitoring

With this software, it is also possible to check the quality of the signal measured by evaluating the harmonics. The harmonics and their limits are represented graphically and also in a table [Figure 43].



Harmonics
Meter: 01059307 Readout : 2011-11-23 17:43:49

No.	U1	U2	U3	I1	I2	I3	EN 50160
1.	100,00%	0,00%	0,00%	100,00%	0,00%	0,00%	
2.	0,16%	0,00%	0,00%	1,12%	0,00%	0,00%	2,00%
3.	0,24%	0,00%	0,00%	1,53%	0,00%	0,00%	5,00%
4.	0,10%	0,00%	0,00%	0,94%	0,00%	0,00%	1,00%
5.	0,73%	0,00%	0,00%	1,37%	0,00%	0,00%	6,00%
6.	0,10%	0,00%	0,00%	0,90%	0,00%	0,00%	0,50%
7.	0,80%	0,00%	0,00%	1,15%	0,00%	0,00%	5,00%
8.	0,09%	0,00%	0,00%	0,69%	0,00%	0,00%	0,50%
9.	0,10%	0,00%	0,00%	0,88%	0,00%	0,00%	1,50%
10.	0,08%	0,00%	0,00%	0,73%	0,00%	0,00%	0,50%
11.	0,17%	0,00%	0,00%	0,89%	0,00%	0,00%	3,50%
12.	0,09%	0,00%	0,00%	0,77%	0,00%	0,00%	0,50%
13.	0,18%	0,00%	0,00%	0,93%	0,00%	0,00%	3,00%
14.	0,09%	0,00%	0,00%	0,80%	0,00%	0,00%	0,50%
15.	0,09%	0,00%	0,00%	0,93%	0,00%	0,00%	0,50%
16.	0,07%	0,00%	0,00%	0,49%	0,00%	0,00%	0,50%
17.	0,10%	0,00%	0,00%	0,60%	0,00%	0,00%	2,00%
18.	0,06%	0,00%	0,00%	0,59%	0,00%	0,00%	0,50%
19.	0,09%	0,00%	0,00%	0,67%	0,00%	0,00%	1,50%
20.	0,06%	0,00%	0,00%	0,60%	0,00%	0,00%	0,50%
21.	0,09%	0,00%	0,00%	0,82%	0,00%	0,00%	0,50%
22.	0,08%	0,00%	0,00%	0,84%	0,00%	0,00%	0,50%
23.	0,11%	0,00%	0,00%	0,92%	0,00%	0,00%	1,50%
24.	0,08%	0,00%	0,00%	0,76%	0,00%	0,00%	0,50%
25.	0,09%	0,00%	0,00%	1,13%	0,00%	0,00%	1,50%
26.	0,09%	0,00%	0,00%	1,02%	0,00%	0,00%	---
27.	0,12%	0,00%	0,00%	1,11%	0,00%	0,00%	---
28.	0,12%	0,00%	0,00%	1,09%	0,00%	0,00%	---
29.	0,14%	0,00%	0,00%	1,08%	0,00%	0,00%	---
30.	0,15%	0,00%	0,00%	1,44%	0,00%	0,00%	---
31.	0,18%	0,00%	0,00%	1,69%	0,00%	0,00%	---

Figure 43: EMH-COMBI-MASTER. Evaluation of the harmonics

The last option of the menu bar is Configuration. The operation and user surface COMBI-TOOL [Figure 44] enables the advanced user of EMH electricity meters to configure and read out meters from the series LZQJ.

- Meter identification
- Setting of the interface
- Reset/pre-value formation
- Time control
- Tariff configuration (seasons, holidays, tariffs)
- Ripple control characteristics
- Display- and read out lists
- Log books
- Configuration of transformer factors and digitness (accuracy)
- Create a configuration list as a text file

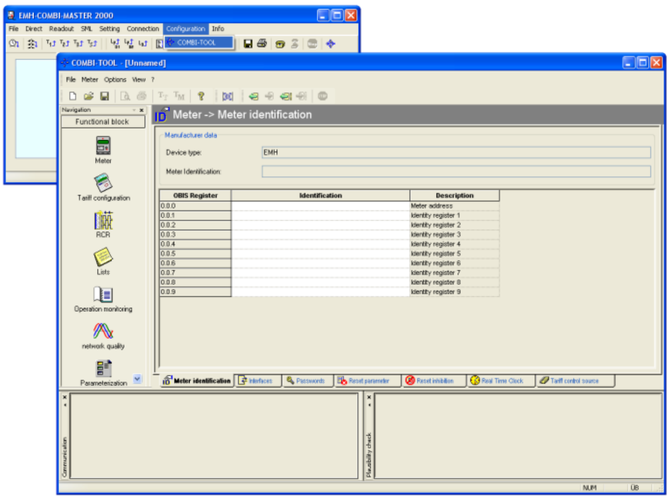


Figure 44: EMH-COMBI-MASTER. COMBI-TOOL

The COMBI-TOOL has been utilized to configure the meter. Change the baud rate of the meter [Figure 45] or customize the tables [Figure 46] that can be read are some of the options used.

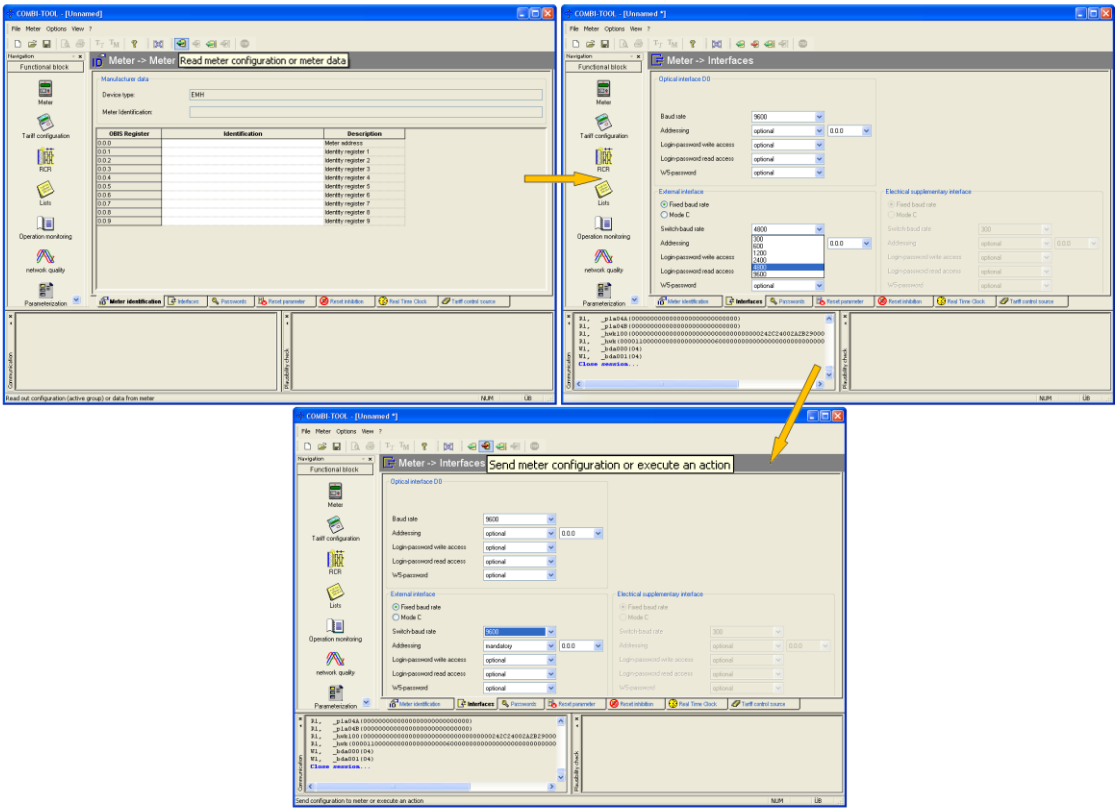


Figure 45: COMBI-TOOL. Meter features, selection of the baud rate.

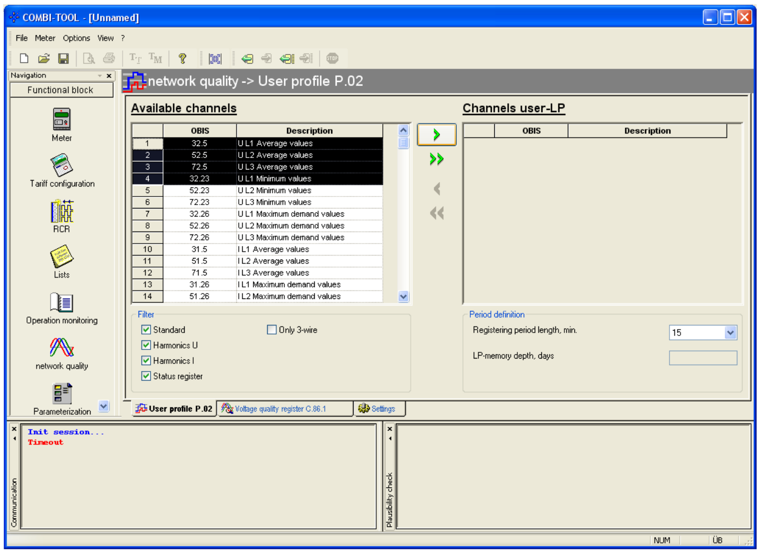


Figure 46: COMBI-TOOL. Selection of the variables printed in tables

In the realization of the thesis the option to read by direct commands will be used. To compare the times required for communication, the Service table will also be used. Therefore, program options designed to read electrical variables are going to be utilized. What has been explained in this section is enough for understanding the rest part of the project related to the use of the EMH-COMBI-MASTER 2000. The manual “Operation manual EMH-COMBI-MASTER 2000” provided by the manufacturer is available for more information about the rest of the possibilities.

4.4 Communication protocol

The program that is developed within this work asks the smart meter some of the measures that can be directly accessed (line voltage, line current, total active power and total reactive power). Before programming the code, it is necessary to know the communication protocol (IEC 62056-21). To achieve that the following programs are going to be used: 'EMH-COMBO-MASTER', 'Null modem connected (com0com)' and 'Termite'.

4.4.1 Software used

Before explaining each one of the programs mentioned above, it will be said briefly what is intended with these three programs running together.

The 'EMH-COMBO-MASTER' is going to work normally, using its communication protocol to ask the smart meter about the variables desired. Internally the PC, the EMH software is going to be connected to one of the couple virtual ports created by 'Null modem (com0com)'. 'Termite' is going to be connected between the other virtual port and the physical serial communication port of the PC, the one linked to the smart meter [Figure 47].

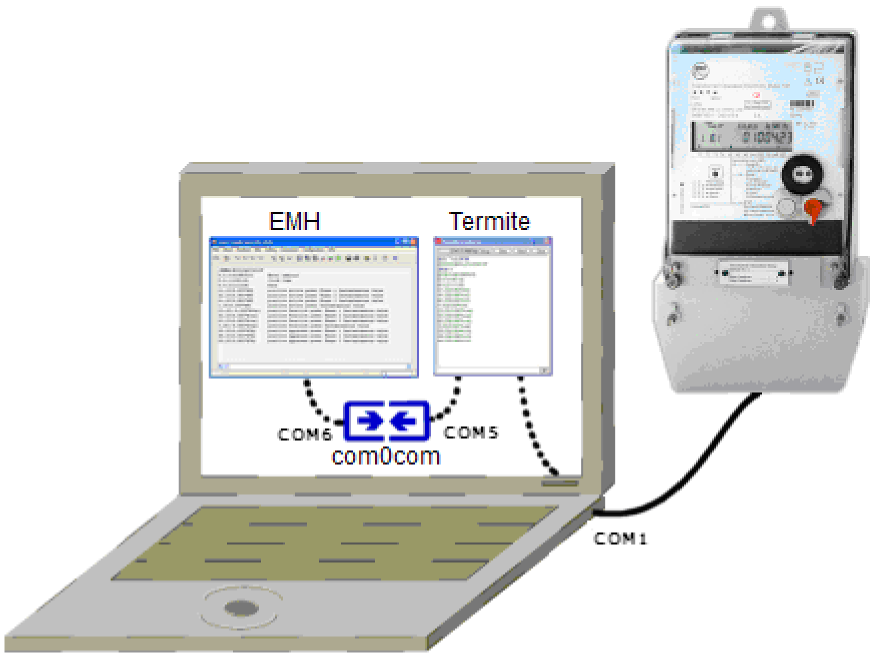


Figure 47: Scheme of the connection between the different programs

To communicate correctly, the EMH software settings have to be the ones shown in Figure 48. The COM port is chosen to communicate through, in this case the virtual port COM6, the baud rate is set at 4800 Bd and also the ID of the meter is written.

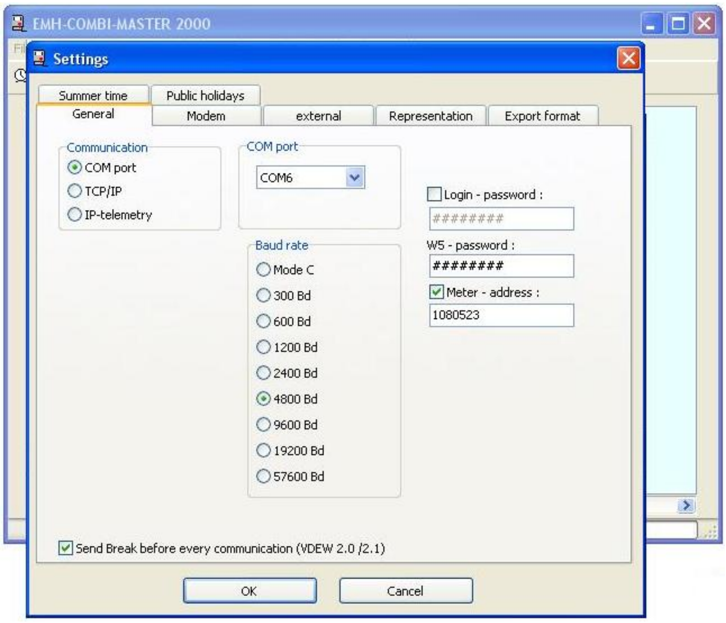


Figure 48: EMH-COMBI-MASTER settings

´Termite´ is used to display the information flowing between the two ports at which it is connected.

