UNIVERSIDAD PONTIFICIA COMILLAS

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

OFFICIAL MASTER'S DEGREE IN THE ELECTRIC POWER INDUSTRY

Master's Thesis

Improved maintenance and management of distribution assets due to the digitalization of the electrical grid.

Author Sara Gil García

Supervisor Mariano Gaudó Navarro

Madrid, July 2016

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ABSTRACT

In the energy sector, **digitalization** is transforming the business architecture, redrawing boundaries and redefining relationships between consumers and utilities. Advances in technologies, telecommunications and data analytics are progressively changing the environment for Distribution System Operators (DSOs), consumers and suppliers.

Digitalization allows DSOs to gain more insight and control over their traditionally passive network. It allows them to drive new levels of operational efficiency and modernize their communication with network customers.

This Thesis has been developed as motor for change aiming for an efficient use of the **digital infrastructure** by the electric utilities and more precisely by the DSO. For this purpose it has been prepared a strategy to improve maintenance of assets in the distribution network. In particular, this Thesis will focus on **improving maintenance in Secondary Substations** (Medium to Low Voltage) owned by Gas Natural Fenosa, making use of the data provided by digital equipment, mainly by Smart Meters and Low Voltage Supervisors that send remotely hourly data.

The solution that has been proposed in this Thesis will move from a preventive maintenance to a **predictive maintenance** in Secondary Substations. The conventional maintenance is characterized by random and seasonal visits (winter and summer) in some of the Secondary Substations. In these visits, maintenance members take sporadic and isolating reading at the moment of metering the currents in the feeders. In fact, currents oscillate a lot; therefore, making decisions with punctual measures is not too accurate.

The methodology followed to improve maintenance is based on the development of an **algorithm to estimate the currents** that flow in the Low Voltage feeders of the Secondary Substations. These estimations will allow to determine the **hourly and daily status of the assets** and detect those that are more critical. After calculating the estimated currents and comparing them to the real measured values, it has been verified that real and estimated values differ within an acceptable range. Not only this solution will save Operation and Maintenance costs to the company Gas Natural Fenosa due to the reduction of visits to Secondary Substations for maintenance but also this solution will enable to do much more things that were not done until now in the company.

In conclusion, **digitalization** has changed the way things are done in distribution companies. DSOs have to make use of the information that digital devices provide in order to **improve their systems** and the way they operate the network.

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ABBREVIATIONS

AC	Alternating Current
ADVAPPS	Advanced Applications
AMI	Advanced Metering Infrastructure
AMR	Automatic Meter Reading
CAPEX	Capital Expenditure
CBA	Cost Benefit Analysis
CBM	Condition Based Maintenance
CEER	Council of European Energy Regulators
CIS	Customer Information System
CM	Corrective Maintenance
CNMC	National Comission of Markets and Competence
CRM	Customer Relationship Management
CROM	Control Room Operations Management
CO2	Carbon Dioxide
DC	Data Concentrator
DER	Distributed Energy Resources
DG	Distributed Generation
DMS	Distribution Management System
DR	Demand Response
DSM	Demand Side Management
DSOs	Distribution System Operators
EAM	Enterprise Asset Management
EC	European Commission
EDSO	European Distribution System Operators for Smart Grids
EE	Energy Efficiency
EPRI	Electric Power Research Institute
ERP	Enterprise Resource Planning
EU	European Union
EV	Electric Vehicle
GIS	Geographical Information Systems
GNF	Gas Natural Fenosa
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communication
HMI	Human-Machine Interface
HV	High Voltage
Hz	Hertz
ICT	Information and Communication Technologies
IEA	International Energy Agency

IEC	International Electrotechnical Commission
IED	Intelligent Electronic Devices
IIT	Instituto de Investigación Tecnológic
IP	Internet Protocol
IT	Information Technologies
JRC	Joint Research Centre
KPI	Key Performance Indicator
kW	Kilowatts
LF	Load Flow
LV	Low Voltage
MV	Medium Voltage
NIS	Network Information System
OECD	Organization for Economic Cooperation and Development)
OM	Outage Management
OMS	Outage Management System
OPEX	Operational Expenditure
OT	Operation Technologies
PBC	Performance Based Contract
PLC	Power Line Communications
PM	Preventive Maintenance
PRIME	Powerline Intelligent Metering Evolution
PV	Photovoltaics
QoS	Quality of Service
R&D	Research and Development
RAB	Regulatory Asset Base
RES	Renewable Energy Sources
RTU	Remote Terminal Unit
SCADA	Supervisory Control And Data Acquisition
SCL	Substation Configuration Language
SF6	Sulfur Hexafluoride
SG	Smart Grid
SM	Smart Meters
SME	Small and Medium Enterprise
SS	Secondary Substation
TBM	Time Based Maintenance
TCM	Trouble Call Management
TCP	Transmission Control Protocol
TSO	Transmission System Operator
UK	United Kingdom
USA	United States of America
V	Volt
VLAN	Virtual Local Area Network
WMS	Work Management System

1. INTRODUCTION

Power systems worldwide are in the middle of a technological renovation.
The exponential increase of the electrical demand as well as quality requirements of supply increasingly demanding have forced to advance towards a new concept of electrical network, the Smart Grids.

The principal characteristic of a smart grid is that it allows the distribution of electricity from the suppliers up to the consumers, using digital technology with the aim to save energy, reducing costs and increasing reliability.

To achieve this, it is necessary an ideal distribution of the energy. This would imply, well its storage when a surplus exists (slightly complex and costly), or a restructuring of the current system to adapt to the demand taking advantage of the existing technology.

The Smart Grid will use the latest technologies to optimize the use of its assets over two different time horizons: the short term will focus on day-to-day operations and the longer term will focus on improving asset management processes.

1.1. MOTIVATION

The purpose of this master thesis is to give a conclusion to the Official **Master's Degree** in the **Electric Power Industry** at University of **Comillas** taught in Madrid during the academic year 2015-2016. The work undertaken has been supervised by Mariano Gaudó Navarro, head of Smart Grids and network innovation department at Gas Natural Fenosa (GNF).

All the work that is covered in this Master Thesis has been done on the distribution side, referring to the distribution grid.

Under the umbrella of Smart Grids, new equipment is being deployed and new systems are being built to add information to the energy fluxes. This transformation comes at a fast pace in order to change the way networks are operated.

The traditional management of electric utilities may put them in risk of missing part of the benefits of this renovation if no research is done to take full advantage of its functionalities. This thesis tries to outstand the importance of the **integration of digital infrastructure in the electric utilities**.

The digitalization of the network is seen then in this text as a **driver** for the rethinking of systems, organizations and processes aiming to **improve the efficiency of the electricity distribution business**.

The digitalization of the network is progressively increasing. This is promoted by both European and National organisms and regulations.

1.2. OBJECTIVES

The objective of the master thesis is: **"*to improve maintenance and management of distribution assets due to the digitization of the electrical grid''***.

In other words, the main idea is to find out what (and how) could be improved in the maintenance and operational activity of the distribution company, considering the information available after the deployment of the new **digital** infrastructure.

1.3. STRUCTURE

This report is structured to help the reader understand the objective of the master thesis.

In chapter 2, the global context is presented in order to understand the main challenges that DSOs have to face in the years to come. Furthermore, the main responsibilities of DSOs are explained as well as their future role.

In chapter 3, the current status of the network is presented: its design, operation and focusing on maintenance and asset management. Future challenges that utilities face due to the transformation from a "traditional" network to a digital one are also covered in this chapter.

Chapter 4 introduces the subject of digitalization of the network at a European Level, the opportunities and challenges of this digitalization for consumers, suppliers and DSOs. This chapter will focus on Medium Voltage and Low Voltage digitalization. Finally, the importance of interoperability and standardization will also be explained.

The systems developed due to the digitalization of the network are explained in chapter 5 under the European context: SCADA and DMS, as well as maintenance systems. The change of those systems with the digitalization will be also covered.

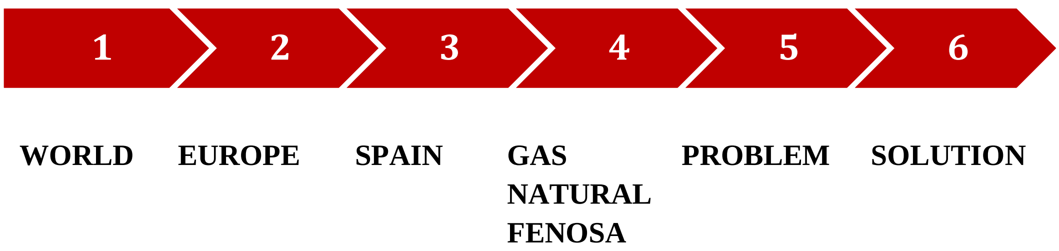
Chapter 6 introduces the Regulatory Spanish Context, the new changes in remuneration that the CNMC has approved last years and that affect distribution companies and the way they operate and perform.

Optimization of asset management is the main issue of chapter 7. New strategies and practices to improve the management of assets are explained in this chapter.

The optimization of maintenance of assets is covered in chapter 8, where the context is Gas Natural Fenosa. This chapter explains the methodology followed to improve the way maintenance has been done until now in Secondary Substations at Gas Natural Fenosa. The inefficient conventional maintenance (preventive based maintenance) will be replace by a more efficient predictive based maintenance, following the methodology that is explained in this chapter. This methodology will be applied to several case studies in order to verify the results provided by the new solution to maintenance. Finally, this chapter will evaluate the benefits provided by the results of the application for the company Gas Natural Fenosa.

Chapter 9 summarizes the problem that this Master Thesis is covering, the solution proposed and the main findings that have been achieved.

In order to make easier to follow the steps of this Master Thesis, it has been included in the chapters of the Thesis the following chain that refers to a particular context:



There have also been included different annexes for further explanation of:

I. Smart Metering deployment in EU
II. Smart Metering Cost Benefit Analysis (CBA) in EU
III. Digitalization of networks and DSOs.

2. DISTRIBUTOR SYSTEM OPERATOR

1 2 3 4 5 6

CONTEXT: WORLD

2.1. ENERGY TRANSITION

During the last three decades, strong economic growth and expanding populations have lead to a significant increase in global energy demand.

To support the energy demand, global net electricity generation has increased quickly from 1990 to 2010 and will supply an increasing share of the total demand from 2010 to 2040.

Heating and cooling in buildings and industry today are estimated to accounts for more than 40% of final energy consumption a larger share than transportation with 27%. Figure 1 shows the evolution in energy consumption for heating and cooling under two scenarios: the 2°C Scenario (2DS) is the main focus of Energy Technology Perspectives and the 6°C Scenario (6DS) which is largely an extension of current trends.

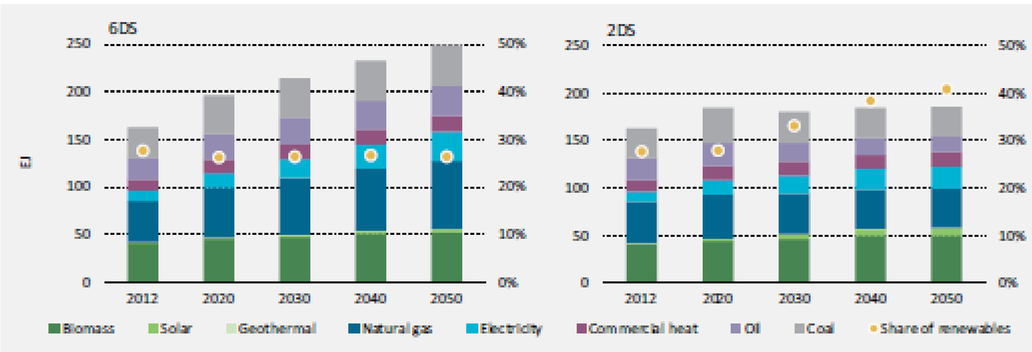


Figure 1. Global final energy consumption for heating and cooling. Source: (IEA, 2015).

Overall, industrial final energy consumption for heating and cooling accounted for more than half of the final energy consumption in industry in 2012.

Non-energy-intensive industry sectors (such as food and tobacco) combined were responsible for almost 40% of industrial heat demand, while consumption by individual energy-intensive sectors was diverse. Iron and steel accounted for one-third of total heat demand; chemicals and non-metallic minerals each consumed a share of 13 (IEA, 2015).

Heating services in the buildings sectors (space heating, warm water and cooking) were responsible for almost three-quarters of the sector's final energy consumption in 2012.

Looking at the energy mix, around 70% of the final energy consumption for heating and cooling today is based on fossil fuels. Figure 1 takes into account the generation mixes for electricity used for heating and cooling, and for commercial heat. Renewables account for the remaining 30%, of which almost 90% is the traditional biomass use mentioned above.

Electricity consumption by end-users is expected to grow faster than the use of other energy sources due to the increase in the standard of living and a higher demand for home appliances and electronic devices. Global growth in final electricity demand by 2050 is three times higher than the growth in total final energy demand; electricity becomes the largest final energy carrier, ahead of oil products, with a share of 26% in total final energy consumption (IEA, 2015).

Combinations of primary energy sources to produce electricity will be evolving in a significant way over the next three decades:

- Most renewable energy in OECD (*Organization for Economic Cooperation and Development*) countries is expected to come from non-hydroelectric energy, because all resources have already been developed (except Canada and Turkey).

- In non-OECD countries, hydroelectric power is expected to be a dominant source of growth (in particular Brazil, China and India). Nevertheless, growth rates for wind power electricity will also be high.

Facing the challenge of a growing demand of energy, many regions of the world are engaged in a dymanic phase of energy transition.
At the same time, consumers are changing their attitude toward energy savings.

The changes in generation means and consumption trends will impact energy systems worldwide:

- ***Producers*** will have to alter their business models in order to make their investments in existing generation facilities profitable, as well as to optimize operational management of energy combinations that increasingly integrate intermittent renewable energy sources (RES).

- ***Transmission system operators (TSOs)*** will have to anticipate the risks of an unbalanced supply-demand ratio that may lead to a decrease in frequency and potential blackouts. They must also develop interconnections.

- ***Distribution system operators (DSOs)*** will have to connect massively decentralized RES generation, electric vehicle recharge stations, modernize the networks and deploy smart grid technologies including metering systems.

- ***Energy suppliers*** will have to reevaluate their offers and services in response to consumers' expectations in the context of an increasingly competitive environment (progressive market opening, with the end of regulated tariffs).

The energy transition makes a major impact for DSOs, insofar as intermittent RES generation installations are predominantly connected to distribution networks.

The **digitalization** of the energy system and the advent of smart meters can bring **benefits** to all **energy players** listed above. In the short term, **consumers** will gain **more control** over their energy use and benefit from additional services. **Suppliers** will **optimise their business**, tailor new offers and target their communication**. System operators** will benefit from **new tools to manage their grids more efficiently** and integrate an increasing amount of variable renewables in the system.

In the long term, interaction between intelligent appliances, grids and home platforms will usher in a new era with radically different consumption patterns **centered on automation and remote controls.**

For **Distribution System Operators** (DSOs), **digitalization means** gaining **more insight and control over their traditionally passive network**. It allows them to drive new levels of operational efficiency and modernise their communication with network customers. It will also enable them to handle more data and potentially move to (centralised or decentralised) data hub operations (depending on country models) where DSOs are responsible for metering operations and data exchange. Regulators should recognise the broadening role of DSOs as neutral market facilitators and encourage efficient technological innovation (EURELECTRIC, 2016).

2.2. EU DSOS LANDSCAPE

The electricity distribution business in Europe includes more than 2,400 companies, which serve around 260 million connected customers supplying move than 500 million people, operating 10 million km of power line, distributing around 3,000 TWh a year and directly employing more than 240,000 people.

In most European countries, intermittent energy generation is developing very fast, leading to a total installed capacity of 106 GW of wind and 70 GW of PV by the end of 2012 (Observ'Er, 2013). The vast majority of these plants are connected to distribution grids. Together with the development of active demand and electric vehicles, this will lead to a transformation of the role of the DSOs, a real challenge for electric systems.

In yesterday's market, the distribution networks were often designed to be operated radially in order to distribute electricity from HV/MV substations connected to transmission level, down to the end user consumers. With the energy transition, tomorrow's electricity distribution network operation and management will change. The distribution networks will have to manage more complex interlinked networks mixing generation and demand with much higher variations and reverse flows from distribution to transmission networks. Also, new market players are developing, such as load curtailers, virtual power plant operators and aggregators, etc.

To tackle the challenges of energy transition, electricity networks will need to be more reactive and flexible to ensure the security and stability of the system, and also enhance interactions between market players.

2.3. DSOs RESPONSIBILITIES AND FUTURE ROLE

In the Directive 2009/72 (EC, 2009), part of the third EU energy package, the responsibilities of the DSO were identified:

> *Ensure the ability of the system in the long term to meet reasonable demands for the distribution of electricity and to operate, maintain and develop economically secure, reliable and efficient electricity distribution system in its area of operation with due consideration environmental and energy efficiency.*

There are then three main functions of the DSO: operate, maintain and develop the network.

Furthermore, DSOs play an important role in ensuring **security** in the system operation and quality of supply.

Regarding transmission and distribution activities, the DSO provide Transmission-Distribution Interface **reliability coordination with the TSO** for a local distribution area and provide physical coordination with the TSO for energy transaction across the Transmission-Distribution interface.

The DSO also procures distributed **reliability services** from qualified flexible DER to support distribution system operations.

A regulated utility DSO comply with standards of conduct to separate the natural monopoly functions entailed in operating the distribution system from potential conflicts related to energy sales, trading, generation production or other marketing efforts involving DER.
In order to adapt to the growth and also enhance the competitive strength of DG and renewable energies (RES) in a regulated and competitive electricity market, distribution system operators (DSOs) have to change their business by developing new business activities, thereby **diversifying the business model**, and by transforming operational philosophies from passive into active network management.

DSOs can overcome the threats that arise from the increasing penetration of DG, incentive regulation, regulated connection charges, and unbundling. In order for DSOs to embrace such opportunities, regulation also needs to evolve such that it provides DSOs with a wider range of options and incentives in choosing the most efficient ways to run their businesses in the new decentralized electricity market (Scheepers, 2005).

An active DSO provides market access to DG by acting as a **market facilitator** and it provides several network and ancillary services through intelligent management of the network. This includes the incorporation of advanced information exchange between generation and consumption, the provision of ancillary services at the distributed level, management of the network to provide network reliability and controllability, and improve customer benefits and cost-effectiveness. The transition from passive to **active network management** may be accompanied by developing new services for the electricity market, creating new revenue drivers for the DSO.

A DSO must also be able to **accommodate the overall power consumption** of all customers connected to the network and **anticipate the evolution of the peak** power consumption. Consumption is particularly irregular and depends on the time of day, as well as weather conditions.

Because DSOs are operating in a regulated environment instead of a competitive market, the thesis that competition leads to innovation does not hold for DSOs. There is little incentive coming from the regulated market itself. It is **regulation** that should simulate a competitive market environment. It should **provide incentives to DSOs** to change their passive behavior into an active and entrepreneurial attitude.

It is vital that as new markets services develop and consumers understand more about their energy needs and become more active, energy regulators oversee arrangements to ensure there is a level playing field, that consumers are protected, and that new entrants can participate in the market.

Although there is not a single DSO model, as there are differences between countries in the number, size and activity profile of DSOs, there are **some principles for DSOs** that determine a framework to be followed (CEER, 2015):

- DSOs must run their business in a way which reflects the **reasonable expectations** of network users and other stakeholders.
- DSOs must act as **neutral market facilitators**.
- DSOs must act in the **public interest**, taking into account the costs and benefits of the different activities.
- DSOs must **safeguard consumers' data** when handling this data. Data management is a key area for the operation of existing and new markets. Consumers have the legal right to own their own data3. However, DSOs, who in most cases have access to data directly from smart meters, have a special responsibility to act impartially and to make available necessary data to other parties, while respecting data privacy legislation.