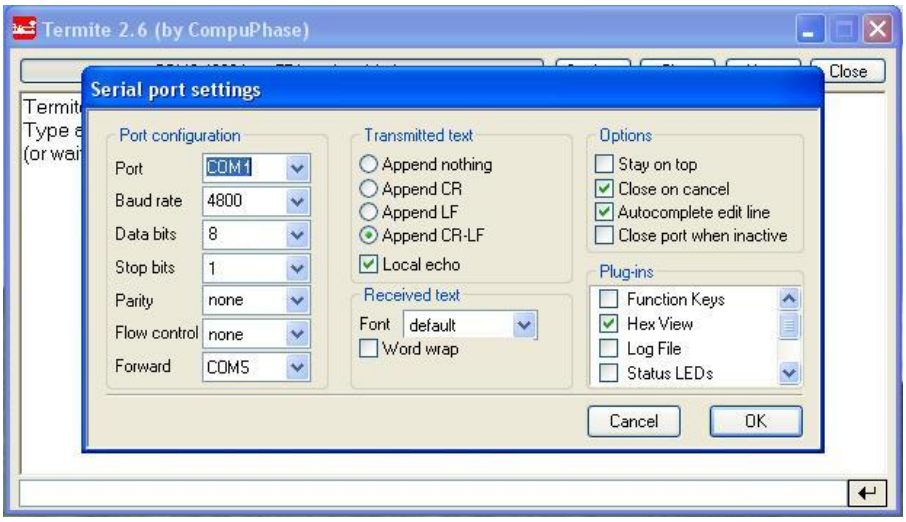


Figure 49: Termite settings

The settings [Figure 49] that can be configured in ‘Termite’ are classified in: port configuration, transmitted text, received text, plug-ins and other options.

- It is not necessary to change ‘Received text’ and ‘Options’ as they are by default.

- In the ‘Plug-insp, ‘Hex View’ is chosen because the commands needed to follow the communication protocol are going to be taken in hexadecimal. One reason why the commands are going to be taken in hexadecimal is because some commands will start by 0x06, ACK, a flag used to acknowledge the receipt of a message. When the command is sent, it is possible to write 0x06 but if ACK is written the command will not be recognize. The same will happen with other characters as CR (0x0D) or LF (0x0A). Because of this, hexadecimal is selected.

- The parameters selected for 'Transmitted text' are 'Local echo' and 'Append CR-LF'. With 'Local echo', it is solved the problem that sometimes can appear in communication in which the command transmitted is also received because of echo problems. That is because the receiver returns the data that has been sent before. For the communication it is also needed to add the carriage return (CR), to continue at the beginning of the line, and the line feed (LF), to continue in the next line, at the end of the commands transmitted.

- The most important settings are the ones related with the communication port, because they have to match with the way the data is going to be sent and received from the meter. The baud rate, that indicates the speed at which data is transmitted, is of 4800. This value has been chosen because it is the one at what trying to communicate with 'EMH-COMBY-MASTER' does not appear the message "Communication timeout". This message can be shown because of different reasons (the meter is disconnected, the ID of the meter is wrong…), but the most common reason is because of a wrong baud rate is being selected in EMH software. The meter was configured internally for 4800 Bd. This is why 4800 is the baud rate at which the EMH software can communicate with the meter. By now the rest of parameters are going to be: 8 data bits, 1 stop bit, no parity and no flow control. With this set up the communication is going well. Another important issue are backward and forward ports. The communication is going to follow between the physical computer communication port, COM1, and one of the virtual ports created by the 'com0com', COM5.

'Termite' is not the only program that has been used to display the information transmitted, also 'PuTTY' [Figure 50] has been used.

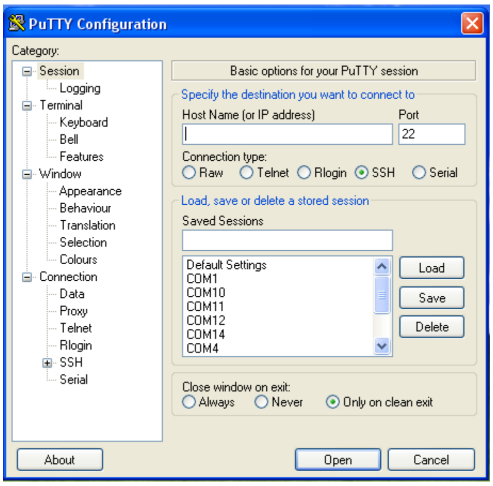


Figure 50: PuTTY

'PuTTY' is also a terminal emulator but as it is not possible to show the information in hexadecimal, it has not been used to collect the communication commands. It has been used to check at some times if 'Termite' was working correctly.

The third program which is used is 'Null-modem (com0com)'.

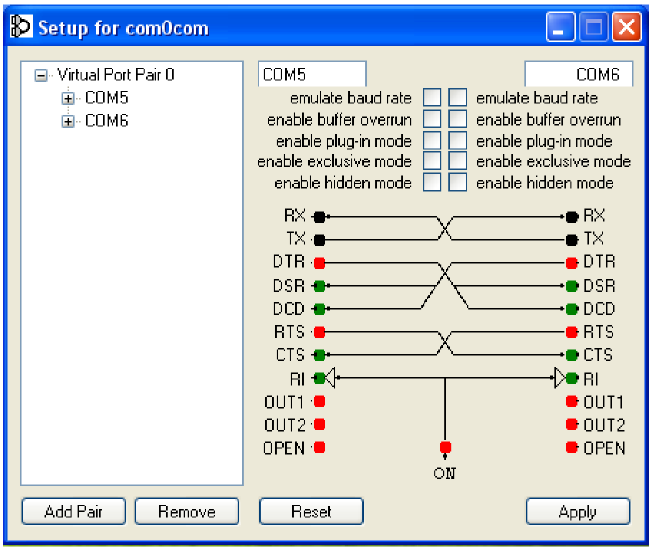


Figure 51: Null-modem (com0com)

'Null-modem (com0com)' creates COM5 and COM6 [Figure 51], two virtual ports, and it is also connecting them. The serial port is a point to point communication. It is not possible to connect more than one device to another at the same time. That is the reason why if 'Termite' is going to be connected between EMH software and the smart meter a new couple of serial ports are needed. 'Null-modem (com0com)' is working as an internal link between the two parts permiting the communication between EMH software and the smart meter and showing the data flow on the 'Termite' [Figure 52].

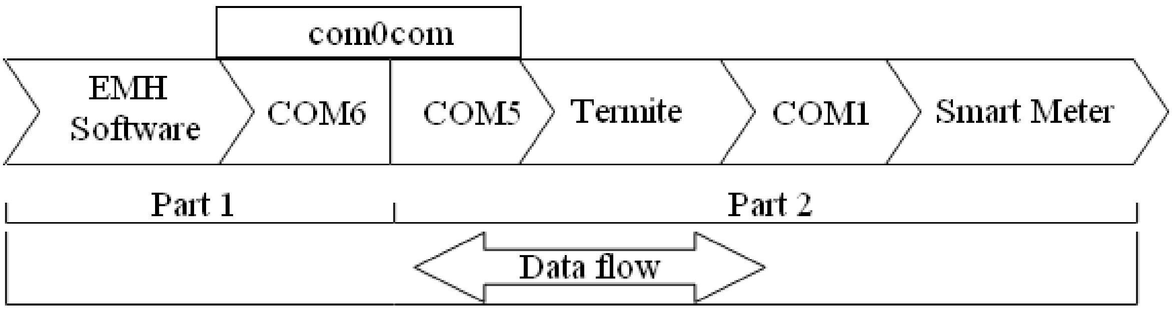


Figure 52: Data flow between all programs

4.4.2 Commands of the communication protocol

Now that tools needed to obtain the commands of the communication protocol are prepared. First that has to be decided is what information will be read.

From among all options that the smart meter offers (to obtain the commands and as long as the basic measures are in this group), single commands that can be read directly [Table 6] are going to be used.

These are the measures able to be read by using direct commands:

Recording of instantaneous values	
I1	31.25
I2	51.25
I3	71.25
I∅	11.25
U1	32.25
U2	52.25
U3	72.25
U∅	12.25
kW L1	21.25
kW L2	41.25
kW L3	61.25
kW Σ	1.25
kvar L1	23.25
kvar L2	43.25
kvar L3	63.25
kvar Σ	3.25
kVA L1	29.25
kVA L2	49.25
kVA L3	69.25
kVA LΣ	9.25
Power factor L1	33.25
Power factor L2	53.25
Power factor L3	73.25
Power factor LΣ	13.25
Hz (Frequency)	14.25
φ U1-I1	81.7.40
φ U2-I2	81.7.51
φ U3-I3	81.7.62
RTC Charging condition	96.6.1
RTC Charging voltage	C.9.3

Log book-Events	
Performance threshold kW+	1.35.0.01
Performance threshold kW-	2.35.0.01
Phase failure L1	C.7.1
Phase failure L2	C.7.2
Phase failure L3	C.7.3
Phase failure LΣ	C.7.0

Energy measurement	
Measuring type	**Energy**
kWh+, LΣ	1-B:1.8.E*F
kWh+, L1	21.8.0
kWh+, L2	41.8.0
kWh+, L3	61.8.0
kWh-	1-B:2.8.E*F
kvarh+	1-B:3.8.E*F
kvarh-	1-B:4.8.E*F
kvarh Q I	1-B:5.8.E*F
kvarh Q II	1-B:6.8.E*F
kvarh Q III	1-B:7.8.E*F
kvarh Q IV	1-B:8.8.E*F
kVAh+	1-B:9.8.E*F
kVAh-	1-B:10.8.E*F

Maximum demand measurement				
Measuring type	**Current average value**	**Last average value**	**Maximum demand**	**Cumulative**
kW+	1-B:1.4.E	1-B:1.5.E	1-B:1.6.E	1-B:1.2.E
kW-	1-B:2.4.E	1-B:2.5.E	1-B:2.6.E	1-B:2.2.E
kvar+	1-B:3.4.E	1-B:3.5.E	1-B:3.6.E	1-B:3.2.E
kvar-	1-B:4.4.E	1-B:4.5.E	1-B:4.6.E	1-B:4.2.E
kVA+	1-B:9.4.E	1-B:9.5.E	1-B:9.6.E	1-B:9.2.E
kVA-	1-B:10.4.E	1-B:10.5.E	1-B:10.6.E	1-B:10.2.E

Others	
Cu-Losses kWh+	83.81.1
Cu-Losses kWh-	83.81.2
Fe-Losses kWh+	83.81.4
Fe-Losses kWh-	83.81.5
Operating hours of the meter	C.50.0
Operating hours with battery supply	C.6.0
Operating hours of all tariffs	C.8.x
Transformer factor I	0.4.2
Transformer factor U	0.4.3
Reset counter	0.1.0
Pre-values reset counter	0.1.2*F
Manipulation of the meter cover	96.70
Manipulation of the terminal cover	96.71
Device address	0.0.0
Identification number	0.0.1-0.0.9
Serial number	C.1.0
Switching clock program number	0.0.2
Ripple control number	0.2.3
Standard data set recognition	94.49.2*02
Parameterization file number	0.2.1*F
Set file number	0.2.1*50
Firmware identification	0.2.0
Last DCF-synchronization	C.51.4
In-/output conditions	C.3
Internal control signal	C.4
Internal operating conditions	C.5
Installation register	C.86.0
Number of parameterizations	C.2.0
Time of the last parameterization	C.2.1
Time of the last switching program change	C.2.2
Time of the last ripple control program change	C.2.3
Measuring period length	0.8.0
Registration period length	0.8.4
Checksum PAR	C.90.0
Checksum SET	C.90.1
Checksum ROM	C.90.2
Checksum System	C.90.3
Display access protection	C.75.F

Impulse constants LED kWh	0.3.0
Impulse constants LED kvarh	0.3.1
Impulse constants output kWh	0.3.3
Impulse constants output kvarh	0.3.4
Impulse constants input kWh/kvarh	1-B:0.7.0/1
Error register	F.F
Clock time	0.9.1
Date	0.9.2
Weekday and week number	0.9.3
Weekday	0.9.5

Table 6: Variables that can be read by using a single command. [17]

The procedure for obtaining the command is:

1. Write the address of the variable that will be read. [Figure 53]

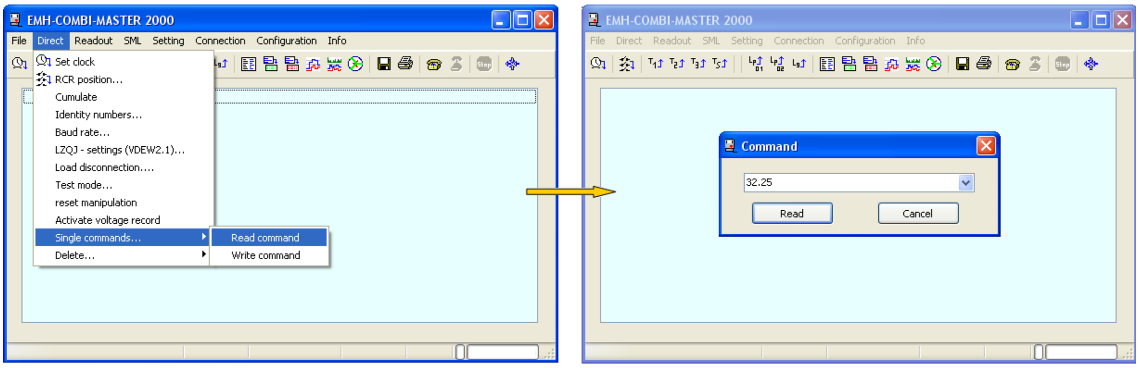


Figure 53: Reading variables by using single commands with EMH software

2. Display the commands at the ‘Termite’. [Figure 54]

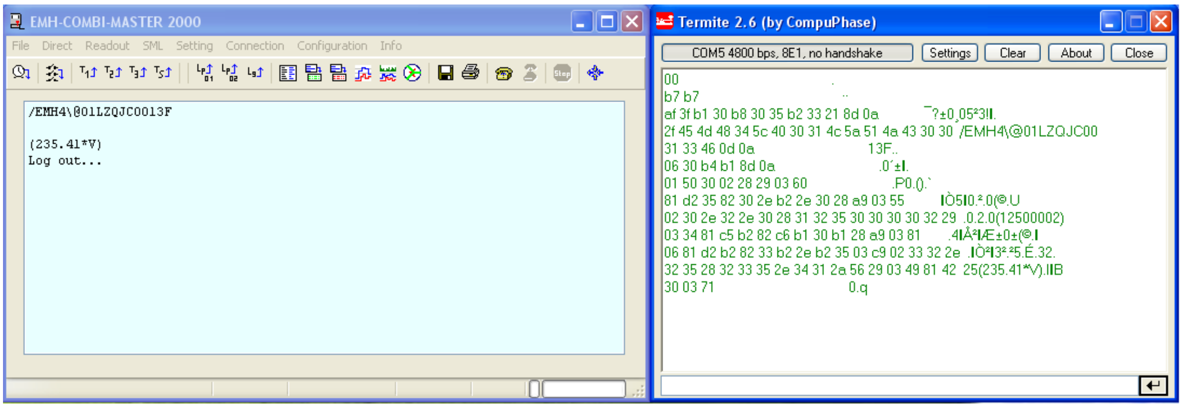


Figure 54: Communication protocol commands display by the Termite

Once all the communication is written, the next step is to differentiate which are the commands sent by the EMH software and which ones corresponds with the smart meter response.

Observing how the communication goes, the first command display at the termite is ¯?±0¸05²3!I., what corresponds in hexadecimal with 00 b7 b7 af 3f b1 30 b8 30 35 b2 33 21 8d 0a. This is the first command sent by EMH software. The next command written is /EMH4\@01LZQJC0013F.., in hexadecimal 2f 45 4d 48 34 5c 40 30 31 4c 5a 51 4a 43 30 30 31 33 46 0d 0a. Following the same reasoning, this would be the answer from the smart meter.

The first problem found is that if ¯?±0¸05²3!I. is written, it is not going to work well. No response is going to be received. Looking carefully the hexadecimal code it is easy to see that the last two digits corresponding to CR and LF are wrong. More exactly, LF in hexadecimal is 0x0a, so it matches, but CR is 0x0d and what is being displayed is 0x8d.

Moving from hexadecimal to binary, it is easy to find what is happening:

Hexadecimal: 0x8d ⟶ Binary:1000 1101
Hexadecimal: 0x0d ⟶ Binary:0000 1101

The first bit, the most significant bit, is always being filled with '1' instead of '0'. If the hexadecimal command is rewrite filling the most significant bit with '0' the command obtained is:

ASCII: ¯?±0¸05²3!I. ⟶ Hexadecimal: 00 b7 b7 af 3f b1 30 b8 30 35 b2 33 21 8d 0a
ASCII: 77/?1080523! ⟶ Hexadecimal: 00 37 37 2f 3f 31 30 38 30 35 32 33 21 0d 0a

As it has been explained before, it is not possible to send the command in ASCII because some of the values has not symbol in this code. However, it is easier to decode the first command in ASCII. Looking '77/?1080523!', the part of '1080523' is the ID of the meter. That means that the first command of the communication protocol is sending the ID of the meter from which the measures are going to be read. Focusing in hexadecimal, by this way, changing the most significant bit from '1' to '0', once the first command is sent the first response is received.

Now when it is known that some changes are needed to send correctly the instructions that the meter expects, it is time to continue differentiating between what the meter has to receive and what sends.
Chopping the information displayed in the termite and testing with the commands if the communication is successful (correct answers for the commands sent) [Figure 55].

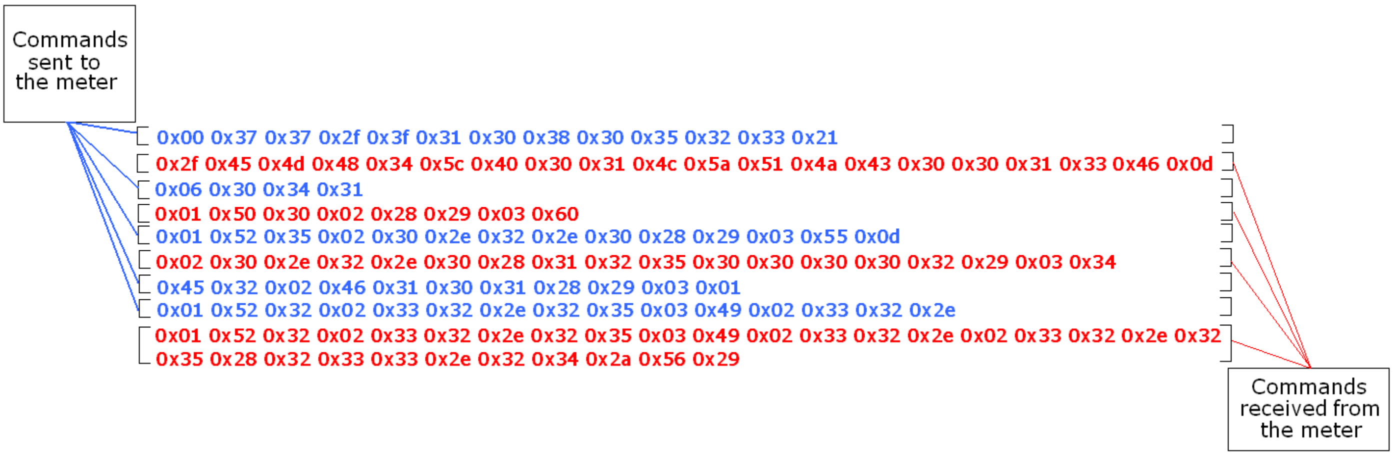


Figure 55: Communication protocol to receive the value of the voltage at line 1

Looking at the ASCII code to understand the meaning of the commands obtained, the first command sent (as mentioned above) is the identifier of the meter [77/?1080523!] and the answer is the confirmation by the manufacturer [/EMH4\@01LZQJC0013F], if the meter to which it relates is connected. The communication protocol continues until the last command received, that it is the one that contains the value of the variable measured, in this case the voltage at line 1 [.R2.32.25.I.32.. .32.25(233.24*V)]. The commands between are necessary to follow the communication, but they have not relevant information.

Continuing with the rest of variables accessible by direct commands, it is seen that the communication protocol for all variables follow the same commands with the exception of the last command sent, which indicates the desired variable.

All the commands that have to be sent to carry out the communication with the meter and get the measures of all variables accessible by direct commands are found in *"Appendix 1: Sent commands. Communication protocol".*

4.4.3 Conclusions

In this section the communication protocol has been studied. It has been proved that for variables read by direct command, all commands sent, except the last in which it is determined the variable to be read, are the same. It should be noted also, that if the meter is changed, the first instruction in which the ID is sent should change, sending the ID of the new meter.

Concerning received commands from the meter, they are also the same for all the variables, except the last command received. Moreover, this changes for the same variable, since the measure value is data that changes over time.

Chapter 5: Test performance

In this section, it is going to be explained, step by step, how the final program has been achieved from a serial communication program. The final program can read by GSM the data from three different smart meters connected simultaneously and save the data in a file. For which, it will make use of the commands obtained in the previous section. Not all the commands to read variables directly will be used, since for developing the program and test it will be enough with line voltages, line currents, the total active power and reactive power total. These variables have been chosen because they are the most common. In addition, the voltage readings from the low voltage networks can be used for voltage control in the medium voltage networks. That is another reason why these variables have been chosen.

The programming language used will be Java. One of the reasons to choose this programming language is because it is widely used and found information about it will be easier than other programming languages.

5.1 Communication with one meter by RS232

The objective of this point is to achieve a program able to receive data values from one smart meter by the serial communication port RS232 [Figure 56].

Figure 56: Communication with one meter by RS232

5.1.1 Serial communication program in Java. Basic communication.

The first step is just writing the code of a program able to send simple data by RS232. To do that, it is needed the package to manage serial communication in Java, called 'RXTXcomm.jar'. At the beginning, the first option was 'javax.comm', but this application is obsolete and it was not possible to find somewhere to download it. The classes necessaries from this package are going to be imported at the beginning of the code as follows:

```
import gnu.io.SerialPort;
import gnu.io.CommPortIdentifier;
import gnu.io.NoSuchPortException;
import gnu.io.PortInUseException;
import gnu.io.SerialPortEvent;
import gnu.io.SerialPortEventListener;
import gnu.io.UnsupportedCommOperationException;
```

Java is an object-oriented programming language. A program in Java can have one or more classes. Each class is a set of primitives and methods (they can be compared to variables and functions in other programming languages). The methods can receive or not some parameters and return or not other parameters, but they are always composed of a set of instructions and can be called more than once along the code. Classes have a method to initialize the class with its same name, it is known as constructor.

Therefore, the code is going to be composed, at least, by a class and its constructor. Both of them are going to be called '*SmartMeterComm*'.

The constructor is going to initialize the class by initializing the port and the input and output streams.

To initialize the communication port, to have a list of all the ports available at the computer is needed and check if some of them matches with the one that is going to be used, in that case a serial port because the communication is going to be through RS232, serial communication. Once the port is located, it is opened and its parameters (baud rate, data bits, stop bits, parity and flow control) are defined.

Input and output streams [Figure 57] are going to be prepared also in the constructor. These streams, in Java, are a tool that simplifies the input/output operations, they are the way where the data is written to be received or sent by the program. Prepare the streams means opened them and have them ready to be used.

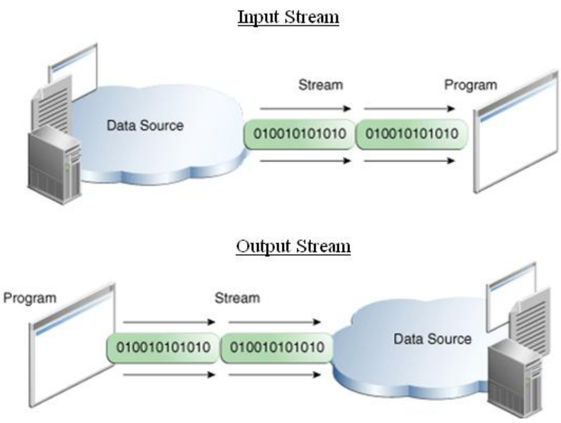
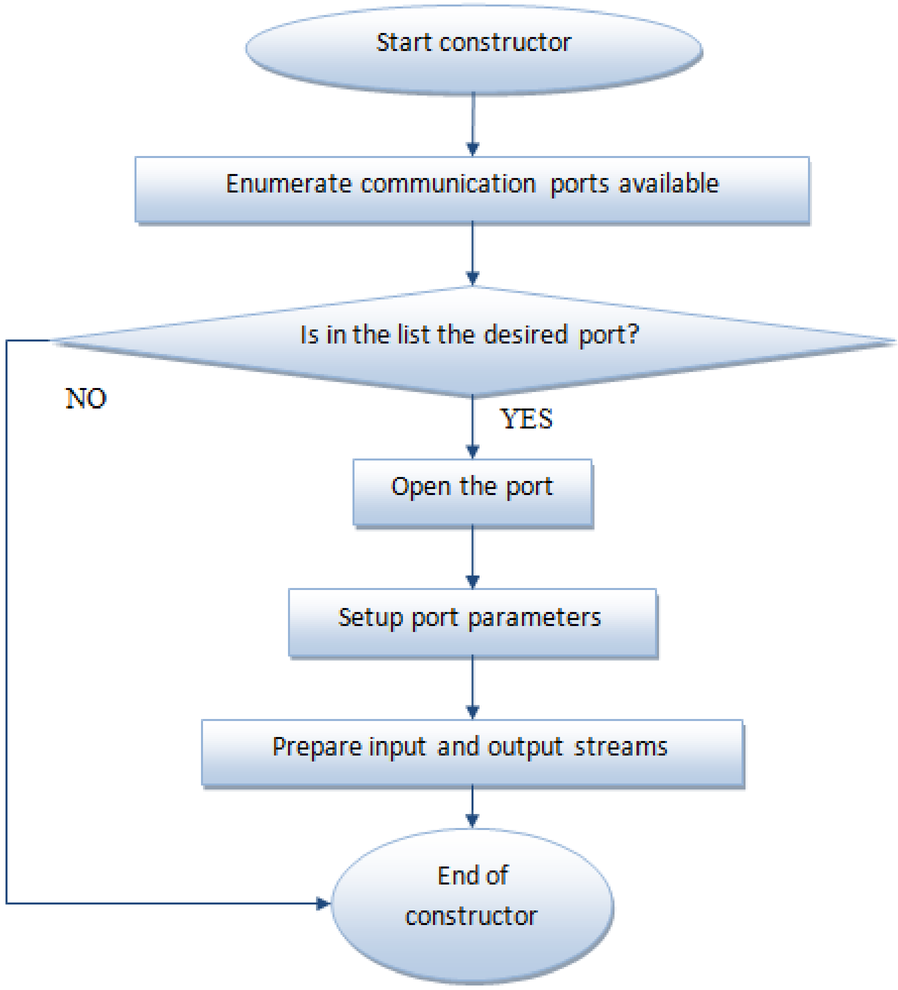


Figure 57: Input and output streams [25]

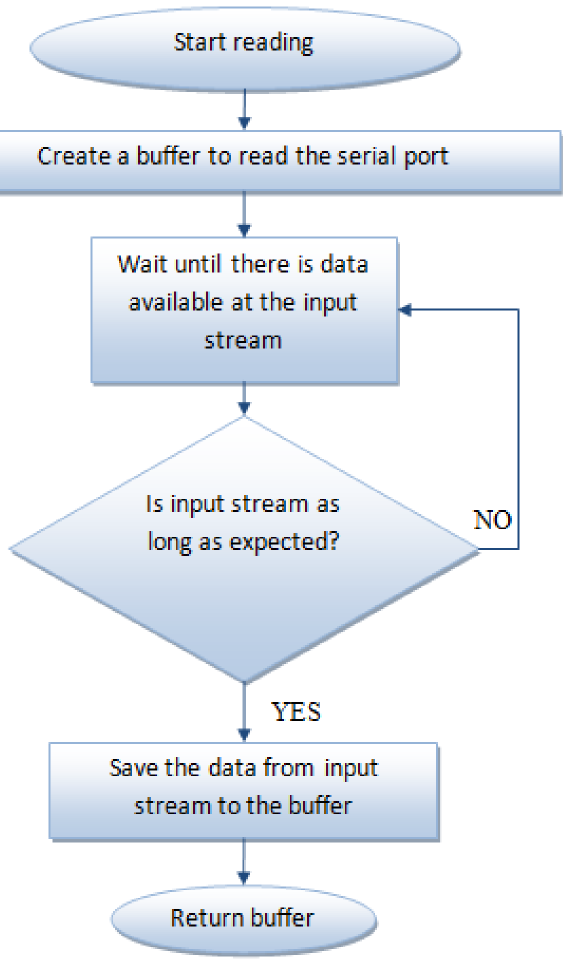
The flowchart of the constructor is the following [Flowchart 1]:



Flowchart 1: Constructor. SmartMeterComm

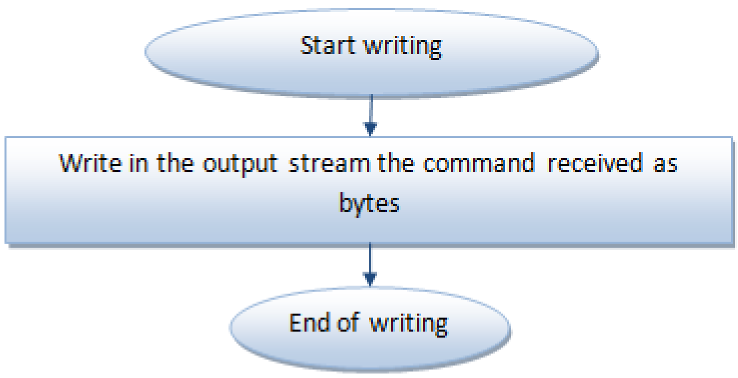
Apart of this, two more methods are going to be needed, by now, to manage the communication. One to read the data received and another one to write the data that is going to be sent.