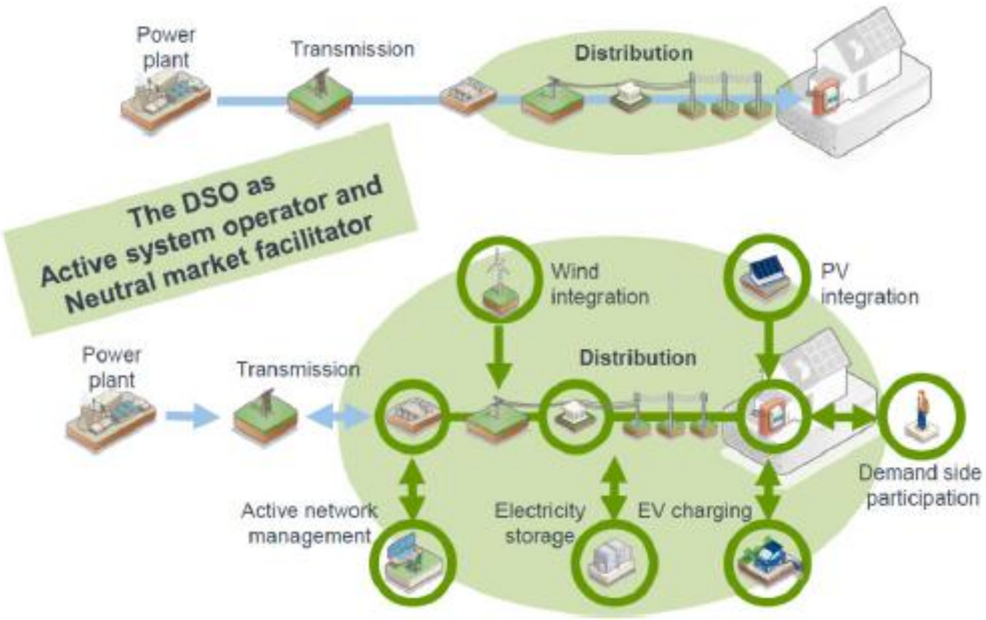


Figure 2. Evolution of DSO's role. Source: (EDSO, 2015).

Technological change is happening rapidly and new markets and business models are starting to develop. The roadmap for DSOs will therefore need to continue to evolve.

At the European level, EDSO, the European Distribution System Operators for Smart Grids, has opened a review of the traditional functions of the DSOs in order to better address the new challenges of DSOs.

New pressures are placed on the grid, such as the connection of more renewable or the increasing tendency of network tariffs. DSOs need more data to manage their grids, but also need to increase cooperation with other network operators (TSOs) (EDSO, 2015). It is necessary to adjust the regulatory framework to guarantee high quality of supply and affordable prices.

3. CURRENT STATUS OF THE NETWORK

1 2 3 4 5 6

CONTEXT: WORLD

3.1. DESIGN AND OPERATION

The electricity networks have been designed to move electricity from large power plants to end users. Mostly due to environmental goals and concerns about security of supply, renewable production has increased in the last years. As a result of this development, an increasing penetration of small-scale distributed generators (DG) connected directly at the distribution level has raised. DGs will alter the power flows in the network and will require more attention and different operational strategies from the network operator.

The majority of the distribution networks have been designed decades ago to meet the customer needs at that time and to provide reliable connection to end users. The networks have been designed for predicable loads of the customers connected and for a relative small annual load increase. Due to the new challenges of today and near future, the network operation has to change to become more efficient.

The entire power system is based on three fundamental components: the generation, the network and the consumers.
During the past 10 years, decentralized power generation (wind and solar PV) has experienced a lot of development. This generation is characterized by low-voltage (LV), high intermittence, high spread throughout the territory and weak correlation with electricity demand.

In light of the rise of renewable energy generation and sustainable development policies, businesses and residential consumers have also begun adopting small localized power generation, particularly in the form of solar panels. Generally, these generation facilities feed into the local power grid.

On the other hand, advanced operating tools to help operators to manage more efficiently the grid are limited, but there is a lot of work to be develop to deal with the vast amount of new data in ways that will enable operators to rapidly comprehend the state of the grid. This “real-time” assessment of the state of the grid is needed to achieve maximum grid efficiency without reducing reliability. Grid operations would benefit greatly from these tools. (NETL, 2009).

3.2. ASSET UTILIZATION

In distribution networks, assets are the most important issue. Because of the high number of assets in the distribution network, compared to transmission network, it is very important to supervise its functional operation and maintenance. There are millions of assets in the distribution network that cannot fail, therefore, asset management plays a very important role in distribution companies.

In today's grid, particularly in the distribution grid, the systems needed to understand and optimize real time asset utilization are not typically available. The relatively low penetration of automation limits the ability to adjust asset loadings.
For instance, the utilization of transformers at distribution substations is currently about 40 percent.

DSOs can optimize its asset utilization by means of measuring efficiently its system operation and improved performance. These meterings are possible with the increasing use of technology in the network.

With the new technology that has been deployed in the recent years, electric utilities can operate the assets they already own for as long as possible. They can retire inefficient equipment and maximize energy throughput of existing assets.

3.3. MAINTENANCE

There are three main approaches in the field of **maintenance**: preventive, predictive and corrective.

Corrective maintenance (CM) is maintenance which is carried out after failure detection and is aimed at restoring an asset to a condition in which it can perform its intended function.

Predictive maintenance is the application of modern analytical techniques to decrease both the cost of maintenance and production downtime by means of early identification of imminent equipment failure (achieved through monitoring changes n condition). Its purpose is to minimize breakdowns and excessive depreciation. It is the key to reliability and integrity for a company. The terms **condition-based maintenance**

(CBM) and predictive maintenance are often used interchangeably because it is based on **measuring the condition of assets** to assess whether they will fail during some future period, and then taking appropriate action to avoid the consequences of that failure.

Preventive maintenance (PM) has the following meanings:

1. The care and servicing by qualified personnel for the purpose of maintaining equipment and facilities in satisfactory operating condition by providing for systematic inspection, detection, and correction of incipient failures either before they occur or before they develop into major defects.
2. Maintenance, including tests, metering, adjustments, and parts replacement, performed specifically to prevent faults from occurring. Predictive maintenance tends to include direct metering of the item.

Preventive maintenance has the following benefits:

1. Increases life of equipment
2. Reduces failures and breakdowns
3. Reduces costly down time
4. Decreases cost of replacement

Another important approach that can be used with both preventive and predictive maintenance is **Time based maintenance (TBM)**. It is maintenance performed on equipment based on a calendar schedule. This means that time is the maintenance trigger for this type of maintenance. Time based maintenance is planned maintenance, as it must be scheduled in advance.

In CBM, data obtained by measuring devices feeds lifespan models and according to their results, the necessary maintenance actions are performed to prevent failure.

For a distribution company of energy it is very important to define how it will perform the maintenance, as well as the time of inspection of the assets of the network. Maintenance has great economic incident, not only for the implicit cost in it, but for the impact in the quality of the given service which affects the income.

In the distribution network it can be differentiated three voltage levels:

- **High Voltage levels** (HV): A fault affects a bigger number of consumers, therefore, maintenance is preventive and condition based.
- **Medium Voltage levels** (MV): Maintenance is usually time based
- **Low Voltage levels** (LV): The observability is lower and the equipment has usually no maintenance until failure, maintenance is corrective. Whenever there is a fault, it is detected by the alerts of the customers who suffer the interruption of supply. Then, crews are sent to repair the fault and restore the service.

In fact, the least sophisticated maintenance is put in place where the bigger number of assets and interruptions are higher.

3.4. ASSET MANAGEMENT

In the context of an electricity distribution utility, asset management can be defined as a systematic process of, cost-effectively, operating, maintaining and upgrading of electrical assets by combining engineering practices and economic analysis with sound business practice. The effectiveness of these processes depends highly on the information that they depend. For instance, the planning decisions are made using load forecasts. The more information available, the more accurate will be the forecasts and the more effective will be the planning.

Maintenance engineers wanting to implement a Condition Based Maintenance will benefit from having asset condition information. Monitoring the state of the equipment in real time is limited without real time information.

In fact, optimized capacity utilization, optimized asset health and optimized operations will result in substantial cost reductions and performance improvements.

Nowadays, improving asset efficiency and utilization is a major priority. The penetration of new technology in the grid allows achieving a higher degree of performance and efficiency. Active asset management, allowing for greater interaction between the key network processes combines with grid automation would optimize the distribution network (EURELECTRIC, 2013).

3.5. FUTURE CHALLENGES

When utilities face the transformation from a “traditional” network to a digital one, there is a bunch of challenges and key issues that should be taken into account to assure network quality, smooth transition to future technologies and cost reductions:

1. Due to the increase of DG, the distribution network has to adapt to allow the connection and integration of the distributed resources. **Active Distribution System Management** is required for the efficient integration of a rising share of Distributed Energy Resources.

2. The network needs to increase its level of automation. The tendency nowadays is to move towards the **remote energy distribution**

3. The evolution of consumers' role (prosumers) will lead to an **increase in the services and products** provided to them and the development of tool to manage the demand.

4. **Coordination** among all **stakeholders** and adequate regulation are necessary.

5. Distribution networks will **evolve to distribution systems**: Congestion management, voltage control, information exchange, connection and planning are fundamental tools to maintain security of supply and quality of service at the distribution level.

6. **Requirement to integrate complex IT systems.** The amount of data collected from the network increases exponentially with the complexity of the network and information must be stored securely and made available to all the relevant systems and departments in the organization.

7. The level of **communication** in the network has to **increase**. The underlying communications networks will play a role of primary importance in guaranteeing adequate networking resources for data collection and task execution. The amount of data and especially signaling traffic are expected to grow exponentially, and the underlying networks must be able to support this growth whilst assuring adequate bandwidth, availability, quality of supply and latency, whatever the evolutions of the communication networks.

To deal with complexity and constant evolution of networks, while controlling costs, it is of utmost importance to continuously assess current and future requirements of all utility networks. This will ensure that all technological choices respond to Strategic business, service and operational direction and that they are reflected into all utility processes (JIEEC, 2015).

4. DIGITALIZATION OF THE NETWORK

1 2 3 4 5 6

CONTEXT: EUROPE

4.1. THE OPPORTUNITY AND CHALLENGES OF DIGITALIZATION FOR ENERGY PLAYERS

4.1.1. CONSUMERS

Consumers can buy electrical appliances which can be connected to one another exchanging data. It is possible to get a deeper knowledge on consumers' habits and behavior.

Due to **digitalization**, consumers can have much **more control** over their energy usage and consumption and can adapt it to their own needs.

In a near future, households and smart cities could potentially cover part of consumers' energy needs through own production, while centralized power stations would be needed for balancing services, back-up needs and to cover industrial demand.

However, there are also some **challenges** that consumers have to overcome. For instance, some digital home appliances are **not at all attractive** to most consumes. This can be because they are not simple enough or because they are **expensive**. Also, **interoperability and complexity** problems are slowing down their adoption.

Another key issue is **data security and privacy**. In particular, in Europe the attitude towards privacy may vary across Member States. Consumers will only be comfortable with access and uses of their data if they are confident that their data is secure and that their privacy is safeguarded. Suppliers and DSOs must take the time to explain carefully the benefits and contributions of smart meters and which are their added value, as well as letting consumers know how the data is used.

4.1.2. SUPPLIERS

Digitalization changes the **interaction between consumer and supplier**. Suppliers will have access to new data sources and tools to communicate with their customers and better understand their needs.

Instead of monthly bills often based on estimated consumption, suppliers will be able to provide consumers with information on their energy usage and consumption patterns, therefore, increasing transparency.

On the other hand, more **personalized offers** can be made to market participants. Some are related to energy delivery, others may contribute to **energy bill reduction**, such as **optimization, energy efficiency**, etc.

However, whilst utilities have considerable experience in collecting and processing meter readings, reporting financial data to regulators, and using data to make investment decisions in generation and networks, mastering **big data analytics will be crucial** to make sense of the growing volume of data and additional layers of information about customers.

In addition, energy suppliers are not alone in this race and consumers are not waiting for them. **Competition intensifies** from all sides. Suppliers will have to proactively find their place in this new ecosystem. They may need to improve operational coordination of activities, invest in data analytics and new IT platforms, recruit data experts or develop partnerships with service providers such as Software as a Service (SaaS) companies.

4.1.3. DSOS

Digitalization brings significant opportunities and challenges to the energy network and to system operators.

As more and more players, such as prosumers, aggregators, distributed storage providers, etc. interact with the energy system, the DSO's role of **neutral market facilitator** needs strengthening. DSOs will have to play a **coordinating role** between all market participants and facilitate markets and services in a neutral and non-discriminatory manner.

Digitalization impacts on DSOs' consumers. Before, the main objective that DSOs pursued with digitalization was to increase the quality of service but now, DSOs have understood that **digitalization is about managing information in order to benefit the client as well.**

More generally, digitalization and big data can help DSOs drive new levels of operational efficiency. They can develop predictive and real-time maintenance of transformers and related substations, prevent and remotely correct outages, reduce restoration times, increase asset performance etc.

DSOs can also **modernize their communication** both internally (making processes more flexible and crossfunctional) and externally (with grid users, be them generators, households, SMEs, or public authorities).

Finally, DSOs are responsible for meter operation and data exchange, digitalization potentially allows them to **handle, manage, and analyze much more granular data**, but also to explore new ways of collecting, storing and processing them (data analytics, complex event processing etc.). Moreover, it allows them to move from bilateral exchanges of information with market players to (centralized or decentralized) data hub operation, thus increasing efficiency while facilitating the retail market.

As DSOs are regulated agents, all these developments are heavily dependent on the regulatory framework. Regulation should make sure that DSOs are able to invest in the IT architecture that best fits their technical needs. A simple regulatory principle to be observed in this instance is that **DSOs must not be financially penalized for using innovative solutions** versus traditional reinforcement options **as long as investments are efficien**t. Possible regulatory approaches to this end are higher rates of return, network innovation contests, shorter depreciation rates or direct R&D funding (EURELECTRIC, 2016).

4.2. DIGITAL INFRASTRUCTURE DEPLOYMENT

The **digitalization** of the network is, in general terms, to increase the level of automation and observability of the grid. Digitalization not only is applied at electrical networks but also in other fields such as telecommunication networks.

The automation is part of the digitalization. Automation means that it is possible to do something remotely. Telemetering improves automation.

In the distribution network, the digital infrastructure and automation aim to improve the quality of service. The collection of all the data that is available in the network has to be well organized and analyzed.

The figure below shows the investments in Smart Grids. It can be seen that the main investors in digital infrastructure in the network are Distribution Companies.

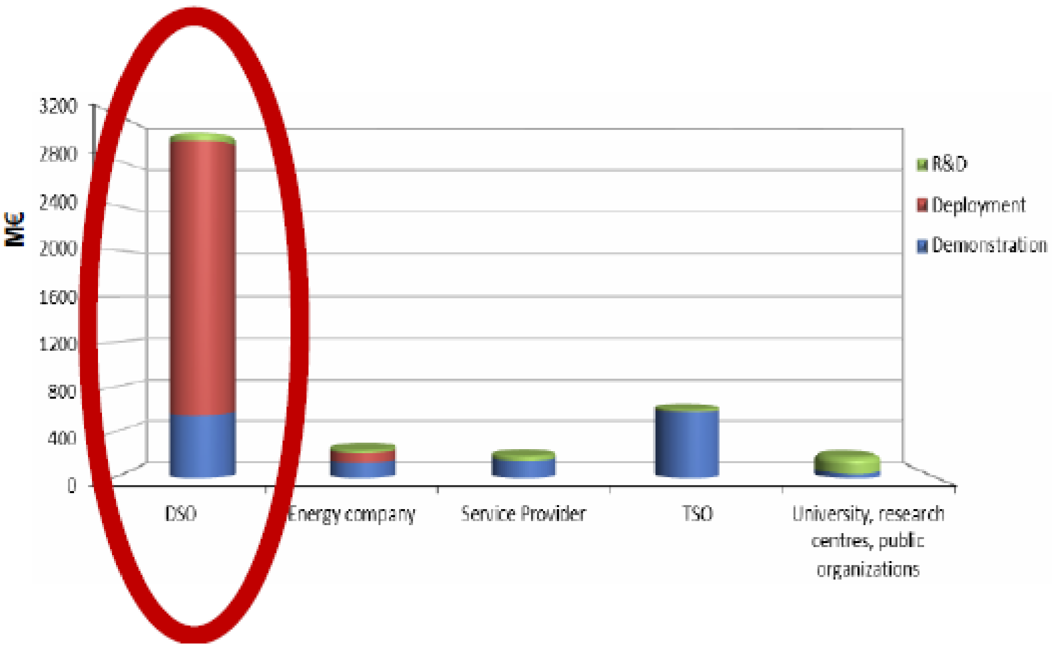


Figure 3. Investments in Smart Grids in Europe 2013. Source: (Eurelectric, 2013)

Digitalization is applied at a distribution level in three parts of the grid:

- **High Voltage Distribution Grid (>36 kV):** The level of digitalization is the highest. High voltage grid has a great level of automation. In addition to the digital devices that are placed in substations, there are also smart meters for generation plants (thermal, wind, solar…) and for big industries that are connected to the high voltage grid. In this case, there are smart meters (type 1 and 2, so as to measure the energy produced and consumed and there are also smart meters in substations from High Voltage to Medium Voltage in order to verify both measures.

- **Medium Voltage Distribution Grid (1-36 kV):** In this part of the grid many digital devices have been deployed recently. These devices are reconnectors, disconnectors, switches, circuit breakers, voltage and current sensors, etc. They detect outages that cut the supply, for instance, when there is a short-circuit in a line due to a tree fall or after striking a flock of birds.

  The digital device detects the fault ant restores the system itself. If it is not possible to restore the supply, the device sends an alarm to the Remote Control System and a crew will be sent to solve the incidence.

  Remote Management and new remote control technology has also been introduced in Secondary Substations. There are also smart meters of type 3 in order to register the energy consumed and generated by plants connected to MV. In general, digital devices are put in strategic places in the network. They are also used to, in case of a fault, to feed the clients affected and reduce the number of people affected by the lost of supply, reducing also the time of interruption.

- **Low Voltage Distribution Grid (<1kV):** In the LV network, **smart meters** have been deployed in the last 6 years. Currently, 60% of meters have ‘’smart’’ functions in Spain. Apart from smart meters, there are also other digital devices, such as **data concentrators (DCs)** that transmit the information from smart meters at regular intervals to a central system (metering system and network supervision).

  This Master Thesis focus on the Low Voltage Distribution Grid.

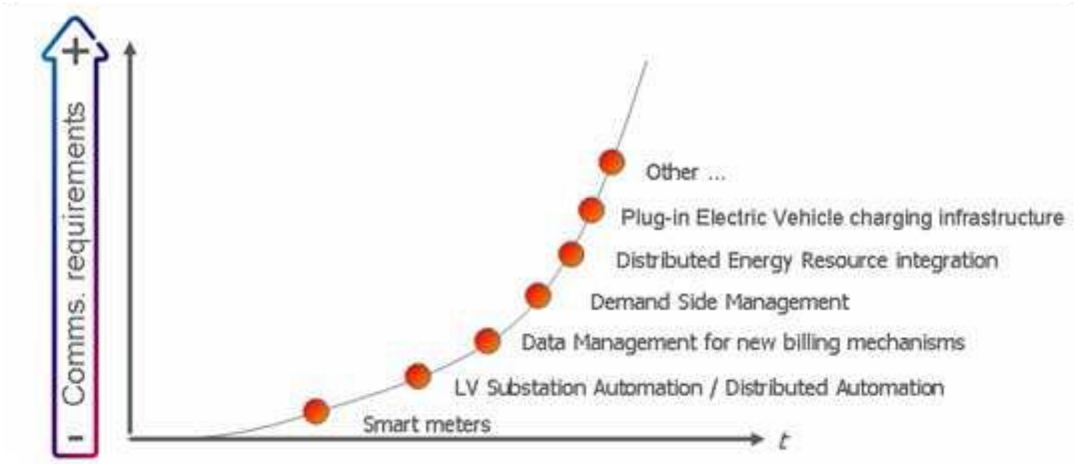


Figure 4. Development of digitalization. Source (JIEEC, 2015).

Figure 5 shows the number of assets according to the voltage level. It can be observed that as voltage decreases, the number of assets increases.

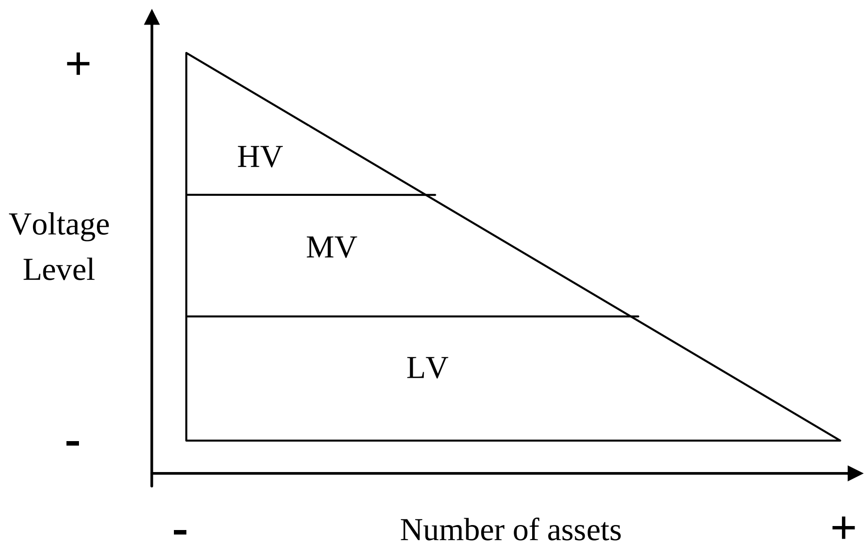


Figure 5. Voltage levels and number of assets. Source: Own elaboration.