The method responsible for reading what is in input stream is called '*SerialReader*'. When data is reading there are different options. At the beginning, it was attempted to wait until having something in the input stream, and then read it. If there is not going to be a lot of data read, there will be no problem, because the input stream is going to be written fast enough to catch all the information. Else, just a part of the information received is going to be read. To solve that problem, this method is going to receive the length that the input stream is supposed to have after reading all the information. Therefore, this method is going to receive an integer that contains the length of the string that has to be read. This length is known because the commands received (except the last one) are known [4.4.2 Commands of the communication protocol]. After that, data is read, saved in a buffer from the input stream and then returned by the method as string. This is the flowchart for the method to read in the simplest case in which only simple data is going to be read. [Flowchart 2]



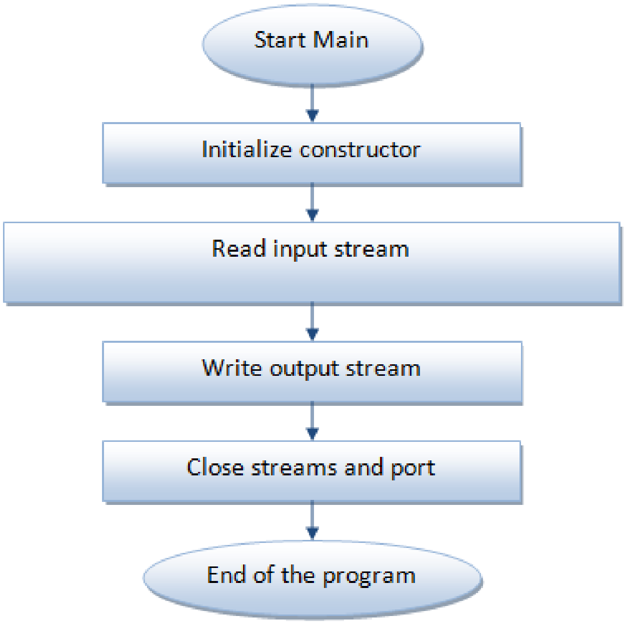
Flowchart 2: Method to read the input stream. SerialReader

The method called '*SerialWriter*' receives a string and writes it in the output stream. To do that the data is converted from string to bytes, because this is the type that the output stream handles. The flowchart of this method [Flowchart 3] is very simple.



Flowchart 3: Method to write the output stream. SerialWriter

Now the methods needed to send and receive data through the serial port are defined, but it is needed one more method linking all of them. This method called 'main' is not going to receive or return any parameter. It is carrying out the main objective of the program. The steps followed at the main are represented at its flowchart [Flowchart 4]. By now, the most simple case, it is only going to be read some character by the serial communication port and after a string is going to be sent by the same port. Before all, the class is going to be initializing and after the exchange of information the port and the streams are going to be closed.



Flowchart 4: Main part of the program

To check that the program is working correctly the scheme is the same used before but using this program instead of EMH software. The program developed is connected to the virtual port COM6, COM 6 is virtually linked by '*com0com*' with COM5, and now the data flow ends at the '*Termite*', where the data sent by the program is displayed and the data that the program has to receive is written.

5.1.2 Serial communication program in Java. Communication with one meter.

Next is to improve the current code to permit the communication with the meter. Some improvements that are going to be developed at this point are: be able to send and receive the commands needed to work with the meter, follow the communication protocol of the smart meter, ask to the user about the variable that is desired and if the user wants or not to continue reading measures from the meter, save the measures in a file and the creation of a thread working in parallel to limit the time waited while reading. To do that, some of the methods explained before (the constructor and the one used to write the output stream) are not going to be changed, other methods (the main method and the one used to read the input stream) has to be changed and new ones have to be created.

The problems and the method followed will be explained, and, at the end, final flow charts will be commented.

Now, it is greatly facilitating the program development, the fact that the communication protocol has been understood previously and also to have noticed that all the commands sent for all variables (except the last one) are the same. The reason is that, thanks to this observation, all the communication protocol could be written in a method shared by all the variables. As the only difference between the measures is the last command sent, it is enough with sending to the method this command as a parameter received.

The communication protocol consists of five sent commands and four received commands.

U1_32.25: Voltage line 1

0x37 0x37 0x2f 0x3f 0x31 0x30 0x38 0x30 0x35 0x32 0x33 0x21

0x2f 0x45 0x4d 0x48 0x34 0x5c 0x40 0x30 0x31 0x4c 0x5a 0x51 0x4a 0x43 0x30 0x30 0x31 0x33 0x46 0x0d

0x06 0x30 0x34 0x31

0x01 0x50 0x30 0x02 0x28 0x29 0x03 0x60

0x01 0x52 0x35 0x02 0x30 0x2e 0x32 0x2e 0x30 0x28 0x29 0x03 0x55 0x0d

0x02 0x30 0x2e 0x32 0x2e 0x30 0x28 0x31 0x32 0x35 0x30 0x30 0x30 0x30 0x32 0x29 0x03 0x34

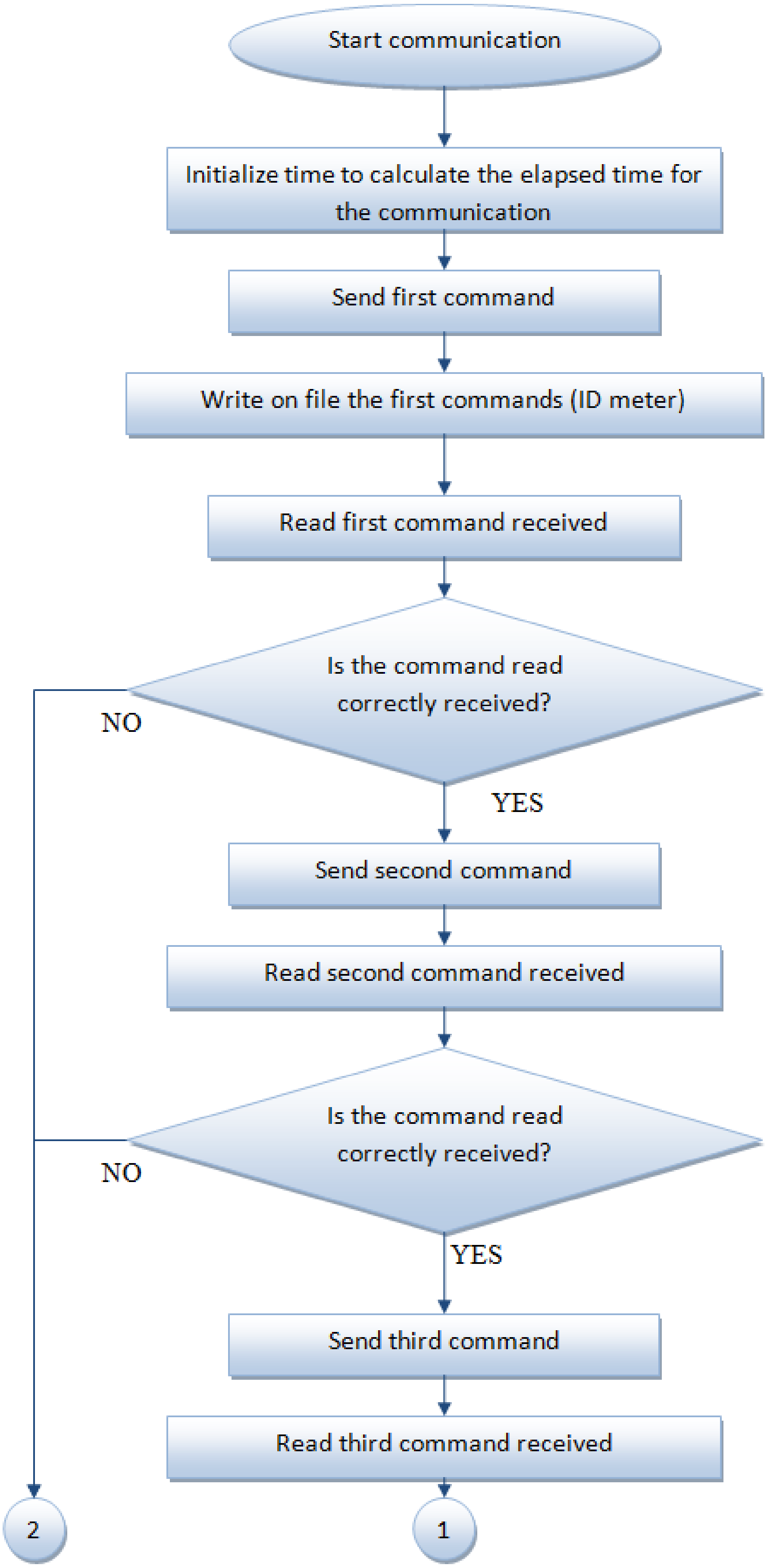
0x45 0x32 0x02 0x46 0x31 0x30 0x31 0x28 0x29 0x03 0x01

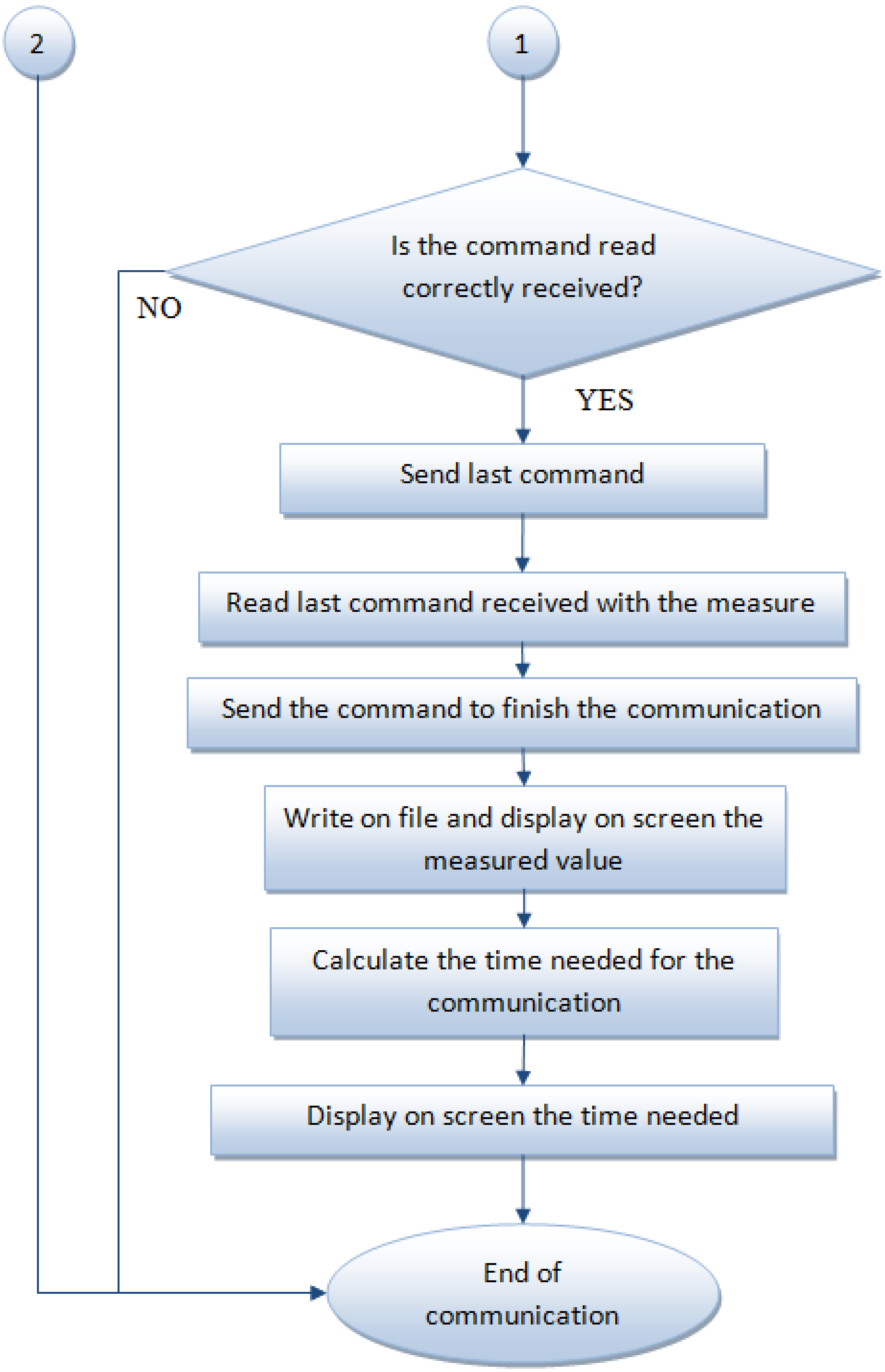
0x01 0x52 0x32 0x02 0x33 0x32 0x2e 0x32 0x35 0x03 0x49 0x02 0x33 0x32 0x2e

Command that contains the measured value

The first command sent is the one that contains the meter ID. Once the command is sent to the meter, this sends another command indicating that the meter chosen is connected. To check that everything is running well, and as it is known the command that has to be transmitted by the meter, this is going to be verified. If it is correctly received the communication continues, else it is finished. After that, the meter will wait for the next command to follow the communication protocol. The same process continues (command sent and then command received and checked if it is correct) until the last part is reached. The last part is more delicate because the command sent and the one received are different. Last command that has to be written in the output stream is composed by two that have to be sent separately. One is common for the rest of variables and the other is the one that comes as a parameter when the method is called. On the other hand, the reading of the last command is different to the rest, because this instruction is not fixed or, in other words, is not always the same. It depends, among others, on the length of the measure read. The solution is going to be a change at the method for reading the input stream. The only difference (by part of the communication method) is that, instead of sending the length to the method mentioned, '-1' is going to be sent. This indicates that in that case what is going to be read is the last instruction, the one that contains the measure.

With this it could be enough, but after that, the meter is still waiting for a command and if it is not sent in some seconds, the meter sends another instruction. This is a problem, because if another variable is wanted to be read, this instruction is not expected and will fill out the input stream. This will suppose that when the first command is sent and the received instruction is going to be verified, the response to the test is going to be wrong, because the input stream has been filled before incorrectly. This problem has been solved just noticing that the meter is expecting a command to finish the communication, if this command is not send, after a while, the meter sends is to end the communication [Flowchart 5].