The development of distribution networks always favors technologies that are simple, reliable, robust and economically viable. By contrast, evolution of network operation favors **improving system monitoring and control.**

The collected information from smart meters, sensors, concentrators and other digital devices is processed by various software for:

- **Supervision and command** (Supervisory Control and Data Acquisition (SCADA)/Distribution Management System (DMS)), to analyze the state of the system, identify and localize faults, and carry out recovery actions when necessary.

- **Forecast management** of consumption and generation based on past usage data collected by the smart meters, and of forecast programs by the flexibility aggregators, which allow to estimate future congestions and constraints.

- **Asset management**, to evaluate at a longer term maintenance and modernization needs based on historical data (power quality, incidents, increases in peak consumption and/or generation, etc.).

Finally, special equipment is also deployed for transmitting commands issued by the dispatching centers or at the suppliers' request:

- **Remote-controlled operation devices**, which allow opening and closing breakers/switches (either to optimize the operation scheme or reconfigure the network during disruptions).

The figures below show the evolution in the level of digitalization in Medium and Low Voltage:

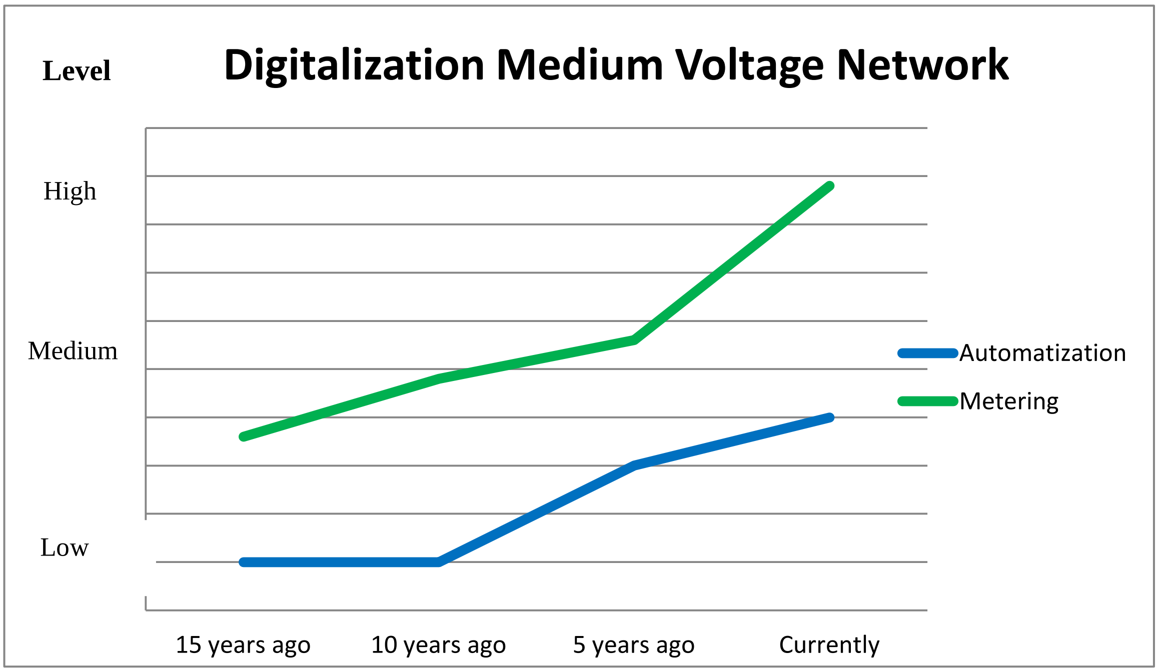


Figure 6. Digitalization Medium Voltage Network EU. Source: Own elaboration.

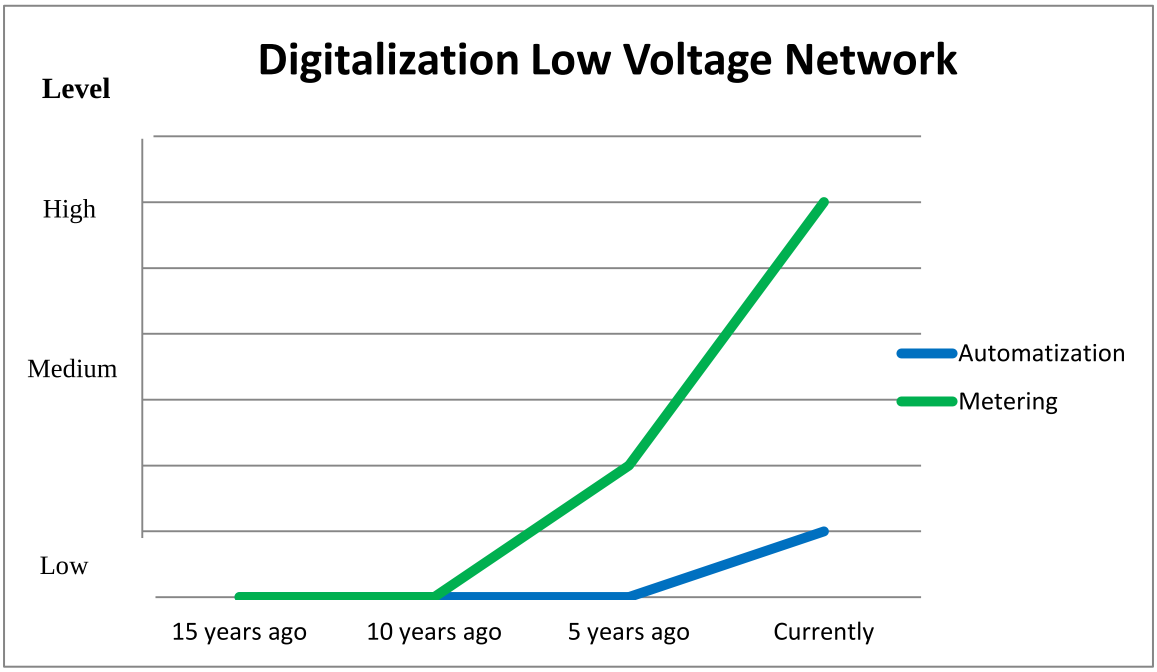


Figure 7. Digitalization Low Voltage Network EU. Source: Own elaboration.

As it can be seen in the previous figure, there has been a great increase in metering devices in the last years, this is due to the deployment of smart meters.

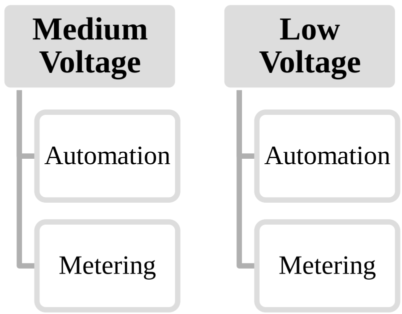


Figure 8. Digitalization in MV and LV. Source: Own elaboration.

This Master Thesis is focused on **Low Voltage network**. Regarding LV, digitalization includes **automation and metering**.

Automation in LV has been developed by new protocols and standards.

One of them is IEC 104, (also known as IEC 60870-5-104) is an international standard, released in 2000 by the IEC (International Electrotechnical Commission). The open communication standard IEC 60870-5-104 is applied in remote control, substation automation, etc.

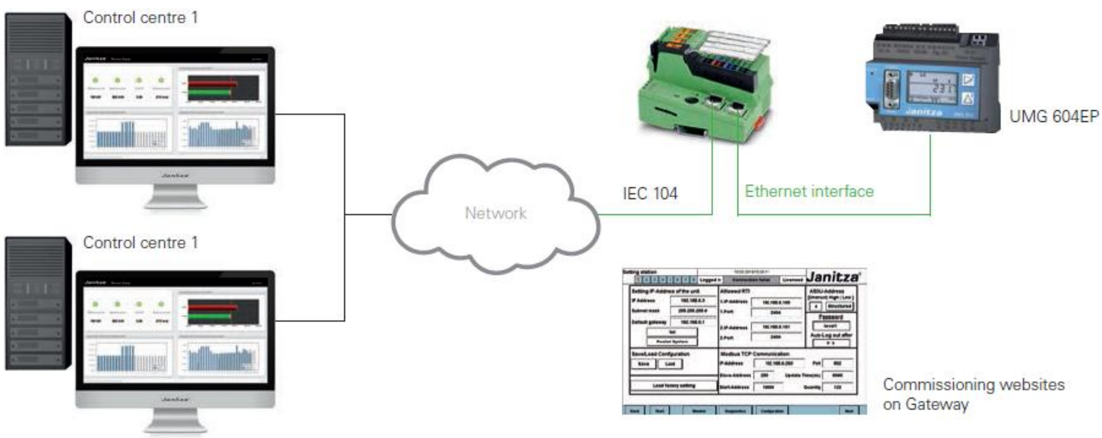


Figure 9. IEC 60870-5-104 Modbus-Ethernet-Gateway ICL. Source: (Janitza, 2015).

This protocol enables communication between control station and substation via a standard TCP/IP network. The TCP protocol is used for connection-oriented secure data transmission.

Interoperability between devices by different vendors is ensured by the interoperability list, which is defined by the standard. In the list, the function range is defined for each device by marking the applicable functions. The common denominator between different vendor lists defines the possible function range.

The biggest advantage of IEC 60870-5-104 is that it enables communication via a standard network, which allows simultaneous data transmission between several devices and services. Moreover, this protocol sets definitions of communication with redundant systems or networks and, with the use of the internet, data encryption.

In 2004 the IEC approves IEC 61850. IEC 61850 is an important new international standard for substation automation that will have a very significant impact on how electric power systems are designed and built for many years to come. IEC 61850 is a part of the International Electrotechnical Commission's (IEC) Technical Committee 57 (TC57) architecture for electric power systems. The model-driven approach of the TC57 standards, including IEC61850, is an innovative approach that requires a new way of thinking about substation automation that will result in very significant improvements in both costs and performance of electric power systems.

Architecture of IEC 61850 is extremely flexible, yet it can be described very simply: Intelligent Electronic Devices, such as relays, implement functions required for protection and control in the form of logical objects.

IEC 61850 has been extended outside the scope of substation automation systems to cover other areas. It can potentially be applied to the power control and asset management of LV grids. Many manufacturers have launched some electric devices with IEC 61850 capabilities such as switches, circuit breakers, etc.

The main goal of IEC 61850 is the interoperability among manufacturers.

The advantages and benefits that IEC 61850 provides are multiple; some of them are listed below.

- Improve communications among devices and increase in flexibility.
- Use of a virtualized model that is used to define how the data is transmitted over the network.
- All object names are standardized and defined in a power system context. All names are defined in the standard and provided in a power system context that enables the engineer to immediately identify the meaning of data without having to define mappings that relate index numbers and register numbers to power system data like voltage and current.
- Standardized Configuration Language: SCL. Using SCL a user can specify exactly and unambiguously what is expected to be provided in each device that is not subject to misinterpretation by suppliers.
- Lower wiring costs.

- Lower Commissioning Costs: the cost to configure and commission devices is drastically reduced because IEC 61850 devices don't require as much manual configuration as legacy devices. Client applications no longer need to manually configured for each point they need to access because they can retrieve the points list directly from the device or import it via an SCL file

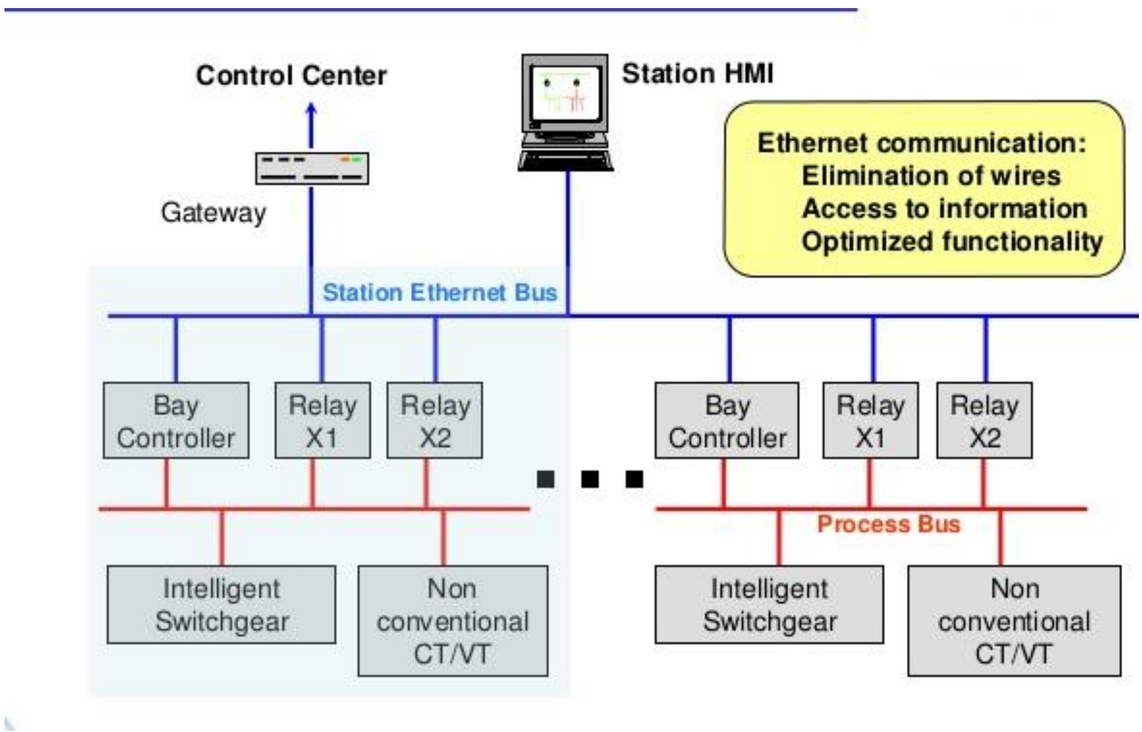


Figure 10. Architecture IEC 61850. Source: (Gunther, 2014)

Figure 10 shows the architecture under IEC 61850. As it can be observed, the standard introduces a Process Bus. It provides several benefits to the system networks:

- Increased operational safety
- Reduced life cycle costs
  - Permanent real-time system supervision increases system availability by increasing maintenance cycles and reducing outage times
  - Computer based tools enable simple measurement.
- Reduced copper cabling
  - By replacing parallel copper wires with optical process bus
- Independent signal distribution
  - Signal distribution is virtually independent from cable length

Regarding **Metering in Low Voltage**, some alliances have been formed last years in order to standardize smart metering and smart grid capabilities. They will be described in the next section 4.3.

4.3. SOLUTIONS TO COMPLEXITIES

Concerning **metering in Low Voltage network**, one of the most important concerns is interoperability, because there is a large number of equipment and different manufacturers in the network.

4.3.1. INTEROPERABILITY

Distribution utilities are developing solutions that enable the communication between Secondary Substations and smart meters associated to that Secondary Substation. In the majority of the cases, utilities are installing concentrators at Secondary Substations with capacity to communicate with the Control Center of the distribution utility via GPRS, GSM or a similar way. On the contrary, for the communication between the Secondary Substation and Smart Meters, the tendency in Europe is to use PLC (Power Line Communications), it allows sending data using the conventional power lines that are converted in a high speed digital line by using high frequencies.

In USA, they use wireless systems because their normative relating to emissions is less restrictive than in Europe.

Spain and its neighbouring countries are developing in parallel three principal solutions:

1. **PRIME** (PoweRline Intelligent Metering Evolution) **Alliance** was created with the purpose of developing and using open and standardized to support smart metering and smart grid solutions capabilities. It was founded in Europe 2009 by 8 companies but today has more than 65 companies and has recently spread to Brazil and Australia.

   The benefits of using an open standard are creating systems with redundancy to ensure 100% uptime at all times, enabling the design of scalable systems according to the number of devices to manage and meet the requirements of responsiveness and performance (PRIME, 2016).

Today is a mature, consolidated and worldwide PLC standard for Advanced Metering, Grid Control and Asset Monitoring applications and the objective to establish a set of open international PLC standards has been met.

With an increased number of PRIME certified products interoperability among equipment and systems from different manufacturers has been achieved and deployments of over 10 million PRIME meters by utilities and solution providers, across Europe with recent expansion into Brazil and Australia. PRIME is now being used and installed in over 15 countries worldwide (PRIME, 2016). PRIME includes 60 % of the electrical distribution in Spain and 100 % of Portugal.

The **PRIME Alliance** is focused on the development of a new open, public and non-proprietary telecom solution which will support not only smart metering functionalities but also the progress towards the Smart Grid. Power line communications (PLC) is the most suitable and natural technology to provide the needed telecoms performance, even in complex underground electricity grids.

Box 2. PRIME Benefits.

Source: (PRIME, 2016)**.**

1. **Lower cost:** Non-propietary, license free, open standard that results in lower meter device costs (CAPEX) and lower communication carrier cost (OPEX).

2. **Lower risk:** Decentralized network architecture approach provides distributed intelligence that eliminates many risks.

3. PRIME is a solution serving utilities communication needs due to vertical integration of MV and LV networks, in-home and distributed energy resources

4. A system platform based on open standards eases the integration of future communications, grid monitor and control solutions in MV, LV and in-home networks.

2. **G3-PLC Alliance.** This Alliance organization is sponsored by ERDF and was formed in order to support, promote and implement G3-PLC in smart grid applications. Its members come from the key stakeholders in the smart grid ecosystem, including utility companies, equipment and semiconductor manufacturers, system integrators, IT vendors and automotive companies (Alliance, 2016).

   The objectives of the G3-PLC Alliance consortium are described below:

   - Support G3-PLC in internationally recognized standards bodies to achieve the rapid adoption of G3-PLC specification worldwide.
   - Develop a framework for equipment testing to facilitate interoperability among G3-PLC adopters.
   - Educate the market and promote the value, benefits and applications of G3-PLC.
   - Establish a forum and process where the consortium members may meet to discuss suggested revisions and enhancements to the specification, make appropriate submissions to internationally recognized standards bodies, meet with developers and providers of G3-PLC compliant products to indentify requirements for interoperability and general usability.

3. **Meters&More Alliance**. PLC is also installed by means of this Alliance. The Association maintains and promotes the communication protocol meters and more, that enables bidirectional data transfer in an Advanced Metering Infrastructure (AMI) system. Meters and more is a new generation protocol which leverages from the experience of Enel's Telegestore, the unique AMI solution in operation worldwide over 40 million customers.

   The protocol enables bidirectional data transfer between smart meters and central billing systems in an Advanced Smart Metering environment.

   In particular, in Spain it powers the smart meters that Endesa is installing up to 13 million customers in Spain.

4.3.2. STANDARDIZATION

Standardization is carried out under the Mandate issued by the European Commission in March 2009. It tasks to develop European Standards for an open architecture for utility meters that is capable to support applications of any complexity, can use current and future communication media, and allows secure interfacing with the protected metrological block. It also requires the development of standards for additional functionalities within an interoperable framework. The work is coordinated by the Smart Metering Coordination Group (SM-CG).

The **objective** is to ensure that all needs of European Member States, with very different energy market structures, regarding smart metering are covered by suitable **European Standards**. The standards should be seen as a toolbox from which the necessary tools for a given project can be selected (Association, 2016).

In line with the need of standardization, the **Open Meter** project was created. The main objective of the Open Meter project is to **specify a comprehensive set of open and public standards for AMI**, supporting electricity, gas, water and heat metering, based on the agreement of all the relevant stakeholders in this area, and taking into account the real conditions of the utility networks so as to allow for full implementation.

The Scope of the project is to **address knowledge gaps for the adoption of open standards** for smart multi-metering equipments and all relevant aspects – regulatory environments, smart metering functions, communication media, protocols, and data formats – are considered within the project. The project is strongly **coordinated with the smart metering standardization mandate** given by the **European Commission** to the European Standardization Organizations (Sanz, 2011).

5. SYSTEMS DEVELOPED DUE TO DIGITALIZATION OF THE NETWORK

CONTEXT: EUROPE

5.1. INTRODUCTION

Traditionally, DSOs have operated as asset-centric companies, physically managing electricity distribution infrastructure assets, such as electrical lines and cables, substations and transformers. With the upgrade of this infrastructure into a digital grid, their asset base is being expanded to include digital monitors, sensors and smart meters.

As a result, DSOs are becoming data-centric companies, using digital technologies to optimize asset management, integrate distributed renewable energy resources (RES) and improve network stability and security. They are also able to leverage consumer and network data to deliver better quality of service and engagement and to serve better as a neutral facilitator among market players (EDSO, 2016).

5.2. ARQUITECTURE

There can be distinguished two areas of systems:

- <u>OT systems</u>: related with the real time operation of the physical assets.
- <u>IT systems</u>: designed to perform back office business processes.