Start communication
Initialize time to calculate the elapsed time for the communication
Send first command
Write on file the first commands (ID meter)
Read first command received
Is the command read correctly received?
NO
YES
Send second command
Read second command received
Is the command read correctly received?
NO
YES
Send third command
Read third command received
2
1



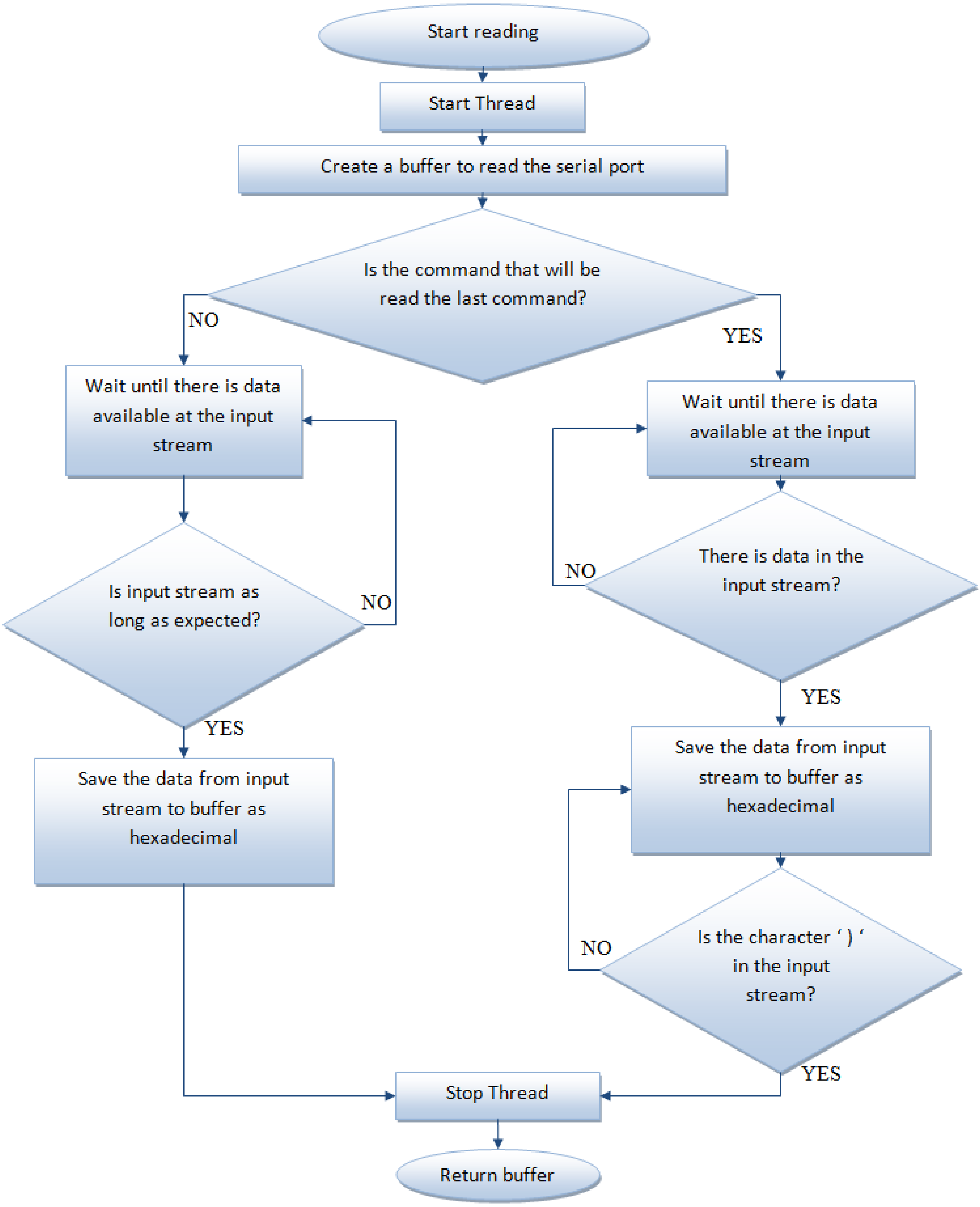
Flowchart 5: Communication

'*SerialReader*' has to be changed [Flowchart 6]. The method that reads the serial port has to distinguish between the last command read and the rest. For this purpose, the integer received as a parameter is going to be used.

- If the parameter is '-1', it is the last command. It is not possible that if some command is going to be read the length will be less or equal to 0, because that means that there is nothing to read.
- If the parameter is bigger than 0, some of the rest of the commands is going to be read and the parameter is indicating the length of the command.

Another change that has to be done is that, before, simple data was read, but now, commands, that have to be verified after, would be read. To verify the incoming data, it has to be converted to hexadecimal. Along the report has been explained that some symbols are not able to be represented in ASCII but they are in hexadecimal. Java has a method to convert the bytes of the input stream to hexadecimal while it is being read ('*Integer.toHexString( )*').
ASCII symbols are represented in hexadecimal by two digits, going each one from 0 to F. By this way, at the conversion, if the first digit is equal to 0, the method is going to take only the second digit. For example, if the result of the conversion is '0F', the method is going to return only 'F'. In those cases, to fix it, the 0 removed is added after the conversion.

When the integer incoming to the method is equal to '-1', the last command will be read and the procedure will be different to the rest. The last data received contains the measured value that is always between parenthesis, (value*measure units). As the length of this instruction is not always the same for all variables, the parenthesis is going to be used to stop moving the data from the input stream to the buffer. Hence, the method will be waiting until data is written in the input stream. Once data is received, it is written to the buffer until the closing parenthesis is received (checking its value in hexadecimal, equal to 0x29). Thereby, it is sure that the measure is returned by the method. As there is more information in the string returned than the desired, some instructions are needed. '*measuredValue*' is a method programmed to take the substring in parentheses from the string returned by '*SerialReader*' when is called to read the command that contains the measurement.

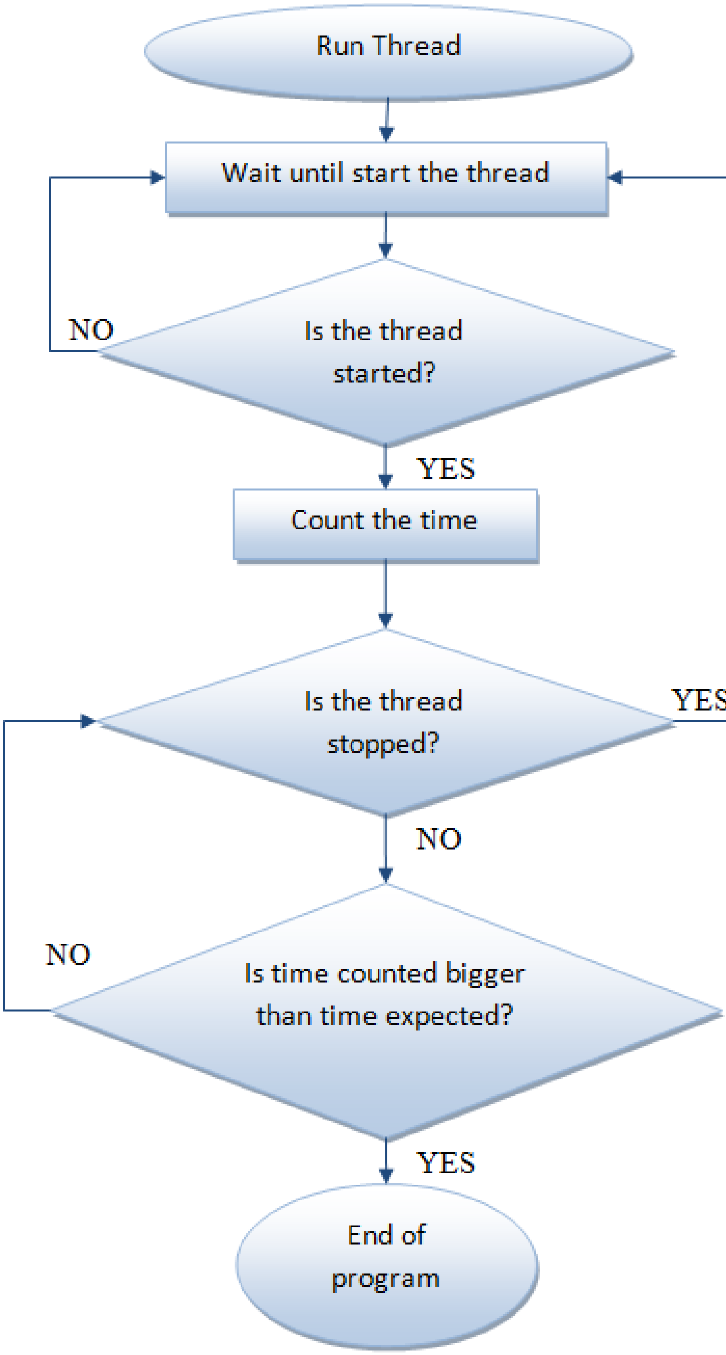


Flowchart 6: Serial reading

Sometimes, during the reading, some problem can occur (the meter is disconnected, problems with the communication port, etc) and the data is not received. That means that the input stream is not written as expected and the program will be suspended in an endless loop waiting to fill the input streams or waiting for the closing parenthesis. To avoid that, the program will be waiting for a while and after that time if the reading has not run correctly, the program is finished. A parallel process counting the time for reading is needed. Threads are used in Java to run a concurrent process.

As Java has not any preset method to stop and relaunch threads, the thread is going to be defined as a class (‘*ThreadClass’*) with its own methods that make it possible. The class consists of three methods: ‘*stopThread*’, ‘*startThread*’ and ‘*run*’.

In Java, the method ‘*start( )*’has to be called to begin the execution of the thread by start running the method called ‘*run( )*’. The last one contains the code to be executed in the thread. The purpose of this thread is to count the elapsed time and if this exceeds a desired value, then end the program. To initialize and run the thread again, the chosen solution is keeping the thread running in parallel while the program is executed. A boolean is going to be set as “true” by calling the method ‘startThread’ and set as “false” by calling the method ‘stopThread’. When the boolean is “true” the counter is going to start and be checked with the limit established. To stop the counter the boolean has to be “false”. That is how the thread is going to be stopped and relaunched. ´startThread´ will be called at the beginning of the serial communication reading method and ´stopThread´ at the end of the method, when reading has finished. ‘*start( )’* will call ‘*run( )*’ at the beginning of the program code, in the ‘*main*’ method [Flowchart 7].



Flowchart 7: Thread

By now the only possibility is to read one measure and then the program ends. Using EMH software, each time the user wants to read a variable, the user does all the process to send a direct command [Figure 53]. It could be better if after reading, the program would ask if the user wants to read some more measures. An interface, to communicate with the user showing the questions that the program makes and taking the user answers, has to be created. To carry this out, new instructions are necessary, to show and collect information from the screen, and the '*main*' method structure has to change.

The instruction to display a message in the screen is:

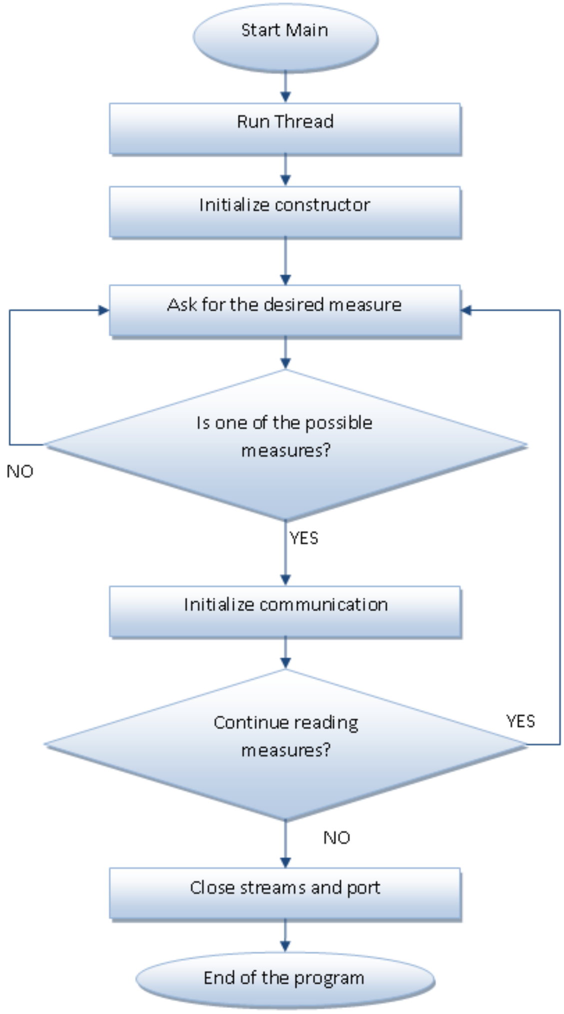
System.out.println(*message*);

On the other hand, the instructions to read what the user writes on the screen are:

```
InputStreamReader isr = new InputStreamReader(System.in);

BufferedReader br = new BufferedReader (isr);

String cadena = br.readLine();
```

These instructions are explained in the code. To understand them better go to *"Appendix 3: RS232 Communication"*.

The structure of the '*main*' method is different due to the addition of: the communication method, the thread and the possibility of continue reading more measurements [Flowchart 8]. It is not as simple as initialize the class with the constructor, read a command, write another one and close the port and the streams. The new structure is represented in next flowchart.



Flowchart 8: New 'main' structure with communication method, thread and interface with the user.

In addition, to ask if the user wants to read some more variables, it would also be good to display some more information on the screen which is useful for the user. The information chosen to be displayed on the screen is more or less the same that EMH software prints [Figure 58].

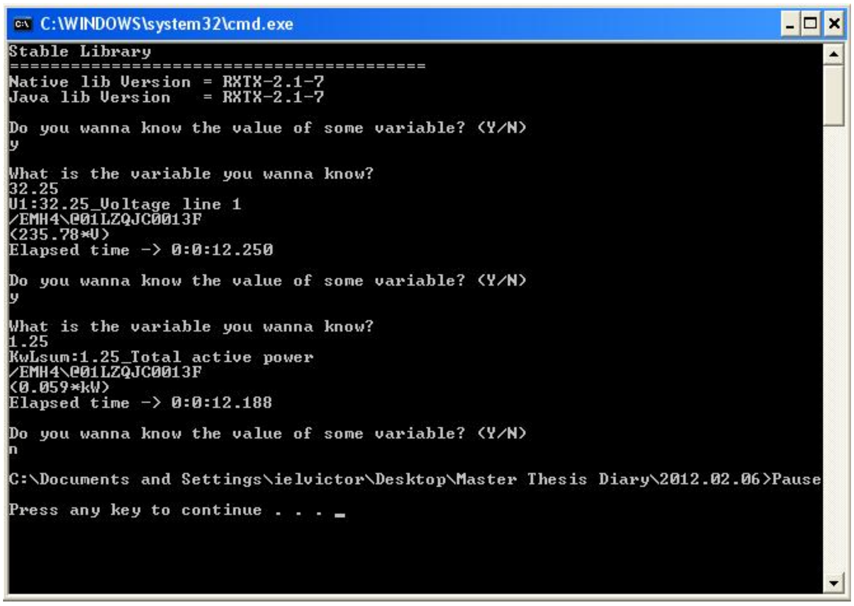
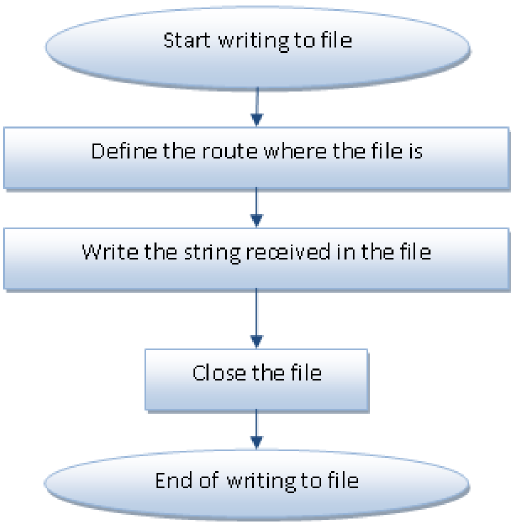


Figure 58: User interface

The elapsed time shown is the time needed to read the variable. It is measured since '*SerialRead*' method is called until it finishes. Later, the thesis will go deeply into the time needed for reading measures [Chapter 6: Evaluation. Time needed for reading measurements].