Operations Technology (OT) represents a broad category of components that utilities depend on for safe and reliable generation and delivery of energy. OT encompasses operating gear, from oil circuit breakers and sectionalizers to solid-state relays, and many devices in between. OT also often includes control room applications, such as supervisory control and data acquisition (SCADA) systems that monitor the network, reaching out to devices as complex as substation gateways, or as simple as sensors. OT is often applied within a mission-critical framework and is recognizable to every person working in utility operations.

The **network operation** systems support the control room operators in maintaining electricity quality and continuity. **SCADA** allows to visualize and Distribution Management System (**DMS**) to act.

Information Technology (IT) systems are in place to allow machines to exchange information directly with humans, usually within a second or longer. The utilities industry has experienced an exponential increase in both quantity and quality of IT systems. Improved **Enterprise Resources Planning** (ERP), **Geographic Information Systems** (GIS), and **Customer Relationship Management** (CRM) systems, along with office-based productivity tools and mobile computing devices are some examples.

For the distribution network, the most relevant systems that affect the network and that will be explained are SCADA, DMS and Maintenance Assets System.

5.3. SCADA

SCADA stands for Supervisory Control And Data Acquisition and is probably the most extended industrial control system used not only in energy sector but in manufacturing, logistics and others. It is not a full control system, but rather focuses on the supervisory level.

A SCADA system is a process automation system which is used to collect data from instruments and sensors located at remote sites and to transmit data at a central site for either monitoring or controlling purpose. The collected data from sensors and instruments that are placed at High Voltage and Medium Voltage networks is usually viewed on one or more SCADA host computers that are located at the central site.

The functionalities of SCADA can be summarized as:

- Collect data from monitoring equipment deployed in the HV and MV network using Remote Terminal Units (RTUs) to convert analog signals from the sensors into digital data.
- Display this data through a Human-Machine Interface (HMI) so it can be useful to an operator thanks to Programmable Logic Controllers (PLC).

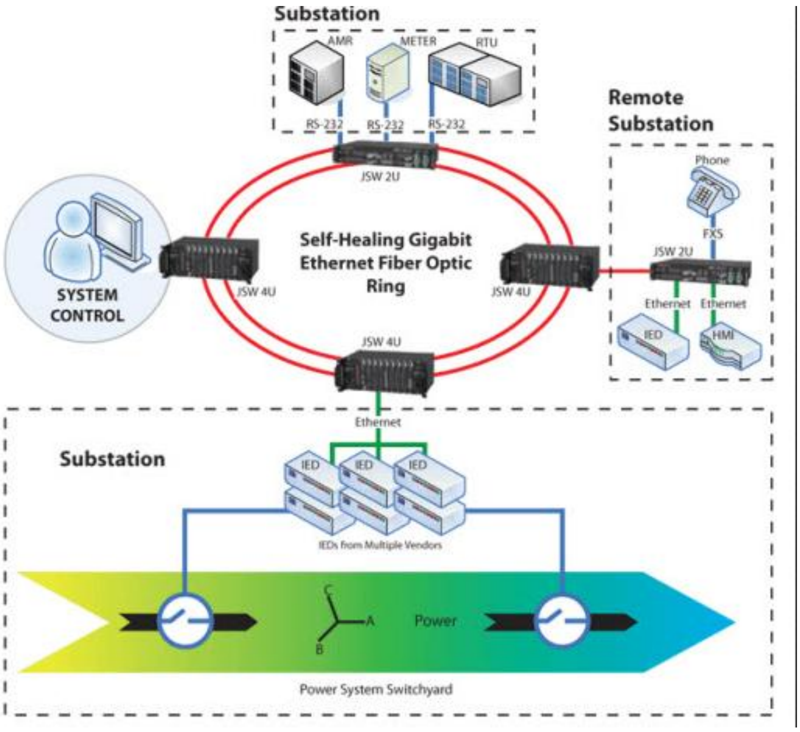


Figure 11. SCADA for Power Distribution System. Source: (Edg).

Figure 11 shows the structure of SCADA in the distribution power system where it collects the entire data from various electrical substations (even at remote locations) and correspondingly process the data.

Programmable logic controllers in substations continuously monitor the substation components and corresponding transmits that to centralized PC based SCADA system.

When there is an outage, SCADA allows to detect the exact location of fault without waiting for the calls from customers. SCADA gives an alarm system to the operator for identifying and solving it. And also in substations SCADA automatically controls isolator switches and circuit breakers for violating parameter limits.

In fact, SCADA allows to have more observability in the network. As the Low Voltage Network is the lowest visible network, the strategy should be to **extend the SCADA to low level networks,** thanks to the digital devices (smart meters, supervisors, etc.).

Smart meters measure voltage at the end consumption point thus the quality of the electricity provided could be monitored by SCADA.

Until now, only some Secondary Substations communicate with SCADA. Digitalization has allowed to increase the number of Secondary Substations that interacts with SCADA system.

5.4. DISTRIBUTION MANAGEMENT SYSTEM (DMS)

The DMS is an integrated systems solution **supporting the day-to-day management** of the distribution network, related construction and maintenance efforts, and proactively guides operators when the system is needed most during storms and related **restoration activities**.

It acts as a decision support system to assist the control room and field operating personnel with the monitoring and control of the electric distribution system. Improving the reliability and quality of service in terms of reducing outages, minimizing outage time, maintaining acceptable frequency and voltage levels are the key objectives of a DMS (SIEMENS, 2015).

A DMS can help improve **control room operations and key performance indicators**. As the utilization of electrical energy has increased, its optimal usage and reliability has become important. Real-time network view and dynamic decisions have become instrumental for optimizing resources and managing demands, thus creating the need for a DMS that can handle increasingly complex work flows.

DMS is rapidly becoming an essential element in maintaining and improving delivery reliability while reducing complexity and automating related work processes.

A DMS can be formulated as comprising four main modules which, when implemented, form a tightly integrated system with common command structure and seamless data transfers. These are the four key control modules.

- Control Room Operations Management (CROM)
- SCADA
- Advanced Applications (ADVAPPS)
- Outage Management (OM) -Trouble Call Management (TCM)

All of which have to be supported by other Enterprise IT systems through a Data Engineering function that provides one point of data entry from these systems.

The overall concept is illustrated in Figure 12 below.

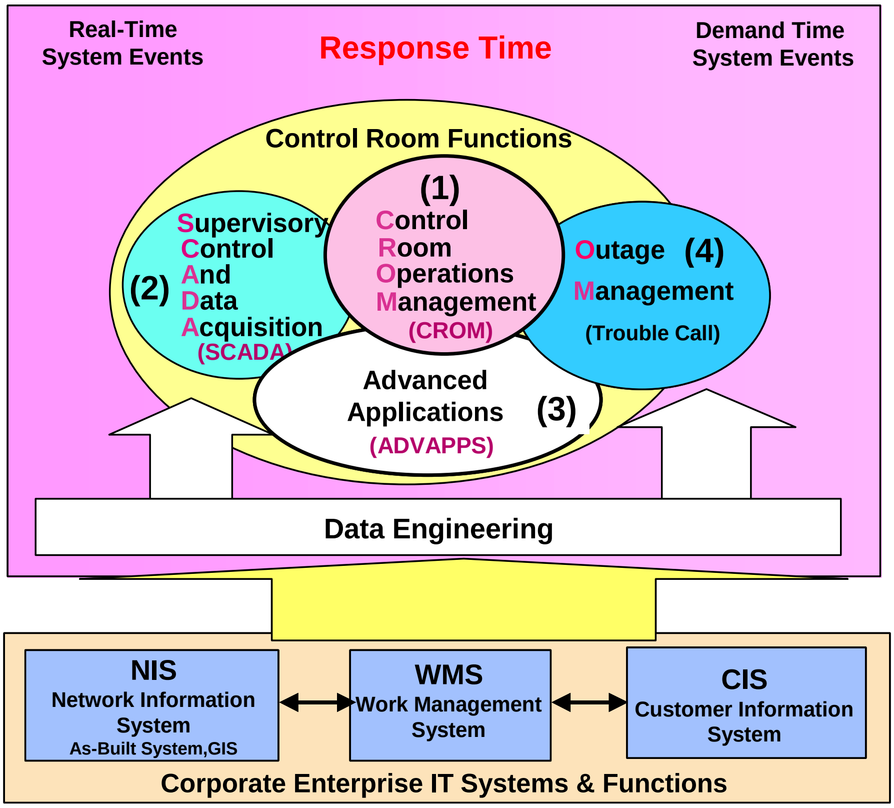


Figure 12. Main modules of an integrated DMS. Source: (ABB, 2013).

Control Room Operations Management

The Control Room Operations Management function is created to encompass the need for one view of the operations process that is conducted in the control room on a daily basis. It represents the user interface or Human Machine Interface (HMI). This function provides the operator with his view on the network.

SCADA

This module provides all the traditional real-time functions such as, data acquisition, control, alarming and alarm management, historical archiving, trend analysis, etc.

Advance Applications (ADVAPPS)

Advance Applications should be viewed as operator decision support tools that allow calculations to be made on the network to access loading conditions and the viability of making switching changes. They also provide a system approach to the optimal control of VARs, voltage regulation, and loss minimization. Intelligent applications are also used for fault location, isolation and restoration in which remedial switching arrangements are proposed automatically.

Outage Management – Trouble Call Management

Outage management is an important function since its purpose is to facilitate returning a faulted system to full supply as fast as possible while minimizing the number of customers affected.

5.5. MAINTENANCE ASSETS SYSTEMS

Both SCADA and DMS are tools to operate the distribution network but in the field of **maintenance the systems are less developed**. The maintenance tends to be more manual.

One of the solutions to Asset Management has been developed by IBM and is called Maximo. Its main goal is the integral management of the assets for the management of their life cycle and maintenance.

Maximo Asset Management allows the organizations to share and to implement the best practices, the inventory, the resources and the personnel.

Maximo Asset Management has six modules of management in an architecture orientated to improve services (IBM).

- **Management of assets**: Obtain the control needed in order to do a more efficient follow-up and to manage the assets and the information of location in the whole life cycle of the assets.
- **Management of work**: Manage the activities of work planned and not planned, from the initial request up the end and record of consumptions.
- **Service management:** Define the offers of services, establish the level agreements of service and monitor more proactively the level delivery of services.
- **Management of contracts:** Obtain complete support for the acquisition, rent, guarantee, rate of work, software and contracts defined by the user.
- **Management of the inventory:** Know the details of the inventory of assets and their use, included what, when, where, how many and their value.
- **Management of supply:** Give support to all the phases of the supply of the whole company, for example, direct acquisition and inventor resupply.

Thanks to digitalization, Maximo system will have much more information and there will be a change in the way to manage the assets.

Before, Maximo system was fed by information set up manually. Now, with digital equipment, these devices send all information to SCADA and some of this information is very useful for maintenance.

6. REGULATORY CHANGES

1 2 **3** 4 5 6

CONTEXT: SPAIN

6.1. NEW REGULATORY SCHEME: IMPACT ON ASSET MANAGEMENT

The remunerative frame of the distribution activity was established in the Royal Decree 1048/2013, of December 27, by which the methodology is established for the calculation of the remuneration of the distribution activity.

For the application of the methodology contained in this Royal Decree there was necessary the approval of a few **unitary values**, fact that took place with the approval of the Order IET/2660/2015, of December 11, for that the facilities approve the **reference unitary values** of investment, operation and maintenance for element of fixed assets and the unitary values of remuneration of other regular tasks that will be used in the calculation of the remuneration of the distribution companies. Therefore, the new model of remuneration of distribution in Spain based on individual assets.

With respect to the previous remuneration in which distribution companies were remunerated according to their collective assets and km of lines, now distribution companies have understood that in order to be more efficient, an **improved asset management** has to be developed. The remuneration has changed and that gives importance to **the management of maintenance of the assets**, in our case of distribution, the need to minimize the costs of maintenance, optimizing the maintenance of assets.

The new regulation contemplates certain economic incentives, which will be able to be even penalties, for the improvement of the quality of supply, the reduction of losses and the decrease of the fraud.

Furthermore, there have been also introduced some modifications in the Royal Decree 337/2014 published the 9th May 2014 that affect distribution companies. Regarding Maintenance of Assets, the Regulation establishes that Distribution Companies are responsible for the maintenance and periodic revision of their own assets and those that are transferred to them. The **periodic verification and revision** of assets is **set at least each 3 years.**

6.2. Regulatory environment needed for the emergence of digital DSOs

Standards priorities for data and ICT topics should be set at EU-level and accompanied by clear development timetables. Such priorities would help standard-setting organisations better to support the digitalization of industry.

DSOs should be a key stakeholder for consultation when the European Commission intends to revise the minimal functional requirements for smart metering, as they are uniquely incentivised to harness the data of consumers and prosumers.

As regulated companies, DSO remuneration is determined by national policy decisions. This national regulation should be consistent with EU digital economy policy objectives and legislation.

7. OPTIMIZATION OF ASSET MANAGEMENT

1 2 3 4 5 6

CONTEXT: SPAIN

The aim of this part is to analyze the new trends of action in the management of assets, and its development and application in the electrical distribution companies in Spain in the new digital context.

It is necessary an integral approach of Management of Assets that allows to contemplate the joint analysis of the activities of operation and maintenance of the assets (operative costs) together with the needs of investment in new assets (capital expenses), taking into account at the same time the impact produced by the regulation.

7.1. NEW STRATEGY IN ASSET MANAGEMENT

The strategy followed by an electric company should take into account several activities simultaneously, so as to take coherent decisions with the objectives of the company:

- Development and expansion of the distribution network taking into account its financing structure and its short term and long term viability.
- Management of the maintenance and replacement of the assets at the end of their useful life.
- Identification of the necessary actions that enable to guarantee the security in the operation and prevent possible restrictions or penalties.

As it can be observed in Figure 13, the variability on the components of the expenses in asset management, that includes financing, technical and administrative costs, implies that the use and selection of the assets should be optimize according to the returns.

However, any modification of the budgetary structure should be analyzed according to the risk associated to each decision, for responsibilities of failure to comply with the quality standards set by the regulatory authority.

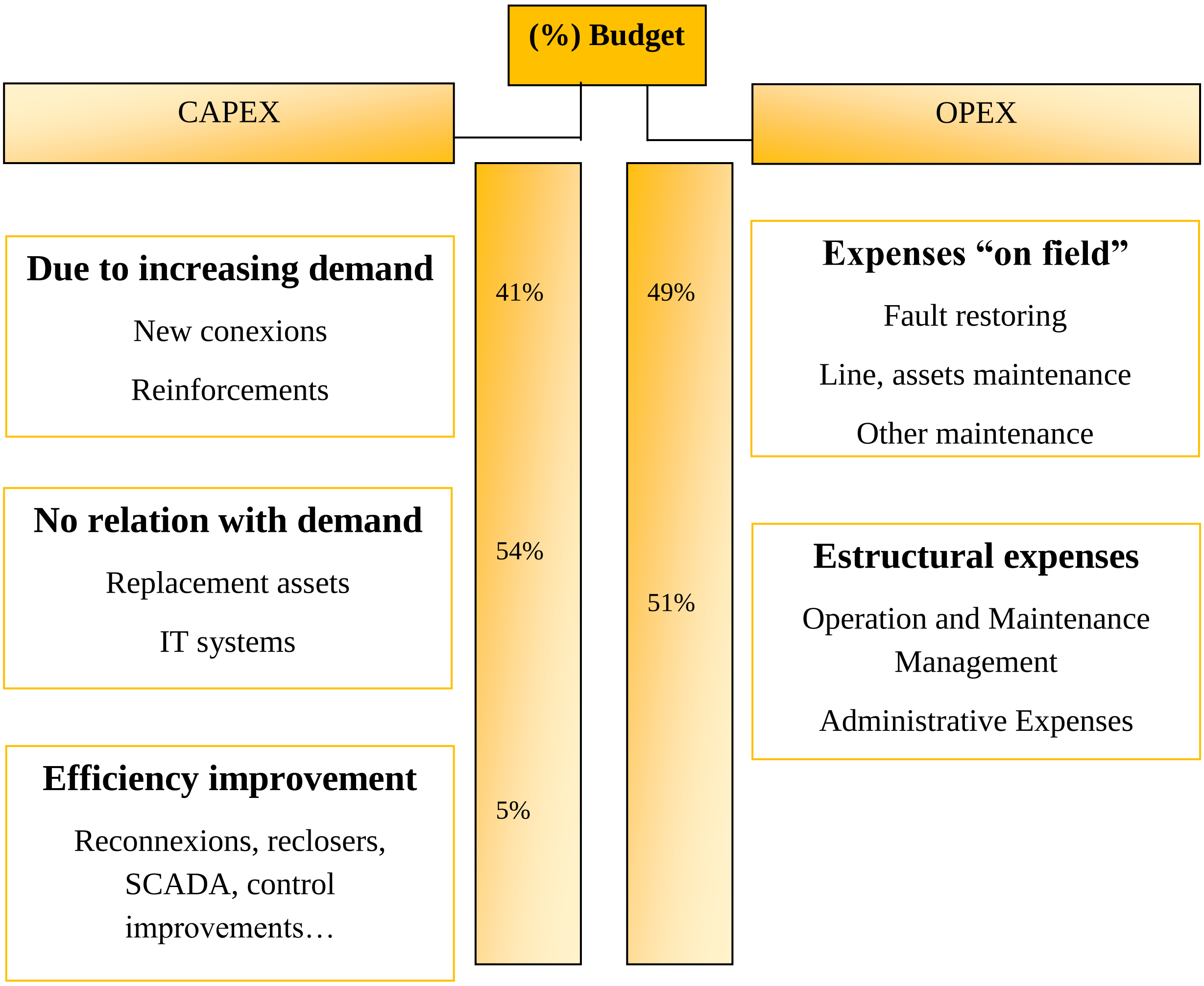


Figure 13. Example of budget distribution utility. Source: (Daniel Galván Pérez, 2014)

The system loop that defines how a distribution company works and operates can be observed below. It is important to notice the need of the **feedback and continuous evaluation** of all variables involved in Asset Management. This is, the operation and maintenance of the network and equipment that guarantee the availability of the assets' functionalities as well as the development of the system.

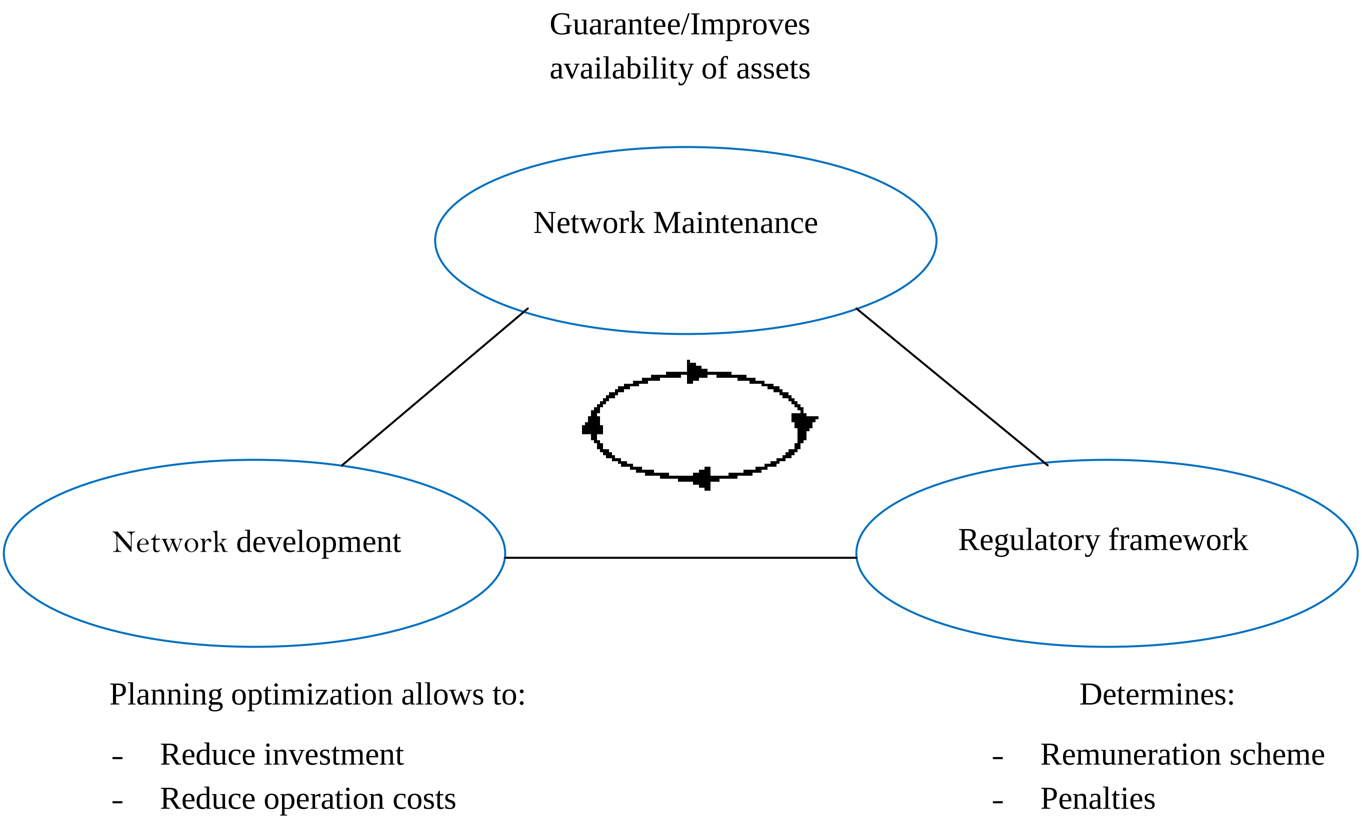


Figure 14. Feedback system. Source: (Daniel Galván Pérez, 2014).