Another function, that the program performs, is to store the values read in a file. For that reason, a new method, called '*writeToFile*', that receives a string and writes it to a file, has been written. To save the historic, newly written data is added to the previously saved. This is the flowchart of this method [Flowchart 9]:



Flowchart 9: Write to file method

To write to the file it is enough with call the function:

writeToFile ( );

The data written within the parentheses will be written in the file [Figure 59]. The aspect of the information saved in the file is similar to the information display on the screen. As the file is an historical data, the date and the hour at what the measurements have been taken are written.

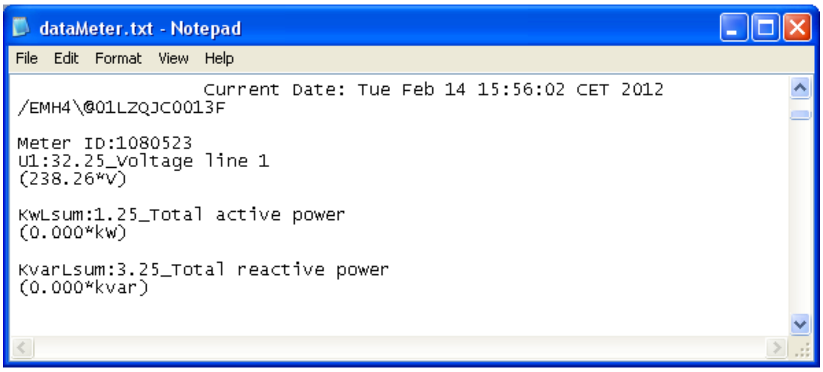
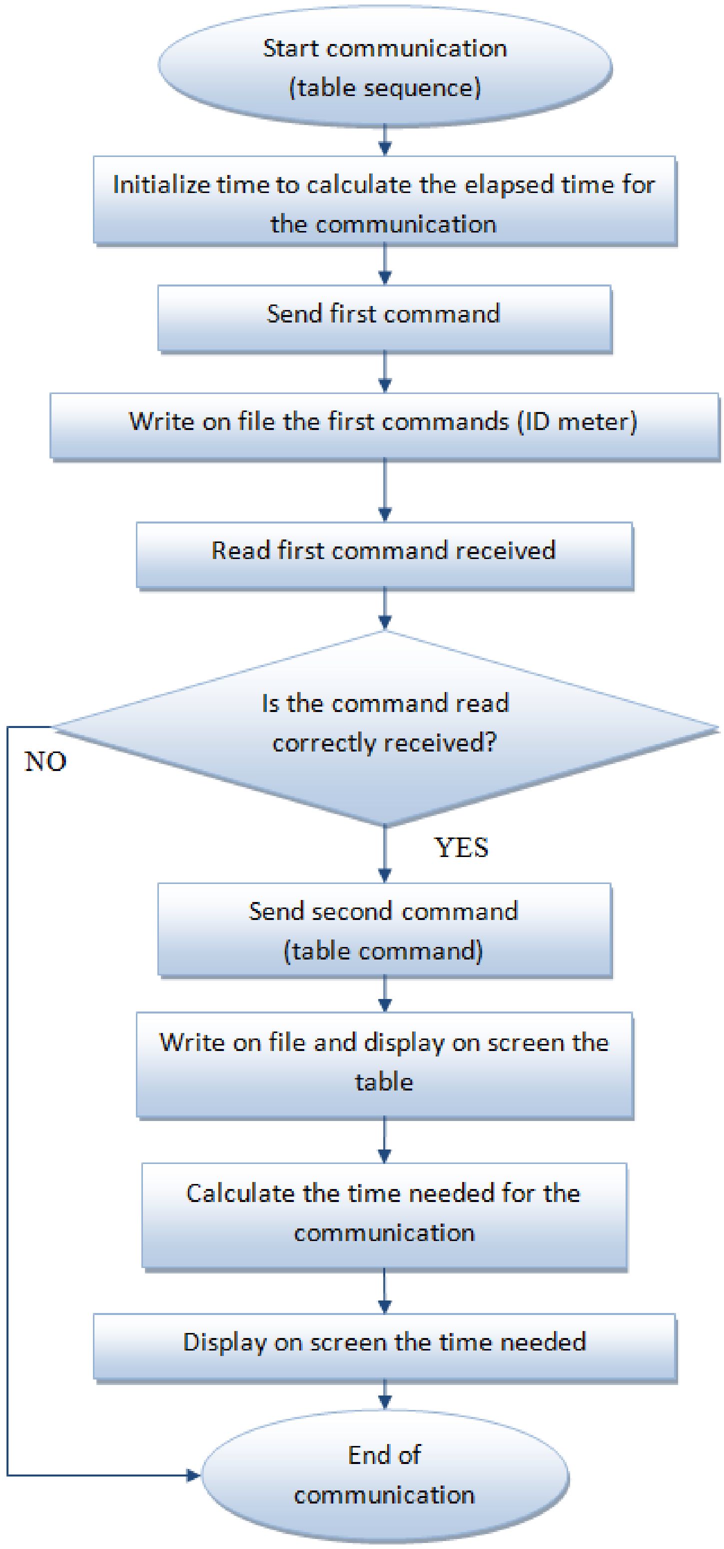


Figure 59: Historical data file

Data shown on the user interface and also data in the file are represented in ASCII. To be able to do this another method that converts a string from hexadecimal to ASCII has been used.

To improve the time needed the code has been changed, to make possible the reading of the Table 1 and the Service table. It will be verified that with these new changes the reading is 2 seconds faster by reading the tables [Chapter 6: Evaluation. Time needed for reading measurements]. To achieve this, a new method has been added [Flowchart 10], because to read the tables a new sequence of commands is used. This method will be called if some table has been chosen for reading [Appendix 3: RS232 Communication].



Flowchart 10: Communication. Command sequence to read tables

5.2 Communication with one meter by RS232. Conclusions

The program developed in this section is able to read measures from one smart meter by serial communication RS232. The user will be asked (by using an interface) about the variable that is going to read. The program sets up and opens the serial port communication. In addition, it carries out the communication protocol, showing the desired information on the screen and saving an historical of the measures read. If, while program is executed, the communication fails, after a time the program will end.

Another important aspect is the time needed to read a measurement. Elapsed time is in the range of [12, 13] seconds.

5.3 Communication with three meters by RS232

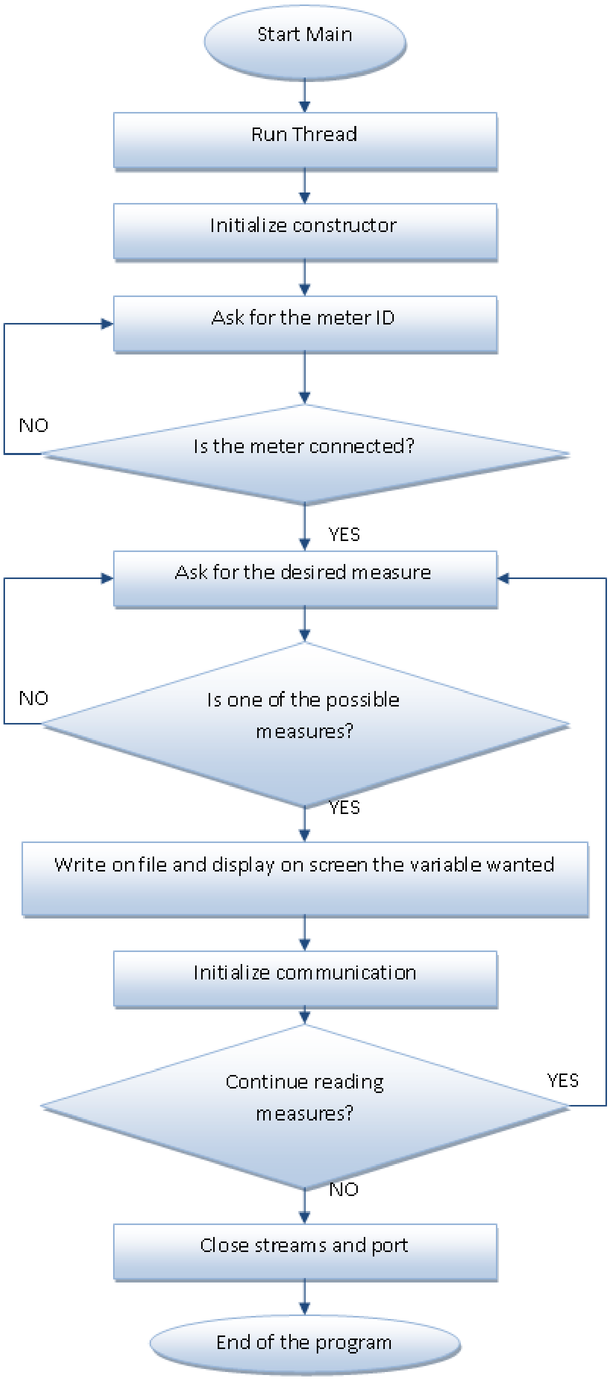
The objective here is to extend the current program to read measurements from more than one meter connected at the same time [Figure 60]. Three meters will be used to check this operation. The reason for using three meters is that this is all the equipment available.

Figure 60: Communication with three meters by RS232

The first that has to be checked is if the program developed works with the new meters as it was working with the meter used before. To do that the only thing has to be changed is the first command sent, because is the one that contains the ID of the meter. Each meter has an ID written in the device. The three meters, that are going to be used, have the following IDs:

-1080523
-1059307
- 1080089

As it was supposed, this change is enough to run the program with one of the three meters. Before connecting the meters the '*main*' method of the class '*SmartMeterComm*' is going to be modified [Flowchart 11], then it will be possible to ask to the user if wants to change the meter before reading a measure and which meter is going to be to read. These changes can be appreciated at the code in *"Appendix 3:RS232 Communication"*. The new flowchart for the method changed is:



Flowchart 11: Main method for more than one meter

Once the code is prepared the next step is to connect the three smart meters together physically.

When the three meters were connected together to check how the programs worked, the program was able to send commands but it did not receive any response from the meters. This was checked with ‘Termite’. To locate the problem an oscilloscope was used to display the data signal transmitted through the serial port. With the oscilloscope connected to the common point where the three meters were connected, the signal sent by the program was transmitted but there was no kind of response on the serial port. The following was to connect the oscilloscope to the RS232 reception and transmission pins of the meter that was being read. At this point, the oscilloscope displayed both data direction signals. Therefore, the problem was at the connection between the counters.

Serial communication RS232 is a point to point protocol. As it has been explained before, this means that only one device can be connected with another device. When try to connect three smart meters at the same communication physical port of the computer, it did not work. The immediate solution give at the ‘Product manual’ of the meter is use RS485 instead of RS232. But this solution needs convertors to adapt the signal from RS232 to RS485 and vice versa. This solution is more expensive that the one carried out in this thesis.

The reason why the connection of three meters to the same serial communication port of the computer does not work is related with the voltage level at the transmission pin (TXD) of the meter. This pin is normally at high level, [-15, -3] V, and if the meter is transmitting the pin is at low level [3, 15] V. As the three transmission pins of each meter are connected together, when one of them tries to communicate and change the signal from high level to low level, the other two meters are keeping this signal at high level. That is why the meter is trying to transmit data but it is not being reflected at the serial port. The solution is to use poll-down resistance at TXD pins.

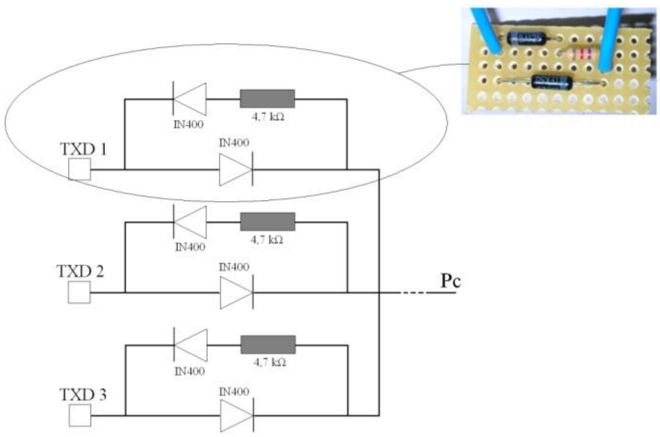


Figure 61: “Pull-down” resistance to communicate three meters at the same time by RS232.

The “pull-down” resistance scheme, normally, is just a resistance connected between the transmission terminal and ground. The scheme of Figure 61 is used to avoid the ground connection and only use the connection with the transmission terminal. As it is shown in Figure 62, when no meter is transmitting the serial port is receiving a high level ([-15, -3] V), but if one of them transmits data and changes to low level ([3, 15] V) the serial port is going to be at low level. That is caused because the signal at high level, coming from the terminal, is attenuated by the resistance. If more meters would be connected, the resistances would not be able to reduce enough the signal at high level and the serial port would receive a high level also when one of the meters would be transmitting data. The values of the resistances (4,7 kΩ) are the common values used for pull-down resistances. The diodes, IN400, are able to manage the voltage from the terminals of the meter.

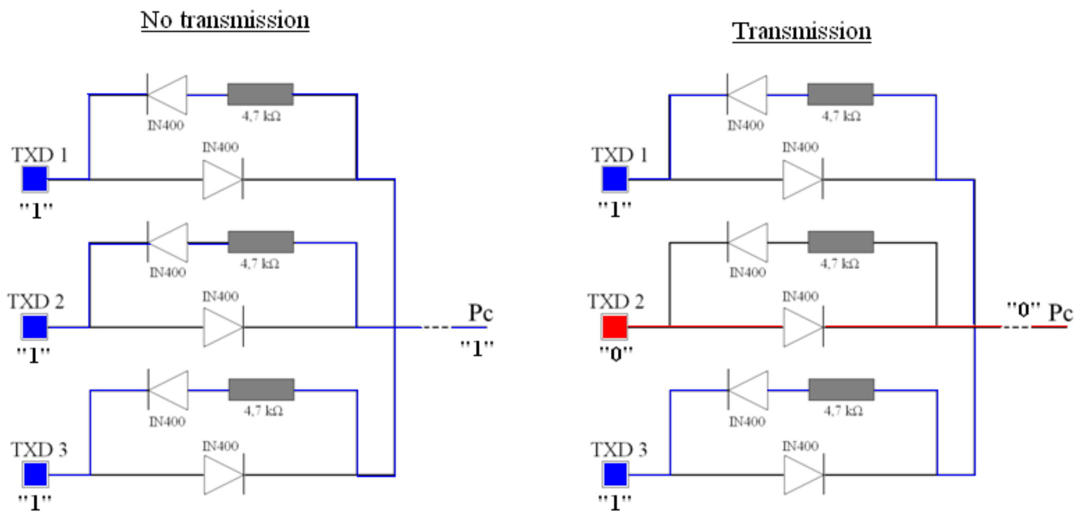


Figure 62: Transmission using “pull-down” resistances.