The roadmap decision-taking to achieve the strategic objectives of a distribution company includes, apart from the strategic process planning, an **adequate Asset Management:**

- Existent Assets: They should be maintain, renew and replace at the end of useful life
- New Assets: They should be incorporated to networks to replace old ones to improve the system
- New Services: IT systems, new engineering processes

7.2. NEW PRACTICES IN ASSET MANAGEMENT

In this part, it is analyzed the new methodologies applied to Asset Management and that can be grouped in the following concepts:

I. Risk Based Planning
II. Performance Based Contracts

7.2.1. RISK BASED PLANNING

The planning to improve and expand the distribution network is a key point to achieve an efficient system that complies with its function that is provide consumers with electricity with a competitive cost. The planning of the network expansion with sufficient anticipation allows anticipating potential problems and rationalizing the investments that should be done for its optimization.

However, the current state of the system is subjected to the historical development, characterized by endogenous constraints (network architecture) and exogenous (topology, market, remuneration scheme). These constraints can restrict the functions of the assets of the system. They can have a negative impact on installed capacity, leading to a more inflexible operation of the system.

Therefore, electric companies should be up to date on system planning, renovating constantly their planning criteria and comparing them to those that are used by other utilities. Moreover, it is also important that companies investigate the effectiveness of the last trends in planning and management used in the electrical sector.

Risk Based Planning allow to bring together technical and economic issues through a probabilistic approach of the planning (multiscenario analysis) and to evaluate the effects of the decisions.

7.2.2. PERFORMANCE BASED CONTRACT (PBC)

The planning and maintenance processes based on risk management allow to identify and to evaluate the variation and the degree of accomplishment of the assets' functional objectives. This circumstance allow to improve the management of the service contracts that companies can articulate, passing from the traditional concept of the relationship company/contractor to a service contract based on performance (PBC).

In this type of contract, the basic objective that is demanded to the service offered by a supplier is to maintain a performance level of the distribution assets that preserves the functions of the assets. This contract will be based on the fulfillment of performance indicators (KPIs) that include and guarantee the accomplishment of the company's strategic objectives.

These performance indicators will measure, among others, the satisfaction of the client, the reliability and security of the system, etc.

The award of PBC contracts make more flexible the service costs in the utility. The transition from a fix cost (normally based on number of working hours) to a variable cost (composed of a fix part plus a supplement of bonus/penalty depending on the performance) the application of the operative economical resources are linked to the strategic objective.

Last years, electrical distribution companies have developed and invested in the integration of their processes through information tools as a fundamental key for the business development.

8. OPTIMIZATION OF MAINTENANCE OF ASSETS WITH THE DIGITAL INFRASTRUCTURE

1 2 3 4 5 6

CONTEXT: GAS NATURAL FENOSA

8.1. CONTEXT: GAS NATURAL FENOSA

The next parts of this Thesis will be focused on Gas Natural Fenosa's performance in Asset Management and Maintenance of assets.

The aim of part 7 is to explain how the maintenance of assets in the distribution network can be improved with the new digital infrastructure of the network, giving real examples and results obtained from the maintenance at Unión Fenosa Distribución.

Gas Natural Fenosa is a multinational company resulting from the merge of a natural gas utility Gas Natural and an electric company Unión Fenosa in 2009. It operates in Spain as well as in other countries in Europe (France, Italy, Germany, Belgium, Portugal, etc.), Latin America (Argentina, Brazil, Colombia, Panama, Peru, etc.), Africa, Asia and Oceania.

The business areas of Gas Natural Fenosa are:

- Procurement of natural gas
- Generation of electricity
- Distribution of gas and electricity
- Retailing of gas and electricity
- Trading
- Telecommunications

In particular, the work reflected in this Thesis has been developed at **Unión Fenosa Distribución**, which is an electricity distribution company that belongs to the group Gas Natural Fenosa.

Unión Fenosa Distribución operates in Spain, mainly in Galicia, Community of Madrid, Castilla y León and Castilla La Mancha.

It operates the distribution network and distributes electricity to small consumers, SMEs[1] and industrial consumers.

In the recent years, Unión Fenosa Distribución has deployed many **digital devices** in the distribution network in three levels: High Voltage, Medium Voltage and Low Voltage.

What is currently working on Unión Fenosa Distribución is to change the way it operates, improving the traditional systems and processes. The aim is to make use of the information and benefits provided by the **digitalization** of the network to improve the way that Unión Fenosa Distribución works.

As the distribution network has a high number of assets, compared to the transmission network for example, an efficient asset management has to be developed. Moreover, once the investments in new assets are done, what costs more to the company is the maintenance of those assets. More assets mean that more maintenance has to be done. This is translated in a decrease of the OPEX[2]. Therefore, maintenance should be optimized in order to obtain better results and higher return.

Therefore, Maintenance should be optimized making use of the digitalization that enables to change the conventional maintenance procedures into more efficient ones that allows Unión Fenosa Distribución to reduce costs.

8.2. ASSETS SUPERVISION

In order to supervise the correct operation of the assets, maintenance is necessary.

This thesis is focused on Secondary Substations' Maintenance that is done by Unión Fenosa Distribución.

Secondary Substations reduce the voltage of the Medium Voltage Lines (15, 20, 35, 45 kV) to Low Voltage values (40 0/230 or 230/127 V). For this reason, they are the last link of electricity transformation towards consumption points.

Regarding their location, they can be classified into overhead or indoor. Indoor Secondary Substations can be of surface or underground.

There are two types of intervention in Secondary Substations: planned maintenance and not planned maintenance.

Planned maintenance is done in the following situations:

- Regulatory reasons
- Load Handling: Metering of charges in the feeders that are the output lines of the transformer placed at the Secondary Substation.
- Revisions

[1] SMEs: Small and Medium Enterprises
[2] OPEX: Operating Expense

- Cleaning
- Festivals and Celebrations: During a celebration, some lines are used to connect additional lighting.
- Review of remote control, teleprocessing systems, locksmithing, masonry and actions derived from periodic regulation check

Making use of the digital technology, several cases of planned maintenance can be avoided or reduced. The visits to Secondary Substations by crews of Unión Fenosa Distribución for **Maintenance due to Load Handling can be reduced or even remove**. This is possible if the remote information is exploited.

Thanks to **teleprocessing**, loads in lines can be calculated, making use of all the information that is available and that is sent remotely by the smart meters and by the Low Voltage Supervisor. Furthermore, not only visits for maintenance will decreased but also, teleprocessing allows to detect whenever there is a fault in a conductor, fuse or voltage oscillation.

On the other hand, **advanced segmentation of the Secondary Substations** should also be regarded. This means, it should be established frequencies of cleaning, revisions and maintenance for celebrations according to the criticality level of the Secondary Substation. Investments should also be analyzed in order to reduce maintenance, for instance, the possibility to invest in flood detectors, video cameras, electronic locks, etc.

Maintenance can also be done for unplanned reasons:

- Fault of material
- Teleprocessing problems
- Blown fuse
- Vandalism

8.3. RELEVANT CHARACTERISTICS AND FUNCTIONALITIES

This part describes the new digital equipment that has been introduced in Secondary Substations by Unión Fenosa Distribución. The following parts of this Thesis will focused on Maintenance of Secondary Substations owned by Unión Fenosa Distribución, so it is important to describe what are the new digital devices that have been installed at Secondary Substations in the last years.

This part will be focused on Medium and Low Voltage digitalization, as the number of assets in those levels is higher and the improvement of maintenance is of real importance.

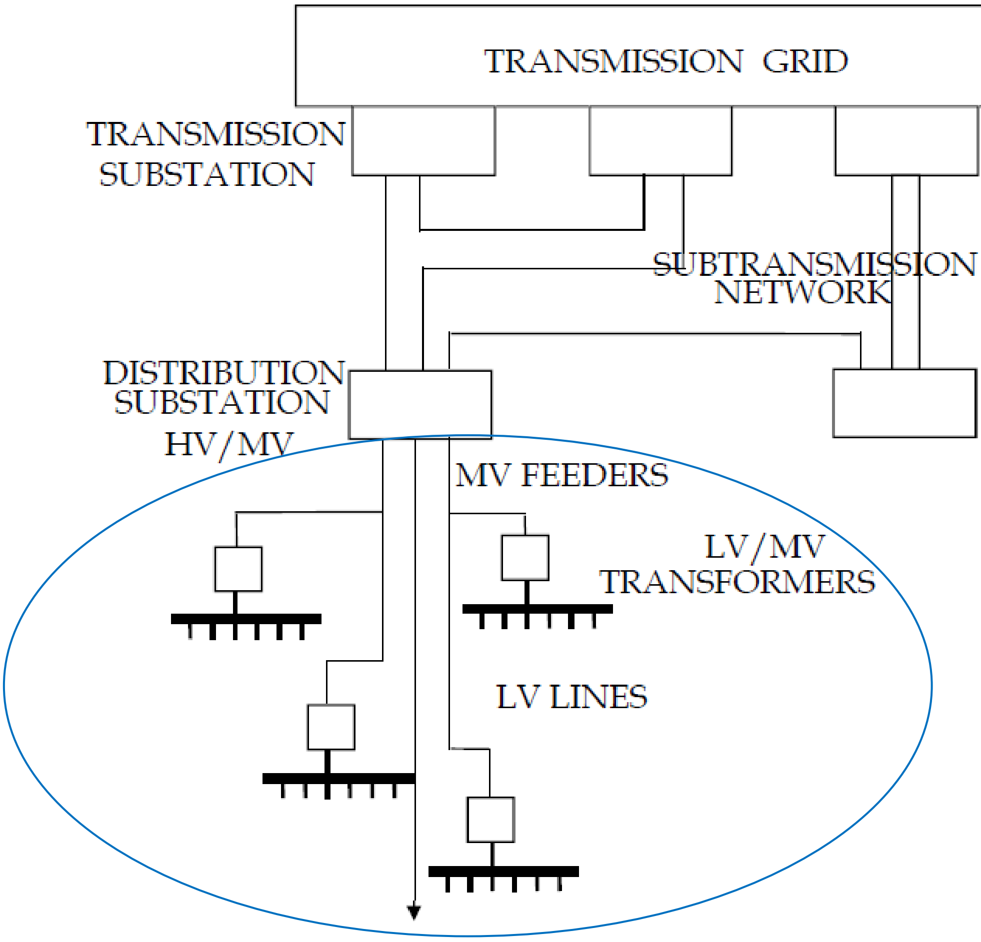


Figure 15. Voltage levels in the network. Source: ICAI.

8.3.1. MEDIUM VOLTAGE

8.3.1.1. Problem

The problem in Medium Voltage is that there are thousands of Secondary Substations. Union Fenosa Distribución owns more than 40 thousand of Secondary Substations.

The technology was very expensive to be introduced to MV because of the high number of assets. The Digitalization in High Voltage was easier because the number of assets are lower than in Medium Voltage. Therefore, because of the high number of assets and the cost of the digital technology, it was very difficult to introduce **digitalization** in MV.

8.3.1.2. Solution

Due to the recent improvements in digitalization, currently there are much more supply of digital equipment at affordable prices. Before there was no technology sufficiently cheap to give the jump to MV digitalization. Now with the advances in technology, it is possible.

There have been some changes introduced in the last years in Secondary Substations. These changes were motivated by a new tender of cells and Secondary Substations (October 2015). These changes include the introduction of remote management in cells, new technology of remote control, incorporation of directional detectors and improvements in security.

The modification of Secondary Substations required new technology that is provided by several companies. Some of the most relevant providers of remote management technology are Siemens, Schneider, Ormazabal, ZIV, etc.

Some of the functionalities that were introduced in the conventional Secondary Substations are:

- Measure of voltage, current in MV and LV
- Detect outages
- Read the consumption in the Secondary Substations and smart meters that are associated to each Secondary Substation.

Figure 16 shows the new Secondary Substation configuration after having introduced digital equipment that provide the functionalities explained above.

Remote control

Remote management

Improvements in security

Figure 16. Digital technology in a Secondary Substation. Source: Gas Natural Fernosa.

The **remote control system technology** can be seen in figure 17. Some of this technology includes:

- **Remote fault passage monitor**, which has been developed to detect MV fault passage and send this information.
- **Remote Terminal Unit** (RTU), device based on microprocessors, which allows to obtain signals and information independent from the processes and to send them to the remote control center where it is processed. Generally in the remote control center there is a central system SCADA which allows visualizing the variables sent by the RTU
-

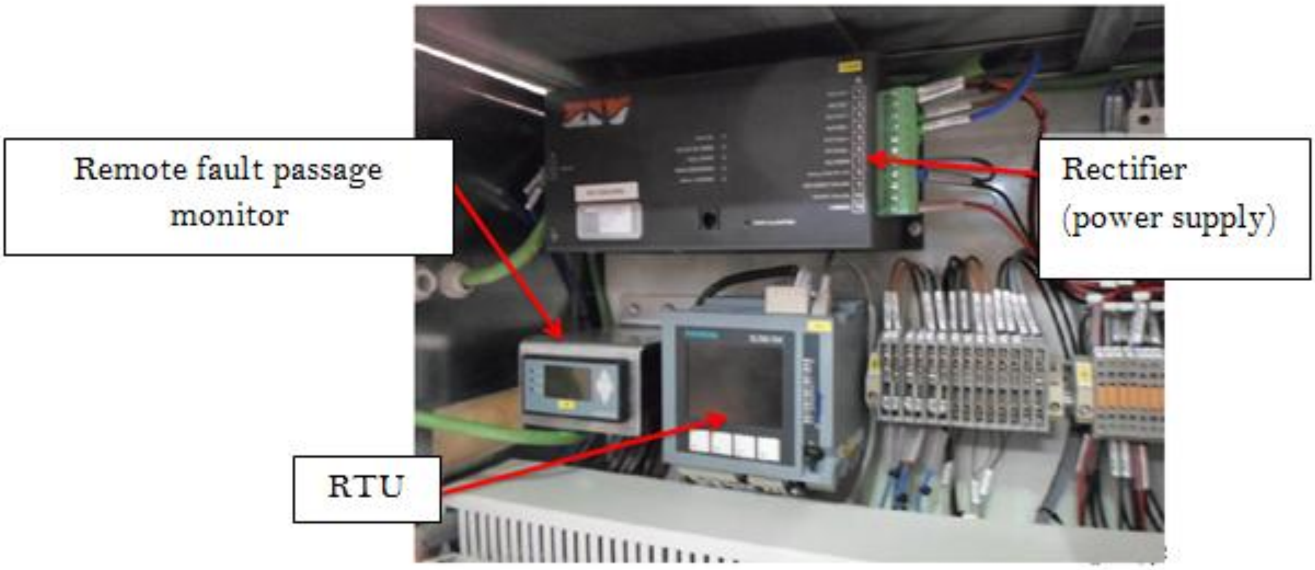


Figure 17. Remote control technology in a Secondary Substation. Source: Gas Natural Fenosa

The **remote management system** in a Secondary Substation can be seen in figure 18.

In the new framework, remote management is a key aspect. It is defined as the management of all the information, principally for telematic means, on electrical magnitudes (including the information for the invoicing of consumers) and of communications, events and alarms, so much of supplies of Low Voltage as of CT, and of the behavior of the equipment involved in the process.

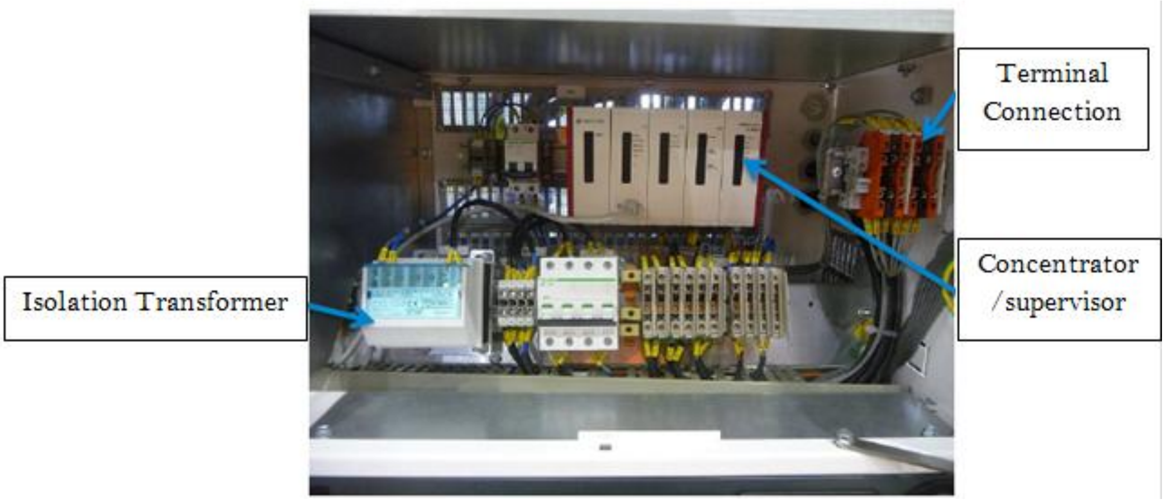


Figure 18. Remote management technology in a Secondary Substation (MV-LV). Source: Gas Natural Fenosa.

Some of the most relevant technology to manage the system remotely is described below:

- The **isolation transformer** transfers electrical power from a source of Alternating Current (AC) power to some equipment or device while isolating the powered device from the power source, usually for safety reasons. Isolation transformers provide galvanic isolation and are used to protect against electric shock and suppress electrical noise in sensitive devices.

- **The Concentrator and supervisor** that will be explained later on.

On the other hand, there have also been introduced improvements in security in Secondary Substations (MV-LV). Some of them can be seen in figure 19.

Figure 19. Improvements in security in a Secondary Substation. Source: Gas Natural Fenosa.

Some of the improvements that have been introduced in order to increase the safety and security in Secondary Substations are:

- Remote supervision of the pressure of SF6 with alarm and block of the maneuver.
- Circuit protection with isolating covers.
- Batteries associated to reliable sources, equipped with protective fuses against short-circuits and encased with protected points.
- LV boards are compacted and adapted for secure operation

Regarding Medium Voltage, there have been also deployed digital devices in overhead lines, forming the **new overhead remote controlled switchgear**.

The equipment that has been introduced are, among others, switch-sectionalisers and circuit recloser-sectionalisers. The main differences among them are shown in table 1.

Switch-Sectionaliser	Recloser-Sectionaliser
Isolation SF6	Solid isolation
SF6 breaker	Vacuum breaker
Opening on load	Opening on load and short-circuit
Control by Remote fault passage monitor	Control by Remote fault passage monitor + protection relay
Includes voltage and current sensors	Includes voltage and current sensors

Table 1. Differences between switch-sectionaliser and recloser-sectionaliser. Source: Gas Natural Fenosa.

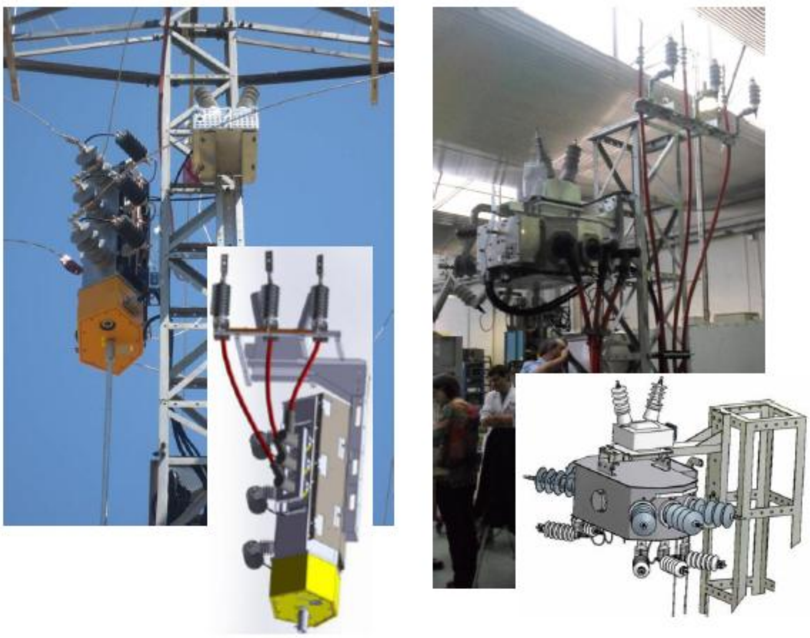


Figure 20. Switch-sectionaliser. Souce: Gas Natural Fenosa.