5.4 Communication with three meters by RS232. Conclusions

Adding these “pull-down” resistances to the connection of the meters, the voltage level of the serial port is changing correctly when one of the meters sends data and the program works. Thanks to the communication protocol, practically the same program is working with three meters. The reason is that all the meters are receiving the first command, but only the one that matches with the ID contain in the instruction is going to answer to the next commands send by the program.

5.5 Communication with three meters by GSM.

The last improvement of the thesis is to communicate with three meters, as it was done before, but instead of using wired RS232, this time the connection between the computer and the meter is going to be wireless by GSM [Figure 63]. GSM, “Global

System for Mobile Communications", is a wireless network technology that makes use of a SIM card to identify the user's account.

Figure 63: Communication with three meters by GSM

To achieve this, the PC is going to be connected to a modem by USB. This modem is going to receive the AT-commands to start and hang-up the communication with another modem connected to the meters. Once the communication between PC and smart meters is allowed, the commands are transmitted by the GSM transparent network as they were transmitted through RS232 before, because between the modem of the meters and the meters, the connection is by RS232.

For the communication with the meters via GSM, the program needs to send some AT-commands to the serial port following this way:

- To connect with the modem:

1. AT<CR>: To check if there is a modem connected ready. If there is, <CR><LF>OK<CR><LF> will be received.

2. ATDxxxxxxxxxx<CR>: The command to start the communication with the modem that matches with the dial sent. The xxxxxxxxxx is the place where the dial, SIM number, has to be written. The dial number used in the thesis is 0703657375, thus the command is ATD0703657375<CR>. If the connection has been done, <CR><LF>CONNECT<CR><LF> is received.

- To hang up:

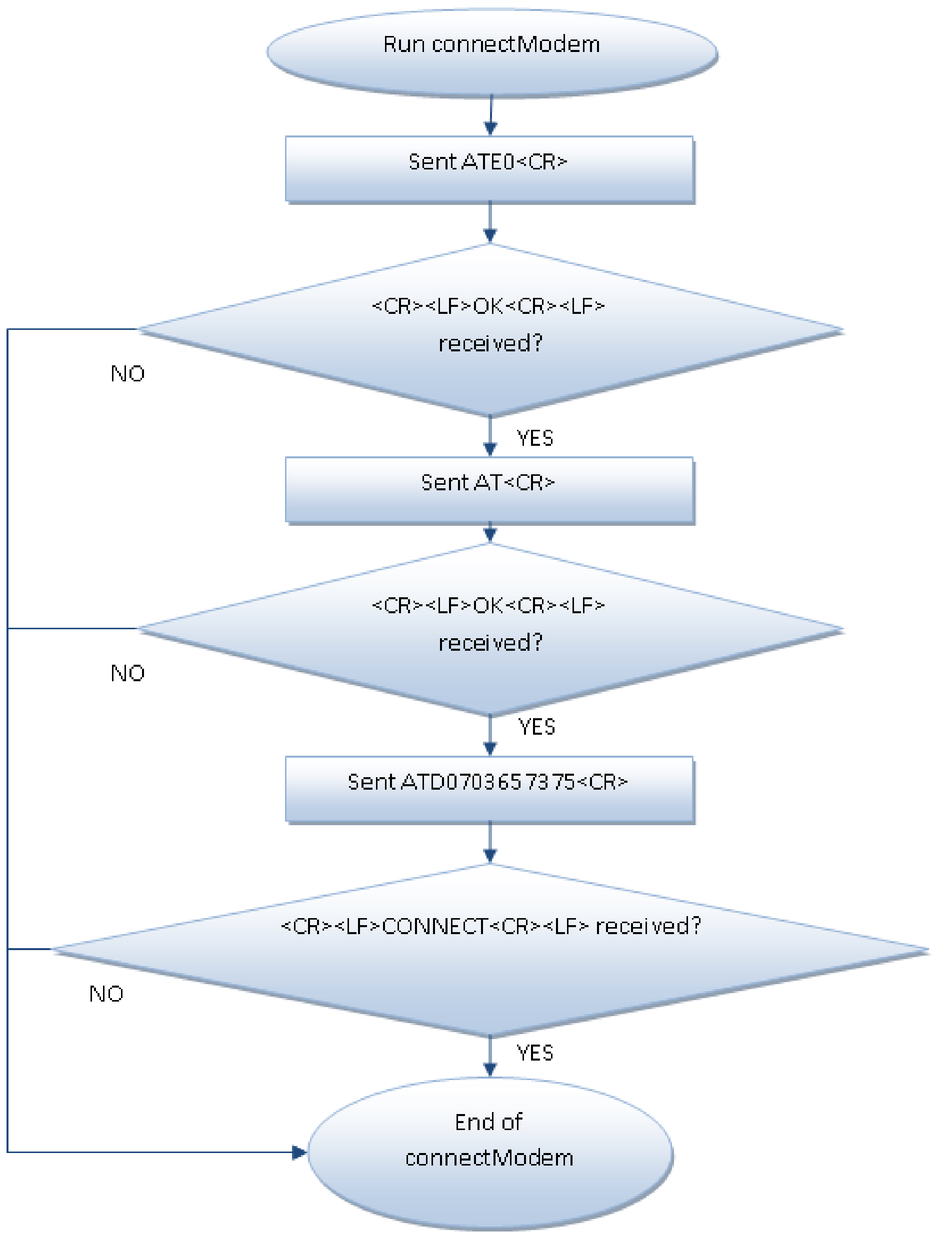
1. +++: This is the default escape sequence. Transfers the modem from data mode to command mode. Must be preceded by at least one second of no characters

and followed by one second of no characters. If +++ is not sent, the modem will not recognize the next command (ATH).

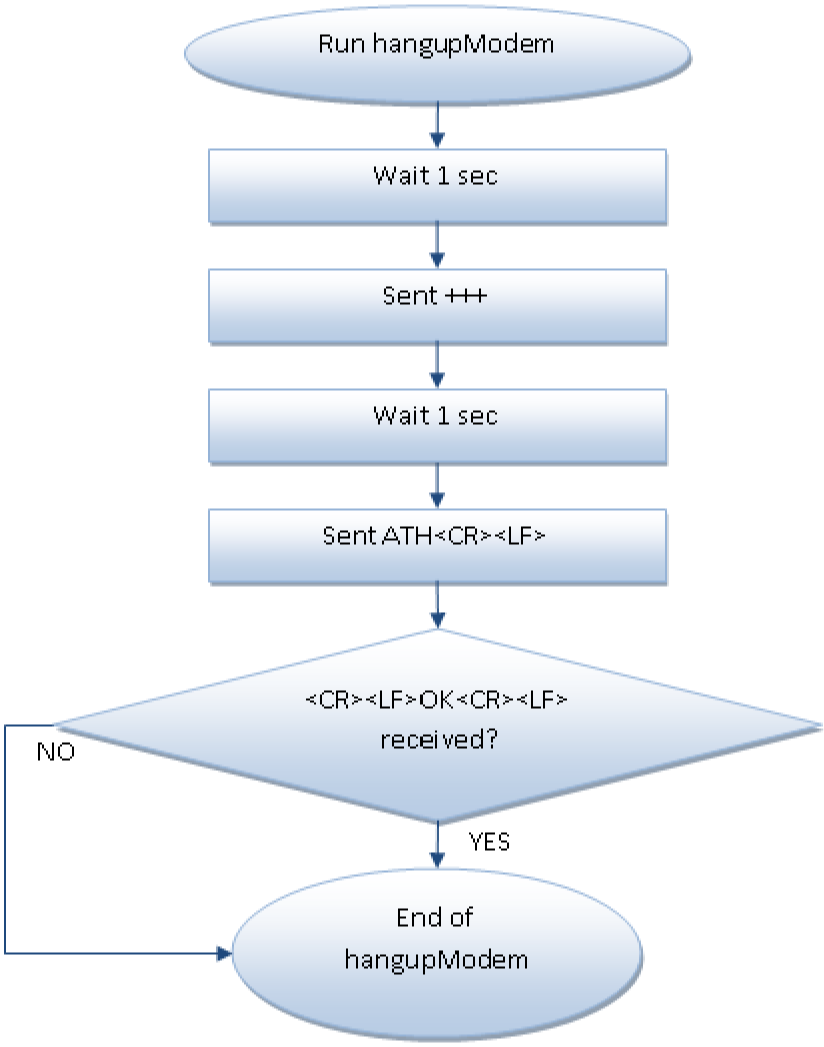
2. ATH<CR><LF>: Hang up the communication. If the hang up has been done correctly, <CR><LF> OK<CR><LF> is received.

If only these commands are used, a problem appears. The commands sent will be back with the response expected. To turn off echo of commands ATE0<CR> must be sent and <CR><LF>OK<CR><LF> received before continuing with the previous steps.

To do this, in the code, two methods have been added: connectModem [Flowchart 12] and hanupModem [Flowchart 13].

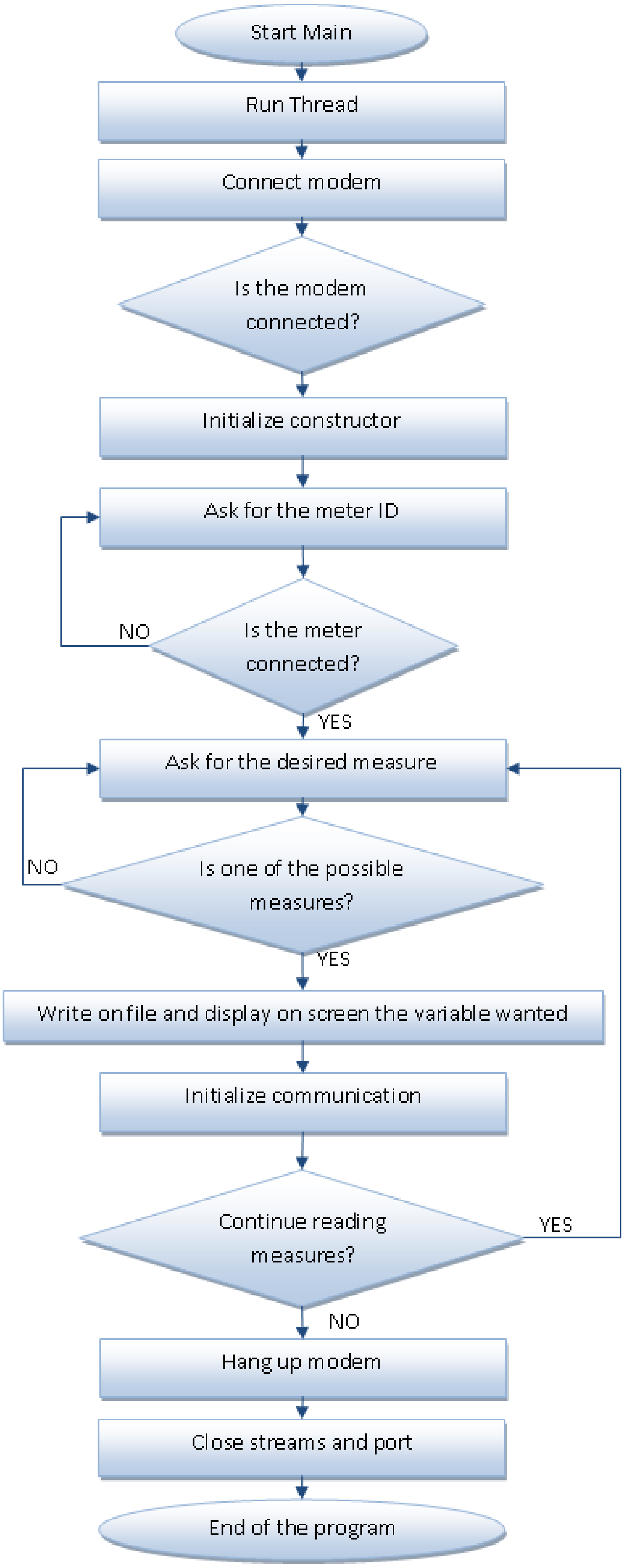


Flowchart 12: Flowchart to connect with the modem



Flowchart 13: Flowchart to hang up with the modem

Also the '*main*' method changes [Flowchart 14], because it is from this method where '*connectModem*' and '*hangupModem'* are called. The modem has be connected before start communication with the meter, and disconnected at the end of the code, before closing the port, because once the port is closed it is not possible to send the At-command necessary to hang up.



Flowchart 14: Main method with GSM communication

Once the code has been changed and the program will be run to verify that it works well. The first command is sent, but no reply is received. The problem is that when the commands for the communication protocol were taken, the most significant bit was changed (look at '*3.3.2 Commands of the communication protocol*'). Now the commands have to be like they were read at the beginning, before changing this bit. The reason is that this bit is the parity bit. The parity bit is used to check that the bytes received at the communication are correct. Once the information is written, the bits are counted, in this case the information is sent in packages of 8 bits, hence, the bits that are one along the 7 less significant bits are counted. If the number of ones is odd, the most significant bit (bit number 8) is set by one, else is set to 0. The reason why it is now necessary to send the commands with the even parity and not before is because before the RS232 serial communication module of the computer handled it, but now the commands are sent by the modem through the USB port and it seems that this port does not manage this verification.

With all of that, a new problem appears. When the first command is sent, the program still does not work well. The reason is that the command sent does not correspond with the command that has been written in the code. When the method '*serialWriter*' is called, the command that is going to be written in the output stream is added to the call. The issue is that the bytes written in the input stream do not correspond with the string that the method receives. Two different strings were tried but the bytes written at the output stream were the same. The problem is located in the function called '*getBytes( )*' [Figure 64].

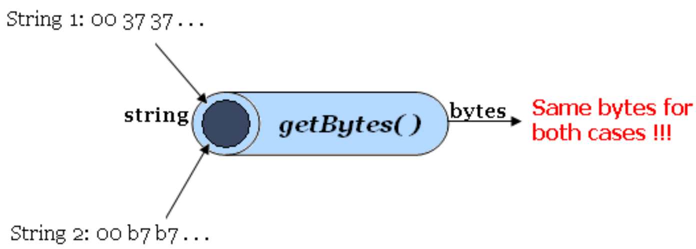


Figure 64: Communication with three meters by GSM

'*getBytes( )*' encodes an string in a secuence of bytes. If it is not specified into the parentheses, the Charset to encode the string is the one used by default. This was the problem, the charset necessary was "ISO-8859-1" and the one that uses by default is "US-ASCII".

Now the communication runs perfectly. The only problem is that with this type of communication GSM instead of needing between 12 and 13 seconds, the communication needs between 16 and 17 seconds.