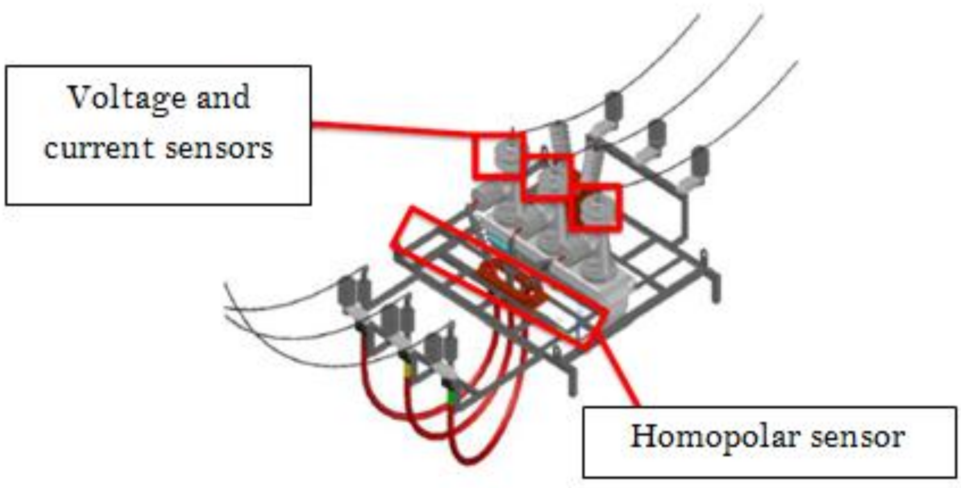


Figure 21. Reconnector-sectionaliser. Source: Gas Natural Fenosa.

In general, the placement of the sensors and the disposition of the equipment is similar for both devices. The main differences are in the type of break element and in the inclusion or not of the protection relay.

On the other hand, there are also **new improvements in security** for overhead remote controlled lines.

- Supervision of SF6
- Emergency manual closer
- Protection against resonance phenomena
- Mechanic protection of transformers

8.3.2. LOW VOLTAGE

Concerning Low Voltage, the most relevant digital devices that have been deployed in the last years are **smart meters and data concentrators**.

The **Smart Meter** is basically an AMI (Advanced Meter Infraestructure). It is an electronic device that records consumption of electric energy in intervals of an hour or less and communicates that information at least daily back to the utility for monitoring and billing. Smart meters enable two-way communication between the meter and the central system. Unlike home energy monitors, smart meters can gather data for remote reporting. Such an Advanced Metering Infrastructure (AMI) differs from traditional Automatic Meter Reading (AMR) in that it enables two-way communications with the meter.

The general structure of the smart meter supports three principal elements: the system of measure, the memory and the device of principal information, which until now was only the system of communications. To extend its operative capacities smart meters can include the following elements:

- Systems of supply
- Calculation and communication processor
- Device of operation or control

The functionalities of smart meters are, among others:

- Bidirectional communications with the electrical company and with other devices
- Possibility of reading under demand or real time
- Synchronizations of date and automatic record of incidents
- Detection of frauds as well as alarms associated with quality of supply
- Customization of the contracting, planning and possibility of bidding and purchase of the electricity at certain moments and control of load

AMI (Advanced Meter Infrastructure), can be considered to be an extension of AMR, these equipment allow the reading of the consumption "à la carte" of the accumulated energy or of the instantaneous power, admit options of differentiated prices, records the demand and programs interval of "load" previously agreed with every client.

The metering equipment of electric power can be distinguished according to its characteristics:

- Technological, being able to be electromechanical or electronic
- Functional: single-phase or three-phase
- Operational: capacity to register and send data

Smart meters allow time differentiation in the energy/network usage. They enable tariff designs that truly reflect the system costs incurred by each consumer, whether in terms of energy or use of electrical infrastructure.

For example, two customers that consume the same amount of kWh during a day, may have a different cost in their bill because of their contribution to system costs and peak load.

This has two main positive effects: on the one hand consumers can become aware of their actual costs and the regulator can opt for a tariff setting that is consistent with those costs.

On the other hand, thanks to smart meters, power contracted can be changed remotely, with no need to go to customer’s home.

The evolution in the deployment of smart meters can be seen in figure 22.

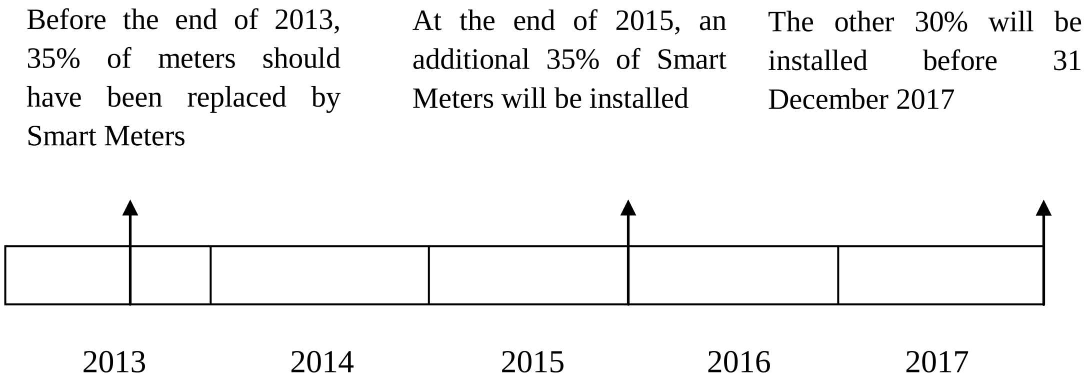


Figure 22. Smart Meter deployment evolution. Source: BOE and CNMC.

Smart Meters not only are deployed in low voltage network, but also in Medium Voltage and High Voltage networks. In fact, there are five types of meters depending on the power contracted by the consumer.

Type of meter	1	2	3	4	5
Number of metering points in Spain	1000	21.000	140.000	700.000	27.700.000
Power	>10 MW	>450 kW	>50 kW	>15 kW	<15kW
Energy	20%	20%	10%	10%	40%

Table 2. Metering Equipment. Regulation of metering points. Source: Gas Natural Fenosa

There are many manufacturers of smart meters. The most relevant world manufacturers of smart meters and their country of origin are described in table 3.

Manufacturer	Country of origin
Circuitor	Spain
ZIV	Spain
Echelon	USA
GE Energy	USA
Itron, Actaris	USA
Elster Group	Luxembourg
Siemens Energy	Germany
Iskraemeco	Slovenia

Table 3. Biggest manufacturers of Smart Meters. Source: (Industry, 2016).

Figure 23. Smart Meters manufactured by ZIV, Circuitor and GE. Source: (metering, 2016).

Concerning **Low Voltage**, another device that is in place in Secondary Substations (MV-LV) is the Concentrator.

The **Low Voltage Supervisor** is integrated with the **Concentrator** in a unique modular compact device. The function of the Data Concentrator is to collect automatically all the information of measures and remote alarms of the smart meters (type five) and the data measured by the supervisor. This information is sent to the Central Information System. The Concentrator is also capable of also capable of sending orders to the smart meters to change, for instance, its configuration parameters.

In addition, the supervisor is designed to measure all electric parameters (energy, current, voltage, etc.) of each transformer belonging to a Secondary Substation. It also generates events and alerts associated to them.

At the communication level, there can be two types of concentrators: principal and secondary. The principal concentrator communicates with the Central System and the secondary concentrator communicates with the principal, sending the data collected to it.

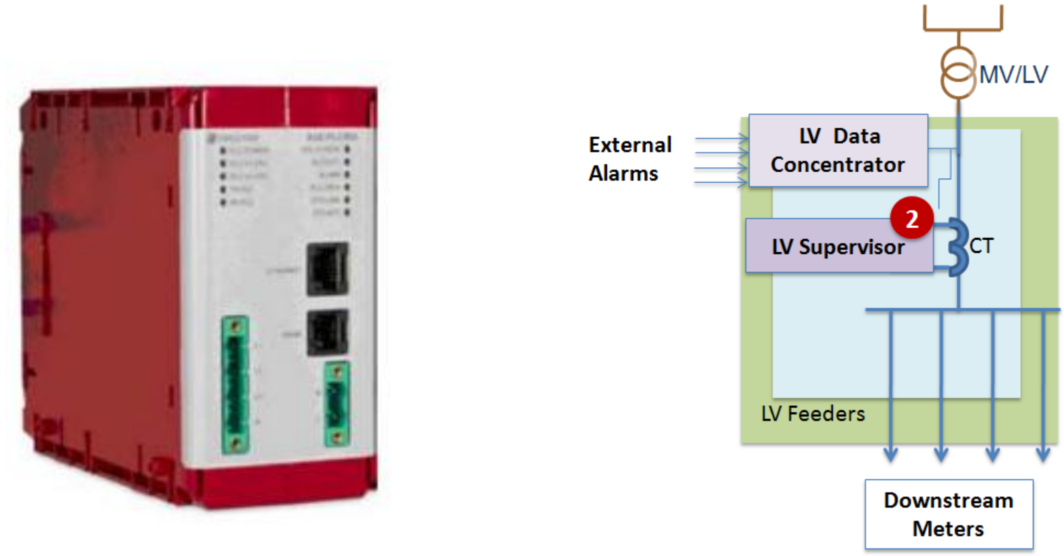


Figure 24. Concentrator + LV supervisor CIRCUTOR and architecture. Source: Gas Natural Fenosa and CIRCUTOR.

Box 1. Low Voltage Supervisor functions.

Source: Gas Natural Fenosa

1. It is a smart meter: it registers the values of energy, current and voltage of the point at which it is located (CT)

2. It generates events (spontaneous or not) associated with measurements (overload, overvoltage, undervoltage, phases unbalance, etc.)

3. It detects LV network anomalies (LV transformer neutral connection opening, opened phase, short circuit with high impedance, etc.)

8.4. LOAD HANDLING

1 2 3 4 **5** 6

CONTEXT: PROBLEM AT GAS NATURAL FENOSA

8.4.1. CURRENT PROCEDURE

The **current procedure** for supervision and maintenance of Secondary Substations at Gas Natural Fenosa is **highly inefficient**.

The procedure is to visit a **small sample of Secondary Substations** and to measure the current that flows in each phase of the output lines (feeders).

Not all Secondary Substations are visited, only the most critical ones (those whose transformer exceeds 70% of its capacity). The visits are done twice a year, during winter and summer.

The objectives of the Load Handling are:

- Measure phase currents and compare them to the cut-out current of the fuse
- Measure of the maximum registered current with a maximeter
- Detect unbalances between phases
- Future load distribution
- Avoid faults due to overloads of transformers
- Detect earth faults
- Contribute with information for studies

This procedure measures the currents in real time with no error. The measure of the maximeter allows to control the maximum load that has had the transformer in order to control its useful life and to see if it is necessary to fit its nominal power to the real loads of the network.

Though the instantaneous measures of the Load Handling are not taken in the maximum top of load, they are sufficient to perform the tasks of preventive maintenance, which are translated basically in load balance from or the installation of a new transformer.

On the contrary, the biggest **disadvantage** is that decisions are taken with just one **isolated measure of the currents**. In fact, currents oscillate a lot depending on the charge that is connected at each moment to that line, so making use of one particular measure at one moment is **not too accurate to make decisions**.

In order to avoid the current physical metering of currents making use of the information available of teleprocessing, a procedure is proposed below.

8.4.2. ESTIMATION OF LOAD HANDLING

CONTEXT: SOLUTION TO THE PROBLEM AT GAS NATURAL FENOSA

The solution to the inefficient maintenance of Secondary Substations that has been done is described in this part and it is of application at Gas Natural Fenosa. Thanks to this solution proposed, it will be possible to move **from a preventive based maintenance** (conventional maintenance at Secondary Substations) **to a predictive maintenance.**

The procedure proposed is based on the exploitation of the information of teleprocessing to calculate **the average and maximum hourly current** of each phase of each output line of the Secondary Substation.

In addition, **energy balances** will be also calculated between the total energy consumed by the smart meter and the energy registered by the Low Voltage Supervisor of a Secondary Substation.

8.4.2.1. THEORETICAL CALCULATIONS

In order to calculate the currents that flow through low voltage feeders, the following formulas of triphase power can be applied:

$$P = 3 * V * I * \cos\varphi = \sqrt{3} * U_L * I_L * \cos\varphi$$

$$Q = 3 * V * I * \sin\varphi = \sqrt{3} * U_L * I_L * \sin\varphi$$

Being:

- P, active power consumed by supplies associated to one output line and registered in its smart meter
- Q, reactive power consumed by supplies associated to one output line and registered in its smart meter
- U_L, triphase voltage in that line (400 V)
- I_L, current that flows in that output line

The scheme of the Secondary Substation is described below.

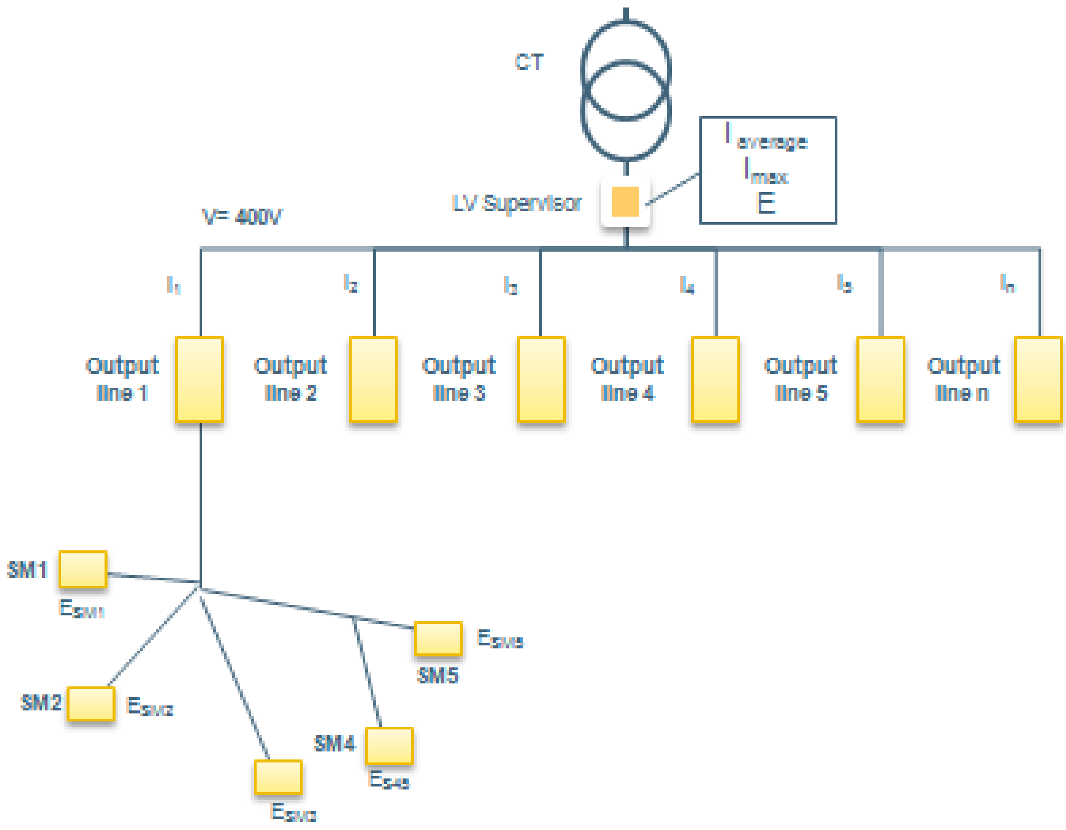


Figure 25. Simplified Scheme CT. Source: own elaboration

On the other hand, the power and current registered by the Low Voltage Supervisor should be equal to the sum of power and the sum of currents of output lines:

$$P_{Low\ Voltage\ Supervisor} = \sum_i P_i$$

Being i the subindex of the output line.

$$\vec{I}_{Low\ Voltage\ Supervisor} = \vec{I}_1 + \vec{I}_2 + \vec{I}_3 + \cdots + \vec{I}_n$$

However, in this Thesis, the calculation of currents that flow in the low voltage output lines will be calculated in another way, using the methodology explained below.

First of all, partition coefficients will be calculated. There are two possible options to evaluate the currents:

a) Caculation of a partition coefficient proportional to the energy consumed
b) Calculation of a partition coefficient proportional to the contracted power

These partition coefficients indicate which percentage of energy consumed or contracted power has each output line (that is consumed by the clients associated to that line and which is registered by smart meters) compared to the total energy consumed or total power contracted by all smart meters of all output lines.

After calculating the coefficients (each output line will have a different partition coefficient), they will be applied to the current measured by the Low Voltage Supervisor (located at the output of the transformer) to estimate the current that flows per phase in each line.

The problems that are faced with this model are:

- Uncertainty of the output line associated to some smart meters. Some SM are not registered at any line.
- Not all the supplies have smart meters with hourly discrimination neither remote reading.
- The presence of fraud or commercial losses. If it is significant, it can distort any estimation.

To overpass these obstacles and make easier the calculations, the model has been subjected to some simplifications.

8.4.2.2. Simplified model

To simplify the calculations, several hypotheses have been taken:

- Cos φ =1 (resistive charges)
- Constant voltages

} Therefore, escalar aggregation of currents

- In case of having a result inside a reasonable margin of losses and that does not detect a significant unbalance, it will be assumed that the association smart meter – output line is correct though this is not conclusive.

8.4.2.3. Complexities

From an electrotechnical point of view, the procedure to estimate the currents is not complicated, but the reality is different. From the point of view of reality, there are some barriers that make more difficult the estimation:

- There is not information about the phase to which each client is connected.
- There are some underground network that are very old and do not appear in the inventory.

- There are some parts of the network where there are mistakes in the association of clients to feeders.

These obstacles may distort some calculations of certain Secondary Substations, but, fortunately, in the majority of cases, the distortion do not lead to a great error.

8.4.2.4. INFORMATION REQUIRED

- Incidents generated in the System of Management of Incidents that could concern consumers in the low voltage network
- Criteria of selection of Secondary Substations on which the Load Handling Maintenance is done recursively.
- Historical information of the measures acquired in the Load Handling
- Information obtained from the association of Smart Meters to points of supply
- Information proceeding from AMI (Advanced Metering Infrastructure). This includes several reports that are sent by Smart Meters and Low Voltage Supervisors:

  S02: Report of the active and reactive power consumed or generated in one hour.
  G03: Report of average curve of voltages, currents and powers of the LV supervisor

  G04: Report of maximum curve of voltages, currents and powers registered by LV supervisor

  Figures 26 and 27 show examples of reports S02 and G03. The last three digits of the number of Low Voltage supervisors and Smart Meters are omitted due to confidential reasons.

  With these figures, it can be observed the high amount of data that has to be managed in order to make the estimations.

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      <Cnt Id="SAG0125277XXX" Magn="1" >
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="190" R2="0" R3="0" R4="0" Bc="00"/>
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Figure 26. Report S02 with data of active and reactive power, exported and imported in one hour. Source: Gas Natural Fenosa.

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Figure 27. Report G03 with mean values of currents, voltages and power of the Low Voltage Supervisor for several hours. Source: Gas Natural Fenosa.

8.4.2.5. ENERGY BALANCE

There has been calculated an energy hourly balanced at the hour when the Physical Load Handling was made.

The energy balance has been calculated taking into account the total energy consumed by the Smart Meters connected to one Secondary Substation and the energy registered by the Low Voltage Supervisor at the output of the transformer.

The difference between these two values (sum Smart Meters and LV supervisor) is equal to the losses.

Losses can be technical or non technical (commercial losses). Technical losses consist mainly of power dissipation in electricity system components such lines, transformers, and metering systems.

Non-technical or commercial losses are caused by actions external to the power system and consist primarily of electricity theft, non-payment by customers, and errors in accounting and record-keeping.

Thanks to the energy balance, it is possible to calculate losses and verify that they are inside certain limits. It is useful to detect fraud, as it will distort future calculations.

8.4.2.6. ESTIMATION OF CURRENTS

After checking the energy balance in a certain Secondary Substation, the next step is to estimate the currents that flow at each phase and for each line.

> The hourly information of the Low Voltage Supervisor and the Smart Meters fed from the same transformer can help to estimate the hourly average and maximum load in each of the low voltage lines, assuming that there can be mistakes of association and using the historical information of Load Handling Maintenance.

8.4.2.6.1. Maintenance Works

In the physical work maintenance that is done at each Secondary Substation, the workers measure with a Current Clamp the currents per phase that flow through each output line.

They also measure the current at the point where the Low Voltage Supervisor is located; this is, at the exit of the transformer.

The **objectives** of these measures are multiple:

- First, verify if the currents are inside limits. Normally, these limits are set by the maximum current that can tolerate the cable.

- Second, identify the lines that have more charge to decide the planning of the network, for instance, to decide where to connect a new customer.

- Third, identify the load capacity of the transformer. Decide whether or not it is necessary to change the transformer. For instance, due to the expansion of the network and the increase in the number of customers, it may be necessary to increase the power of the transformer.

- Finally, identify outages or anomalies in the network or change blown fuses.

The fact is that, due to the digitalization of the network, more digital equipment has been installed in the last years. Thanks to these devices (smart meters, LV supervisors, remote control systems, etc.) it is possible to have access to much information that was no available in the past.

Distribution companies have to adapt its procedures and make use of all the advantages that the digital devices can offer, this is among others, the access to real time information.

Making use of this information that is sent by digital devices remotely, it is possible to estimate the currents per phase that flow through each line, this is, **estimate what is actually measured physically**.

8.4.2.6.2. Methodology to estimate the currents

In order to estimate the currents, the method followed is described below:

- Firstly, it is necessary to **calculate the partition coefficients of each output line** (low voltage line). These coefficients are an indicator of the percentage of energy or power that each line has (consume) with respect to the total amount (sum of the energy or power consumed by all the output lines).

- Secondly, thanks to the **information sent by the Low Voltage Supervisor** to the remote control system, it is possible to know the current per phase at the exit of the transformer in real time. The Low Voltage supervisor sends reports each hour with the information of the average current (per phase) in that hour (report G03). LV supervisor also sends the maximum current per phase registered in each hour (report G04).

- Thirdly, **applying the partition coefficients** (%) of each output line **to the currents** per phase registered by the **Low Voltage Supervisor**, it is obtained the currents per phase in that output line.

- Finally, in order to verify the results, the calculations of currents have been done at the exact day and hour of the physical maintenance work in order to **compare** the **calculated values with** the **values** that have been **measured** by the maintenance crew.

As it has been mentioned before, there are two possible partition coefficients that can be calculated:

Option 1. Calculation of the hourly **partition coefficient** of each low voltage line from the **hourly energies of all the consumers**.

In order to calculate the partition coefficients based on energy, it is necessary to obtain the hourly energy consumed by all customers that are fed by a certain Secondary Substation.

Each smart meter communicates and sends hourly reports (S02) that are collected by the concentrator and sent remotely each hour of the day.

Each smart meter is associated to a point of consumption. These points of consumption are associated to one output line. By adding all the energy consumed in a particular hour of all the smart meters associated to one output line and dividing by the total amount of energy consumed in all output lines, it is possible to obtain the energy partition coefficients.

This method is the most accurate but also the most time consuming. It is not simple to obtain at a particular hour, the energy consumed by each of the smart meter associated to one output line. In addition, not all consumers have a smart meter at their house; therefore, it is not possible to obtain the hourly energy consumption of those consumers which do not have a smart meter.

Option 2. Calculation of the hourly **partition coefficient** of each low voltage line from the **contracted power of all the consumers**.

The information available in the database of Gas Natural Fenosa gives also the information of the power contracted [kW] by each client. Therefore, it is also possible to calculate the partition coefficients based on that contracted power.

Following the same methodology as the one explained before, the contracted power of the consumption points associated to the same output line will be added. After adding all the contracted power at each output line, by dividing this result for the total contracted power of all output lines, the partition coefficients will be obtained.

This method is less accurate than the energy partition method because, although the contracted power is an indicator of the amount of energy consumed by each client, there are some cases where the contracted power is not indicative. This occurs, for instance, in the case of second houses or holiday households. In these households, clients are paying for the contracted power but they have no consumption during the year, only on holidays. These cases can distort the results.

The advantage of this method is that it is much simpler to calculate as it is no necessary to look for a certain hour of a particular day, as the contracted power is independent of the hour.

8.4.2.7. RESULTS OF THE APPLICATION

Three Secondary Substations have been selected in order to do an exhaustive study and compare the results of applying both partition coefficients.

The Secondary Substations selected accomplish the following characteristics:

- A unique transformer
- All meters deployed are smart meters
- Low Voltage Supervisor communicates efficiently
- Maintenance Work has been done during the last year (2015)

Comparing the results with both partition coefficients, it will be selected the most appropriate to do a more extent study of Secondary Substations.

8.4.2.7.1. CASE STUDY 1

- **Characteristics**

  The main characteristics of the first Secondary Substation selected are described in the following table:

ID of Secondary Substation	28CBH3
Location	Madrid, Coslada
Type	Cabin
Number of supply points	104
Number of output lines/feeders	4
Date of the Maintenance (Load Handling)	12/09/2015 at 13.58h

Table 4. 28CBH3 Secondary Substation details. Source: Gas Natural Fenosa.

- **Energy Balance**

In order to calculate the energy balance, it is necessary to make use of the information on energy consumed by each smart meter provided by the reports S02.

However, some problems have been faced:

- Three Smart Meter s did not send information of the consumed energy in the date when the maintenance work was done.

- One Smart Meter is not associated to any output line

The solutions proposed to these problems are based on establishing two possible scenarios for these problematic Smart Meters:

- The first possible scenario is based on associating to those Smart Meters that did not send information an amount of energy equal to the average hourly energy calculated from the rest of the SM.

- Due to the high level of losses, a second possible scenario is proposed. This is, to consider that the Smart Meters with no information consume a higher level of energy than the average. This is the scenario that has been considered to calculate the energy balance.

The results of calculating the energy balance are shown in the table below.

ID of Secondary Substation	28CBH3
LV Supervisor	1.435,456 kWh
Smart Meters	1.336,549 kWh
Losses	98907 kWh
	6,89%

Table 5. Energy balance CT 28CBH3, with data from S02 for date 12/09/2015 at 13.58h Own elaboration.

This table shows the total amount of energy registered by the Low Voltage Supervisor in comparison with the sum of energy of all Smart Meters associated to this particular Secondary Substation.

The difference between both values is the losses. In this case, the losses are quite high. In general, in distribution lines, losses should not exceed 7%.

○ Estimation of currents

The estimation of currents has been calculated following the method described previously.

The objective is to estimate the currents that were measured physically, which are shown in the table below.

	Phase		
Output Line	**R**	**S**	**T**
1	5 A	5 A	5 A
2	30 A	25 A	20 A
3	40 A	60 A	85 A
4	10 A	15 A	25 A

Table 6. Currents in Amperes measured the 12/09/2015 at 13:58h. Source: Own elaboration.

It should be noticed that the accuracy of the Current Clamp used to measure is quite low (±5A).

Using the simplifications on the model that were explained before, it has been calculated the partition coefficients taking into account energy consumed and power contracted. They have been compared to the coefficients obtained from the measured currents for each output line.

	Partition Coefficients		
	Load Handling	Power contracted	Energy consumed
Output line 1	4,62%	6,18%	5,92%
Output line 2	23,07%	27,52%	30,46%
Output line 3	56,92%	44,47%	47,97%
Output line 4	15,38%	21,83%	15,94%

Table 7. Partition Coefficients for the 12/09/2015. Own elaboration.

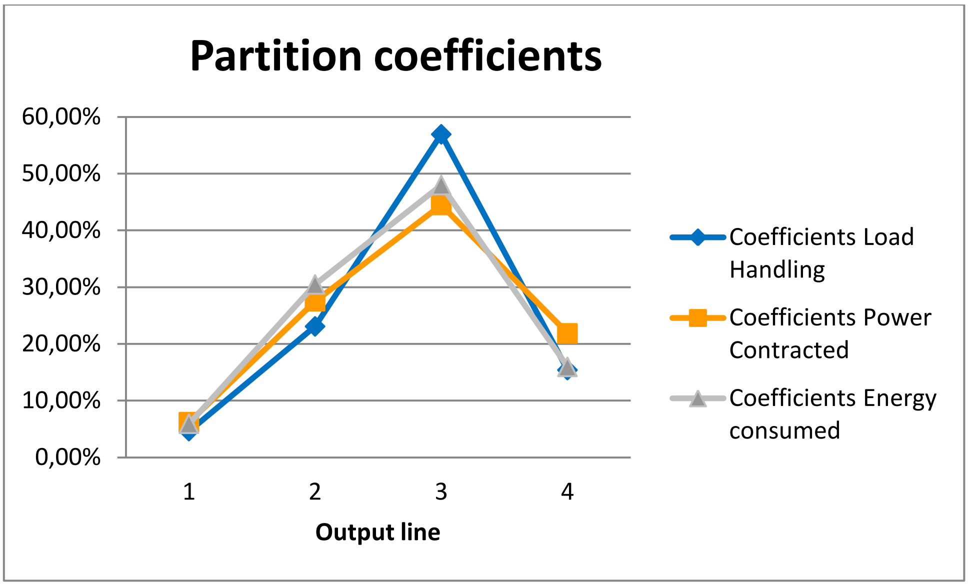


Figure 28. Partition coefficients at each output line for the 12/09/2015. Own elaboration.

The partition coefficients for the Load Handling have been calculating by adding the currents for phase R, S and T of each output line and dividing this sum for the total amount of currents in all output lines (simplified model, additive currents).

As it can be seen in the table and figure above, there are not significant differences among the practical coefficients (Load Handling) and the estimated ones (power contracted and energy coefficients). Although, as it was expected, the energy consumed coefficients are more similar to the measured ones.

The correlation among these coefficients is shown in the following table:

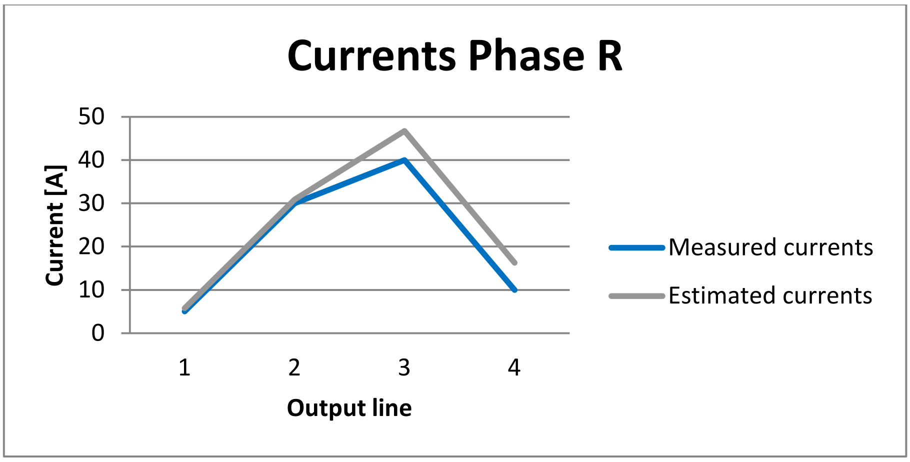
Correlation coefficients among partition coefficients	
Load Handling – Energy consumed	0,967
Power contracted – Energy consumed	0,979
Load Handling – Power contracted	0,962

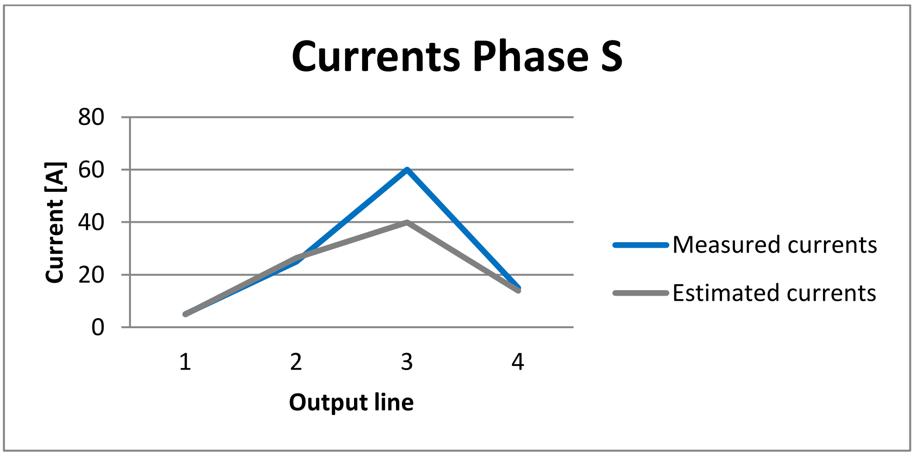
Table 8. Correlation coefficients. Own elaboration.

In this case, as the partition coefficients on energy consumed are more accurate, the estimation of currents per phase at each output line has been calculated with them. After applying the partition coefficients on energy consumed for each output line to the current measured by the Low Voltage Supervisor, the following results are obtained:

	Phase		
	R	S	T
Output line 1	5,8 A	4,9A	5,8 A
Output line 2	30,9 A	26,4 A	31,1 A
Output line 3	46,7 A	39,9 A	46,9 A
Output line 4	16,3 A	13,9 A	16,4 A

Table 9. Estimated currents with energy consumed coefficients. Source: Own elaboration.





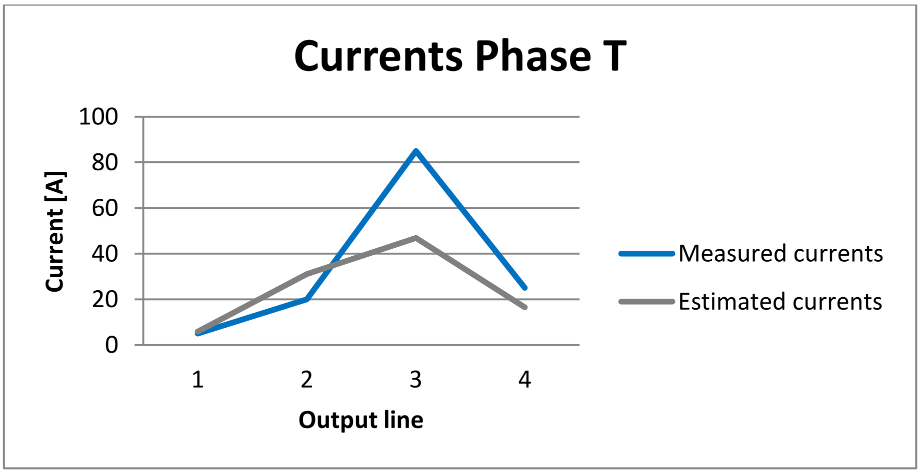


Figure 29. Measured and estimated currents the 12/09/2015. Own elaboration.

In the previous results is observed that the values estimated of electric current for phase and output line do not differ much from the values measured (Load Handling). The major difference can be observed in output 3, being the results obtained for the other output lines very close.

- **Load Handling 02/03/2016**

During the period of internship at Gas Natural Fenosa, the SS 28CBH3 has been visited in order to do a maintenance work and take measures of the currents the 2nd March 2016.

This Secondary Substation is placed in Coslada, in a place with individual households.

The photos taken are shown in the figures below.

Figure 30. Outside and inside of SS 28CBH3. Source: Own elaboration.

Figure 31. Inside of CT 28CBH3. Source: Own elaboration.

Figure 32. Remote Management System ZIV. Source: Own elaboration

Figure 33. Metering of currents with Clamp. Source: Own elaboration.

The measures taken per phase through each output line and at the supervisor side are shown in the following table:

Currents measured at 11.50 h the 02/03/2016				
	R	**S**	**T**	**Neutral**
Supervisor	208,5 A	121 A	208,6 A	
Output line 1	7,5 A	2,3 A	0,6 A	7,2 A
Output line 2	36 A	14 A	60 A	33,9 A
Output line 3	140 A	80 A	133 A	50 A
Output line 4	8,5 A	16,7 A	12,2 A	4,5 A

Table 10. Measured currents. Source: Own elaboration.

Phase T of output line 1 is almost 0 because in this phase the public lightning is connected and, at the moment of the metering, as it was during the day, it was off.

Besides the currents, the voltages have also been measured. The table below shows the voltages:

Simple Voltages		
R	S	T
233V	235 V	233V

Phase to phase voltages		
RS	ST	RT
405 V	405,2 V	402 V

Table 11. Measured voltages. Source: Own elaboration.

As it can be observed, the values measured do not differ much from the low voltage nominal value (230V phase-neutral, 400V phase to phase).

- ### Estimation of currents

The results of estimating the currents per phase using both types of partition coefficients are shown below.

The results of the measured currents through Low Voltage output lines per phase and the estimated currents applying both coefficients are shown in the figures below.

	Estimation of currents applying Energy consumed partition coefficients			Estimation of currents applying contracted power partition coefficients		
Phase	**R**	**S**	**T**	**R**	**S**	**T**
Current Low Voltage Supervisor	**205,9 A**	**133,1 A**	**207,2 A**	**205,9 A**	**133,1 A**	**207,2 A**
Output line 1	6,7 A	4,3 A	6,7 A	12,7 A	8,2 A	12,8 A
Output line 2	73,4 A	47,4 A	73,8 A	56,7 A	36,6 A	57,0 A
Output line 3	101,4 A	65,5 A	102,0 A	91,6 A	59,2 A	92,1 A
Output line 4	24,5 A	15,8 A	24,6 A	44,9 A	29,1 A	45,2 A

Table 12. Estimation of currents for 02/03/2015 from 11-12h. Own elaboration.

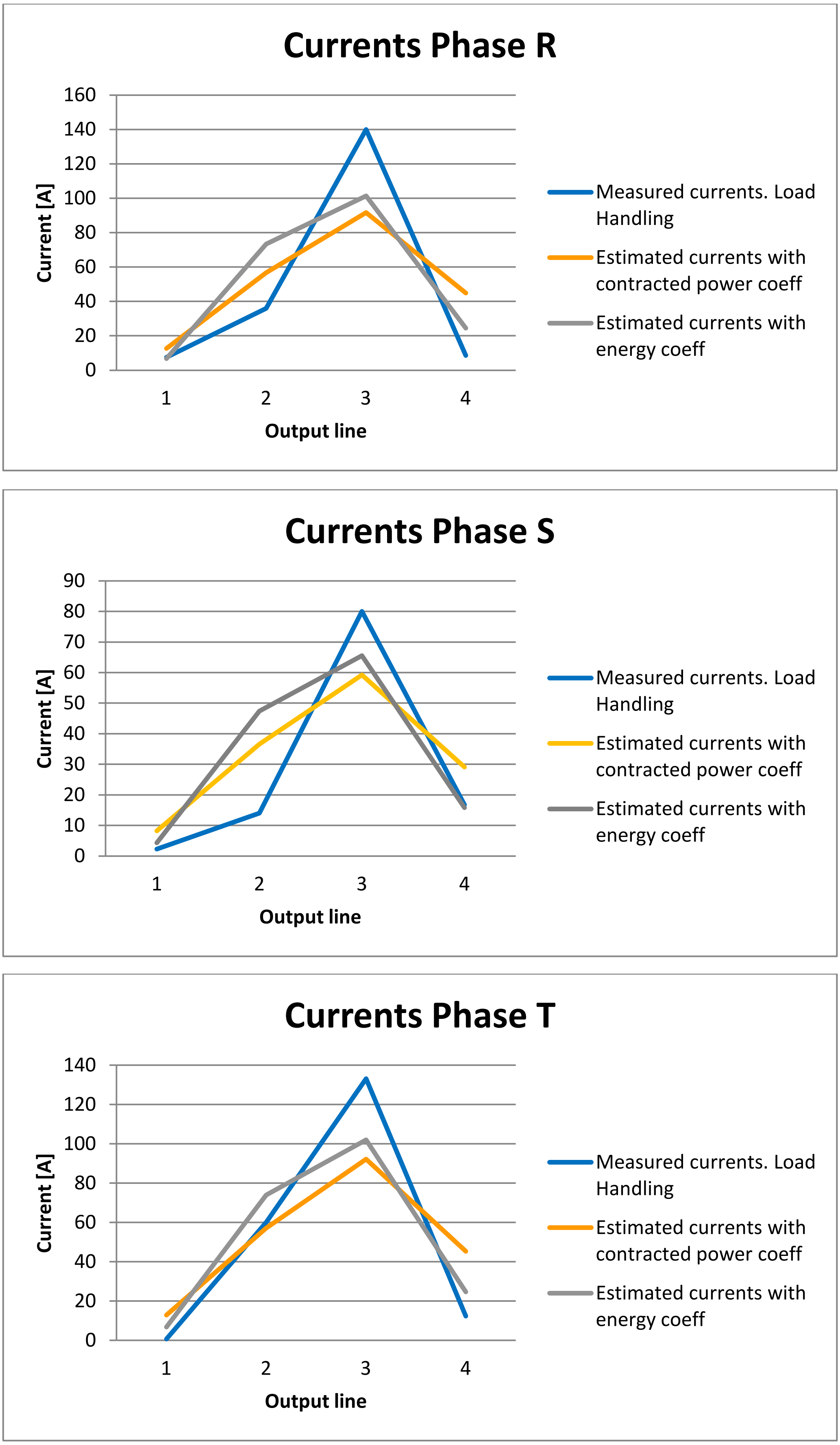


Figure 34. Measured and Estimated Currents the 12/09/2015. Own elaboration.