5.6 Communication with three meters by GSM. Conclusions

This improvement was not as easy as it seemed at the beginning. It is not just adding the AT-commands. The way the data is sent is one of the changes. At the beginning the configuration was 8 bits and no parity and now the configuration is 7 bits and even parity, because the communication port of the computer is different. Some other difficulties as the parity check and encoding commented before were not easy to locate. Another problem of this type of communication is that it needs more time to read the measures.

On the other hand, GSM communication has important upgrades. Wireless communication is good if the meter is not going to be near the computer, and this is the common situation. Another advantage is that GSM is the communication network that mobile phones use, which means that there is no distance limits between the meters and the program that is used to read measures.

Chapter 6: Evaluation. Time needed for reading measurements[7]

To have a conclusion about the time needed to read a measure from the meter, the first comparison is going to be done between the time needed by EMH software to read values by using direct commands and the time needed by EMH software to read values by using the tables saw at section 4.3 EMH Software.

By using EMH software with a baud rate of 4800 Bd, direct commands needs more than 6 seconds and less than 7 seconds (6:724 sec, 6:846 sec...). On the other hand, two tables have been read. To read Table 1, the elapsed time is more than 4 seconds and less than 5 seconds (4:380 sec, 4:730 sec ...). Reading Service table, around 5 seconds are needed (4:965 sec, 5:019 sec ...). Comparing the values read at Table 1 and Service table, the last one has more data but the time needed is practically the same. The most interesting is that less time is used to acquire the information from the tables than the information read by direct commands, despite containing less information.

To read the value of a measure, the program written needs more than 4 seconds and less than 5 seconds (4:360 sec, 4:281 sec ...) by using single commands. Table 1 is read in 2 seconds (2:281 sec, 1:969 sec ...) [Figure 65], some milliseconds less than the Service table (2:562 sec, 2:2594 sec ...). The difference between the program

[7] The EMH times have been measured by using a timer.

written and the EMH software is that the program developed at this Master Thesis is 2 seconds faster [Table 7].

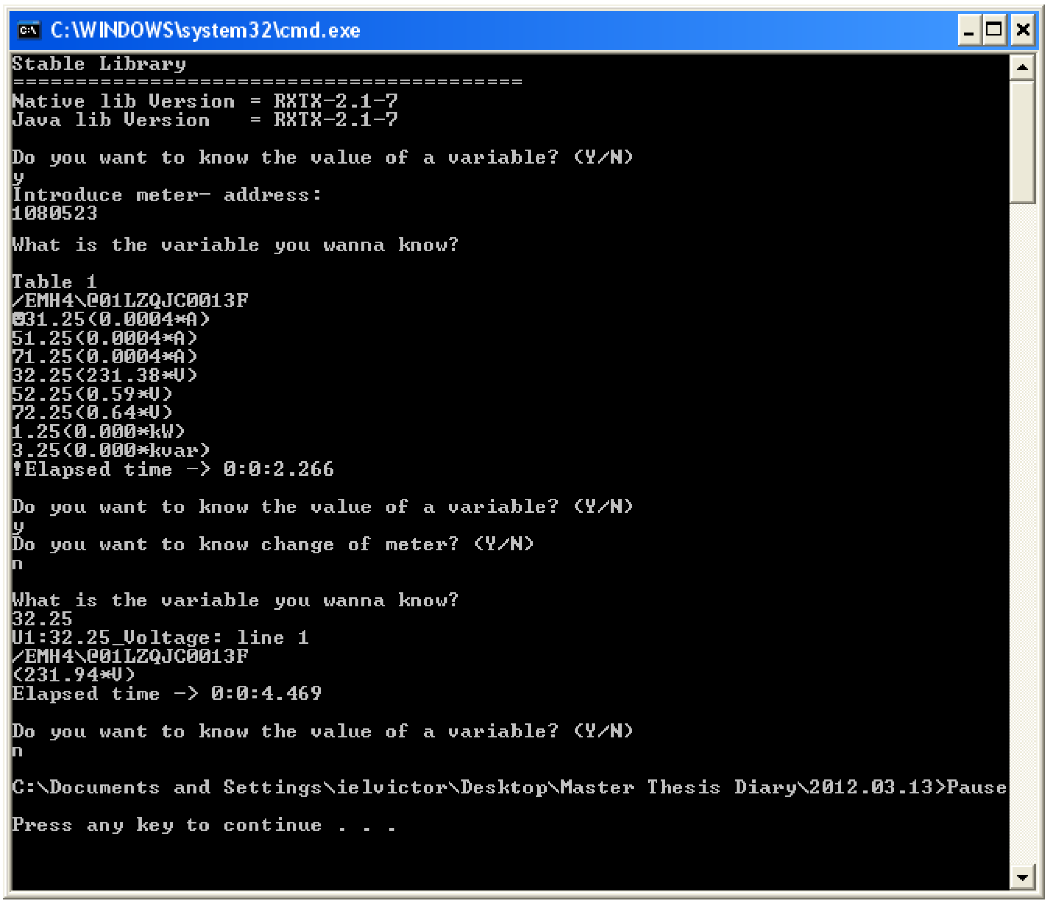


Figure 65: Reading time by using Table 1 and single commands

RS232 (4800 Bd)			
	Single Command	Table 1	Service Table
Master Thesis program	**4:360 sec**	**2:281 sec**	**2:562 sec**
	4:281 sec	**1:969 sec**	**2:594 sec**
EMH software	6:724 sec	4:380 sec	4:965 sec
	6:846 sec	4:730 sec	5:019 sec

Table 7: Comparison between EMH software and the program developed along this Master Thesis. RS232 (4800 Bd)

With the program developed, it is possible to show the time needed to send and to receive each command [Figure 66]. This time depends on the length of the command and the time the meter needs to send the response. With all, for a baud rate of 4800 and RS232 communication, the time needed to send and receive commands is always less than one second. This time is due to the time that the meter needs to reply, it is not something that can be improved by improving the program. This implies that (depending on the amount of data) to change the baud rate, the reading time will not change too much, because the limits are defined by the time of response that the meter needs.

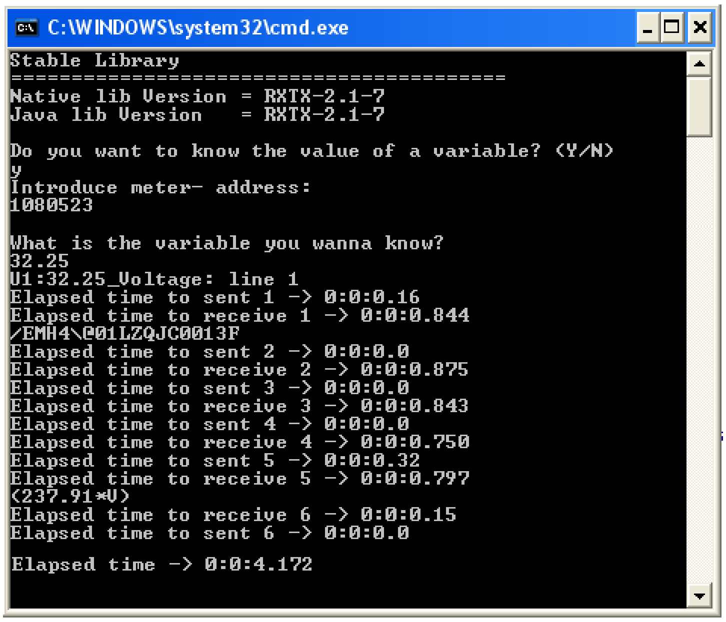


Figure 66: Time needed to send and receive each command during the reading

There is no difference between having one meter connected or more than one, because once the ID is sent with the first command, the communication continues being point to point by RS232, as it was before connecting more than one meter. When GSM communication is used, the time increases from 4 seconds, more or less, to 11 seconds. Using GSM, the elapsed time is more than 11 seconds and less than 12 seconds (11:677 sec, 11:019, 11:789 sec …). The program developed continues reading faster than EMH software, which needs around 13 seconds to read (13:696 sec, 13:175 sec, 13:094 sec …)[8]. Reading the tables continue being the faster way to read data. Table 1 is read in 6 seconds (6:604 sec, 6:508 sec, 6:933 sec …) and Service table is read in 7 seconds (7:823 sec, 7:460 sec, 7:756 sec …). These conclusions are shown in the tables below [Table 8 and Table 11].

EMH software		
RS232	Single command	**6** seconds
	Table 1	**4** seconds
	Service table	**5** seconds
GSM	Single command	**13** seconds
	Table 1	**6** seconds
	Service table	**7** seconds

Table 8: Comparison between reading times by using EMH software (4800 Bd)

If the time that EMH software needs to read by single command is compared for different baud rates (4800 and 9600), the needed time does not change

[8] The time analyzed is the needed time for reading. Connection time and hang up time (times used in GSM communication) are not included.

significantly [Table 9]. Therefore, this is not a good option to improve the time for reading.

Single Command by using EMH Software		
	Baud Rate (Bd)	Elapsed Time (secods)
RS232	4800 Bd	**6:215**
		6:189
		6:213
	9600 Bd	**6:616**
		6:527
		6:505

Table 9: Comparison between different baud rates

The baud rate is more important if the amount of data is bigger, because more time is needed to read all the information. If the amount of data is small, the time needed to transmit it is insignificant compared with the time that the meter needs to send an answer. This can be noticed if the times to read Table 1 and Service table at different baud rates are compared [Table 10]. As Table 1 has less information than the Service table, when the baud rate increases the time needed does not decrease as much as in Service table. Nevertheless, the baud rate does not change significantly the reading time needed.

EMH software (RS232)		
	Table 1	Service Table
4800 Bd	4:451 sec	4:748 sec
	4:025 sec	4:648 sec
	4:154 sec	4:850 sec
9600 Bd	3:854 sec	4:256 sec
	3:984 sec	4:177 sec
	3:811 sec	4:235 sec

Table 10: Comparison between Table 1 and Service Table at different baud rates

As it has been mentioned above, the program developed along this Master Thesis reads faster than the software provided by the manufacturer in all the cases tested [Table 11].

Single Command		
RS232	EMH software	**6** seconds
	Master Thesis program	**4** seconds
GSM	EMH software	**13** seconds
	Master Thesis program	**11** seconds

Table 11: Comparison between EMH software and the program developed along this Master Thesis (4800 Bd)

Chapter 7: Conclusions

In this thesis a closer look was taken at the communication protocol used by smart meters.

To start with the place of electricity meters in smart grids was presented. To do that, electricity market participants have been introduced, to understand why new technologies at electricity networks are needed. A better communication between all electricity market participants and more effective use of the energy, are some of the reasons why smart grids are the solution. But these are not the only possibilities that smart grids offers. Facilitate the increase of renewable energy sources by reducing effects in distribution networks and transmission grids, reduce peak network load or achieve a more efficient energy use by the chance of having active consumers, are some other features of smart grids.
An important part of smart grids are smart meters. These electronic meters are able to handle a two-way communication, what is really important for communication among all smart grid participants. There are different types of meters but the way they work is what causes that European Union start to legislate and regulate the implementation of this technology along all member states. It is verified that countries as Sweden, that are one step advanced and are currently improving the technology installed before, has some economical and environmental benefits, among others.

The thesis focuses in smart meter communication. Different improvements have been developed. To start with, one meter has been connected to the computer by RS232. By using some programs as Termite, EMH-COMBI-MASTER 2000 and com0om, the different commands, needed to establish a communication between the meter and the computer, have been recorded.
Communication protocol starts with the PC sending the ID of the meter that is going to be read. The next step is to receive the command verifying that the meter wanted is connected. Two more instructions are sent and receive. Finally, the command with the measure desired is sent and the meter replies with the value. For the entire variables that have been test, the protocol is the same and the commands used, except the last one with the measured desired, are equals for the same meter.

Thanks to know the commands of the communication protocol, it is possible to read data from one meter, just upgrading a program able to handle serial communication by adding this protocol. Of course, some more enhancements have been added (all of them detailed along the thesis). The time needed to read one variable from the meter, is around 4 seconds (2 seconds using the tables of the meter). Following, three meters are going to be connected.

To connect three meters is not possible to do by RS232 without adding pull-down resistance at the TXD pin of each meter. As three meters are connected at the same point at the same time, when one of them tries to send something and switch from high level to low level, this change does not appear at the serial port because the rest of the meters are keeping it at high level. Pull-down resistances avoid this problem. Another consequence of connecting more than one meter is that the first command has to be changed, writing the new ID of the meter that will be read. The time needed to read one variable from the meter is going to be the same as before. Although three meters are connected at the same time, once the ID is sent, the communication goes exactly equal than before.

Finally, between the meters and PC, GSM communication is introduced. One modem is going to be connected to the computer and another one is going to be connected at the meters side. This second modem receives by one antenna the information sent from the first modem connected to the computer. This means that the RS232 serial communication port is not going to be now the port by which the PC is sending and receiving data. The modem is connected by USB, what means that, even though USB continues being a serial port, it is not going to proceed equal. Now, the data which is sent has to be filtered by an even parity filter that was not needed before. AT-commands have to be used to connect and hang up modem communication. This method has pros and cons. The advantages the wireless communication and the possibility of communicate with more than one meter just using one modem for all of them. GSM network also permits to have a long distance between meters and computer, in this case. The disadvantage is that the time needed to read a variable increases from the 4 seconds to 11 seconds.

Chapter 8: Future work

This work focused on the communication protocol of the smart meters. Different improvements have been developed to see how the communication works, but there is still a lot of work that can be done in the continued work.

In the work presented in this thesis, only some measures read by using direct commands have been taken. It could be interesting to make some evaluation of how long takes to obtain the response for various commands using one instruction. To do that an option is to reprogram the code and make possible a continuous reading. For example, read the data once per minute and save it as a row in the file.

To interact with the user, since GSM communication has been used, it would be interesting to create a mobile application to read the measures with it.

Control the outputs of the meter by commands will be great for the use of smart meters such a part of smart grids, if it is necessary to reduce consumption. The meter can disconnect the user from the grid, if this option has been accorded before between the grid operator and the consumer.

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Figures:

Tables:

Flowcharts:

Appendixes:

APPENDIX 1: SENT COMMANDS. COMMUNICATION PROTOCOL

In this appendix, all the commands that have to be sent to read values by single commands can be found. Only the commands sent to the meter (not the ones received from the meter). These commands do not take care of the even parity, are the commands taken at section: *4.4.2 Commands of the communication protocol*. The blue commands indicate that they are the ones that change between the possible readings by single commands.

APPENDIX 2: SENT AND RECEIVED COMMANDS. COMMUNICATION PROTOCOL

All the commands that have to be sent (black commands) and the commands that are received (green commands) from the meter to read values by single commands can be found in appendix 2. Only the commands to read: voltage at line 1, voltage at line 2, voltage at line 3, current at line 1, current at line 2, current at line 3, total active power and total reactive power. The blue commands indicate that they are the ones that change between the possible readings by single commands.

APPENDIX 3: RS232 COMMUNICATION

Java code to communicate with three meters by RS232. This program can read by single commands, Table 1 and Service Table from the meter.

APPENDIX 4: GSM COMMUNICATION

Java code to communicate with three meters by GSM. This program can read by single commands.