The figures above show the results of the estimated currents per phase in each line. They have been compared to the measured values. It is important to remind that all calculations have been done according to the data for the date where the maintenance was done 02/03/2016. As it can be seen, the results of the estimations are very similar to the measured ones. The higher error occurs at output line 3, due to the volatility of the current that is measured. The results applying the power contracted coefficients and energy coefficients are quite similar, though the ones obtained with the energy coefficients are slightly more accurate.

8.4.2.7.2. CASE STUDY 2

- **Characteristics**

The main characteristics of the first Secondary Substation selected are described in the following table:

ID of Secondary Substation	28CBE5
Location	Madrid
Type	Cabin
Number of supply points	105
Number of output lines/feeders	3
Date of the Maintenance (Load Handling)	02/03/2016 from 10.30 a.m. to 11 a.m.

Table 13. 28CBE5 Secondary Substation details. Source: Gas Natural Fenosa.

The 2nd March 2016, there has been a visit to this Secondary Substation in order to measure the currents and to compare them with the estimated ones.

- **Energy Balance**

There has been calculated energy balance for the day where the maintenance took place. The results are shown in the table below.

With data from S02 for: 02/03/2016	
LV Supervisor	766,598 kWh
Smart Meters	757,879 kWh
Losses	8,719 kWh
	1,14%

Table 14. Energy balance SS 28CBE5. Own elaboration

This table shows the total amount of energy registered by the Low Voltage Supervisor in comparison with the sum of energy of all Smart Meters associated to this particular Secondary Substation.

The difference between both values is the losses. In this case, the losses are very low.

- ## Load Handling 02/03/2016

The 2nd March 2016, during Internship at Gas Natural Fenosa, this Secondary Substation was visited in order to measure the currents and voltages to compare to the estimated ones. The pictures taken to it are shown in the figures below. The Transformer characteristics are: 400 KVA and transformation ratio 1000/5.

Figure 35. Cells of 28CBE5 Secondary Substation. Source: Own elaboration.

Figure 36. Low Voltage output lines/feeders. Source: Own elaboration.

Figure 37. Transformer. Source: Own elaboration.

- **Measured currents and voltage**

The currents measured by the maintenance crew at the supervisor side is shown in table 15. The currents measured in the feeders/output lines are shown in table 16.

Voltage phase to phase	RS	ST	RT
	410 V	409,3 V	406,3 V

Supervisor		Phase	
Time of measure	**R**	**S**	**T**
10:30h	26,5 A	59,8 A	61,4 A
10:55h	52 A	51 A	56 A

Table 15. Currents measured de 02/03/2016 at 10:30h. Source: own elaboration.

		Phase		
Output Line	**R**	**S**	**T**	**Neutral**
1	9,5 A	8,5 A	21,5 A	12 A
2	11 A	28,3 A	27,6 A	22,4 A
3	6 A	9,2 A	6,8 A	5,1 A

Table 16. Currents in Amperes measured the 02/03/2016 at 10:35h. Source: Own elaboration

Voltages have also been measured, to verify that they are inside limits. These measured are shown in table 17.

Voltage phase-neutral		Phase	
	R	**S**	**T**
	235,7 V	237 V	235,3V

Table 17. Measured voltage. Source: Own elaboration.

It is verified that the voltage is inside limits (230/400V).

- **Estimation of currents**

The estimation of currents has been calculated following the method described previously.

The objective is to estimate the currents that were measured physically.

Using the simplifications on the model that were explained before, it has been calculated the partition coefficients taking into account energy consumed and contracted power. They have been compared to the coefficients obtained from the measured currents for each output line.

	Partition Coefficients		
	Load Handling	Power contracted	Energy consumed
Output line 1	30,8%	40,98%	40,3%
Output line 2	52,1%	40,32%	40,3%
Output line 3	17,1%	18,70%	19,4%

Table 18. Partition Coefficients for the 02/03/2016. Own elaboration.

During the Load Handling Maintenance, an error was detected. The transformation ratio is registered wrongly in the database of Gas Natural Fenosa. In the database, it appears to be a 600/5 ratio transformer but indeed it is a 1000/5 ratio transformer. In addition, in the S02 reports that give information of energy consumed, the energy consumed by the supervisor appears to be negative (exported energy) instead of importing energy, that is the coherent solution. This indicates that there is probably a mistake in the connection of the phases in this Secondary Substation.

These errors distort the results. As it can be seen in table 19, there are significant differences between the coefficients for output line 1 and 2, maybe due to an association error of phases and output lines to supply points.

After applying the partition coefficients on energy consumed for each output line to the current measured by the **Low Voltage** Supervisor, the following results are obtained:

	Currents estimated with Energy coefficients			Currents estimated with Power contracted coefficients		
	R	S	T	R	S	T
Low Voltage Supervisor	**26,9 A**	**30,0 A**	**39,4 A**	**26,9 A**	**30,0 A**	**39,4 A**
Output line 1	10,8 A	12,1 A	15,9 A	11,0 A	12,3 A	16,2 A
Output line 2	10,8 A	12,1 A	15,9 A	10,8 A	12,1 A	15,9 A
Output line 3	5,2 A	5,8 A	7,7 A	5,0 A	5,6 A	7,4 A

Table 19. Estimation of currents for 02/03/2016from 10-11h. Own elaboration.

The results from table 20 are represented in the figures below.

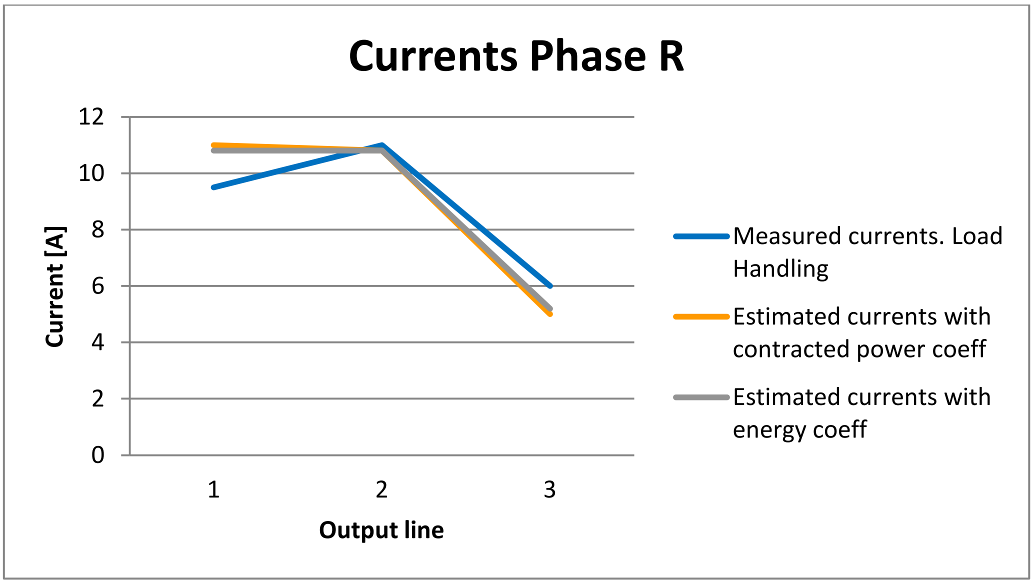


Figure 38. Measured and estimated currents phase R for 02/03/2016 from 10-11h. Source: Own elaboration.

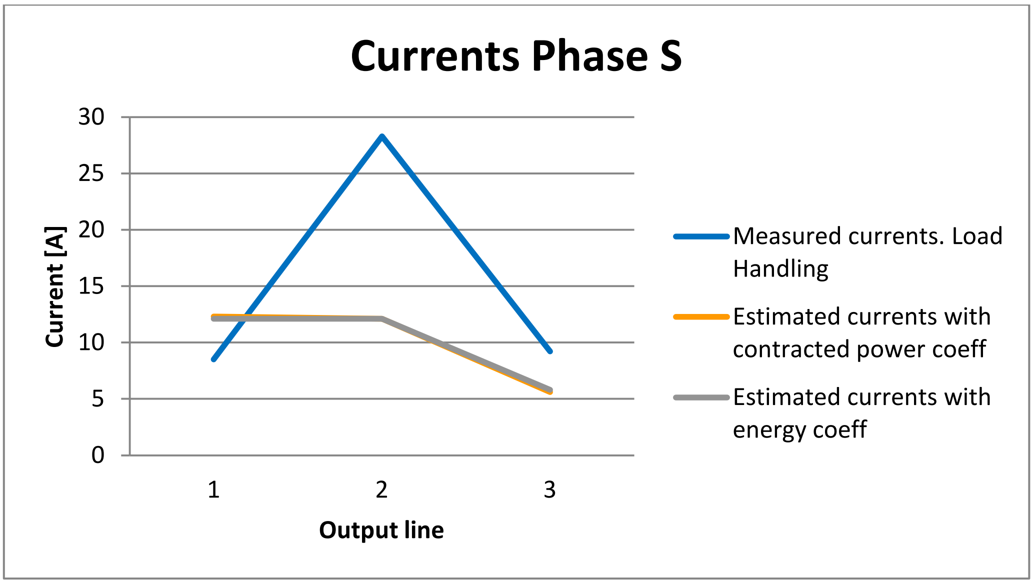


Figure 39. Measured and estimated currents phase S for 02/03/2016 from 10-11h. Source: Own elaboration.

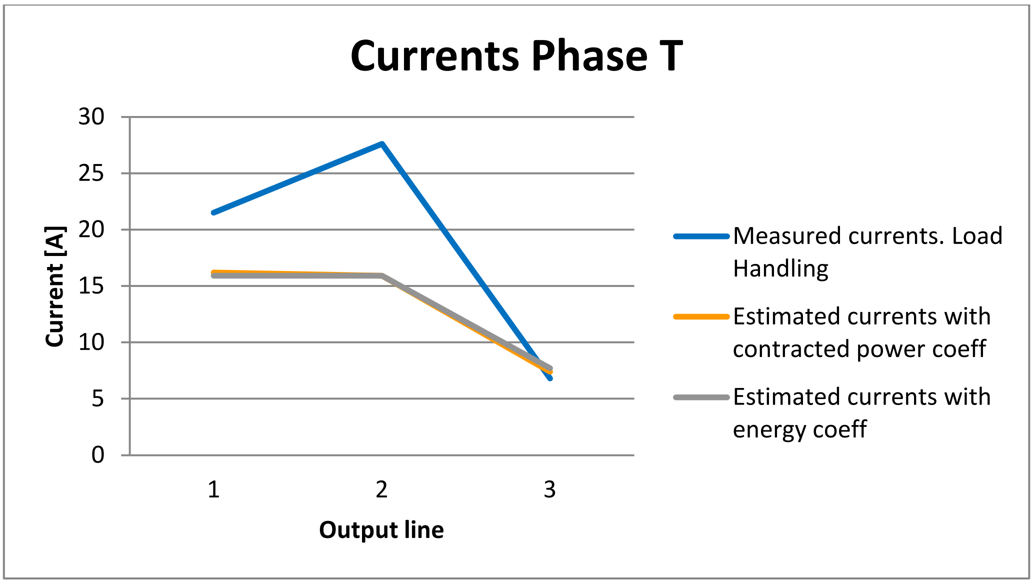


Figure 40. Measured and estimated currents phase T for 02/03/2016 from 10-11h. Source: Own elaboration.

It can be observed that the results obtained of estimated currents applying energy and contracted power coefficients are very similar (they overlap in the previous figures) being very close to the measured currents during the Load Handling.

The results that differ the most occur in output line 2. This can be explained by the great variability that the current suffers in time.

It is important to consider that the **estimations** take the **mean value at that hour** (10-11h) because the information provided by the reports of consumption are hourly reports and the **measured currents** in Load Handling are taken **at one particular moment** in that hour, so clearly, the results should have some differences but the estimations represent a good approximation.

8.4.2.7.3. Case Study 3

- **Characteristics**

The main characteristics of the first Secondary Substation selected are described in table 13.

ID of Secondary Substation	28CBH5
Location	Madrid
Type	Cabin
Number of supply points	113
Number of output lines/feeders	8
Date of the Maintenance (Load Handling)	02/03/2016 from 12-13h

Table 20. 28CBH5 Secondary Substation details. Source: Gas Natural Fenosa.

The Load Handling was done during Internship at Gas Natural Fenosa the 2nd March 2016 in order to measure the currents and to compare them with the estimated currents.

- **Energy Balance**

It has been calculated the energy balance with the information provided by reports S02 that register energy consumed from smart meters and supervisor associated to this Secondary Substation for the period 09/09/2015 to 12/09/2015. This energy balance serves to verify the reliability of the obtained results and the correct association between output lines and supply points.

The results are shown in the table below.

Energy Balance with data from S02 for: 09/09/2015 to 12/09/2015				
Date	**09/09/2015**	**10/09/2015**	**11/09/2015**	**12/09/2015**
Total active power Smart Meters (Wh)	1485782	1422276	1381468	1380050
Total active power Supervisor (Wh)	1596008	1623134	1588587	1564237
Losses (W*h and %)	110226	200858	207119	184187
	6,91%	12,37%	13,04%	11,77%

Table 21. Energy balance CT 28CBH5. Own elaboration

This table shows the total amount of energy registered by the Low Voltage Supervisor in comparison with the sum of energy of all Smart Meters associated to this particular Secondary Substation.

The difference between both values is the losses. In this case, the losses are quite high.

- **Load Handling 02/03/2016**

Wednesday 2nd March 2016, this Secondary Substation was visited in order to do a Load Handling. It is placed in Coslada (Madrid) in a zone with residential houses.

The transformer characteristics are: 630 KVA and transformation ratio 1000/5.

This Secondary Substation is quite old so it has been impossible to measure the currents in the supervisor side.

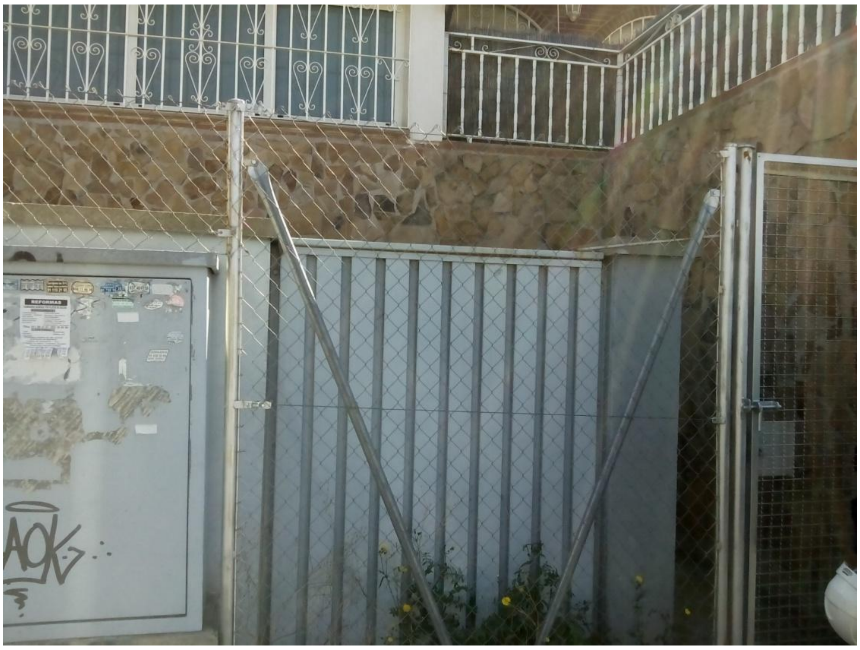


Figure 41. Outside of Secondary Substation 28CBH5. Source: Own elaboration.

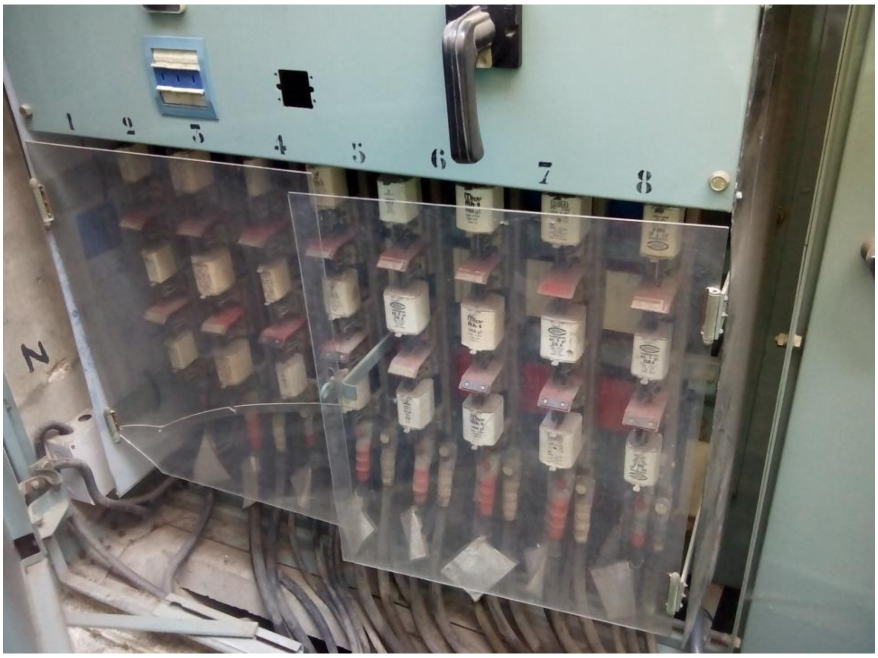


Figure 42. Output lines/feeders. Source: Own elaboration.

Figure 43. Remote control devices ZIV. Source: Own elaboration.

- ### Measured currents and voltage

The currents measured in the feeders/output lines are shown in table 22.

Currents measured at 12.30h the 02/03/2016				
	R	**S**	**T**	**Neutral**
Output line 1	0 A	0 A	0 A	0 A
Output line 2	1,6 A	40,6 A	38,7 A	26 A
Output line 3	4,5 A	1,5 A	1,8 A	9,1 A
Output line 4	23,7 A	21,8 A	25,4 A	6,7 A
Output line 5	3,9 A	33,5 A	11,5 A	39
Output line 6	24,9	5,8	12,8	16,2
Output line 7	13,7	5,3	4	3
Output line 8	23,5	25,7	21,5	9,3

Table 22. Currents in Amperes measured the 02/03/2016. Source: Own elaboration.

Output line 1 has zero current because if the feeder associated to public lighting that, at the moment of measuring the currents, was turned off.

Voltages have also been measured, to verify that they are inside limits. These measured are shown in table 23.

Voltage phase-neutral	Phase		
	R	**S**	**T**
	233,7 V	234,7 V	236,6 V

Voltage phase to phase	**RS**	**ST**	**RT**
	405,2 V	408 V	407,9 V

Table 23. Measured voltage. Source: Own elaboration.

It is verified that the voltage is inside limits (230/400V).

- ### Estimation of currents

The estimation of currents has been calculated following the method described previously.

The objective is to estimate the currents that were measured physically.

Using the simplifications on the model that were explained before, it has been calculated the partition coefficients. In this case it is also taken into account the energy consumed partition coefficient.

Partition coefficients		
	Load Handling	Energy consumed
Output line 1	0,00%	0,0%
Output line 2	23,50%	15,5%
Output line 3	2,12%	6,4%
Output line 4	20,59%	24,4%
Output line 5	14,20%	17,5%
Output line 6	12,37%	4,4%
Output line 7	6,68%	4,1%
Output line 8	20,53%	27,7%

Table 24. Partition Coefficients for the 02/03/2016. Own elaboration.

After applying the partition coefficients on energy consumed for each output line to the current measured by the **Low Voltage** Supervisor, the following results are obtained:

	Currents estimated with Energy coefficients		
	R	S	T
Low Voltage Supervisor	**121,8 A**	**162,8 A**	**99,5 A**
Output line 1	0,0 A	0,0 A	0,0 A
Output line 2	18,9 A	25,3 A	15,5 A
Output line 3	7,8 A	10,4 A	6,4 A
Output line 4	29,7 A	39,6 A	24,2 A
Output line 5	21,3 A	28,5 A	17,4 A
Output line 6	5,4 A	7,2 A	4,4 A
Output line 7	5,0 A	6,7 A	4,1 A
Output line 8	33,7 A	45,1 A	27,5 A

Table 25. Estimation of currents for 02/03/2016 from 12-13h. Own elaboration.

The results of the estimated currents per phase and per output lines estimated for the 02/03/2016 from 12h to 13h are shown in the figures below.

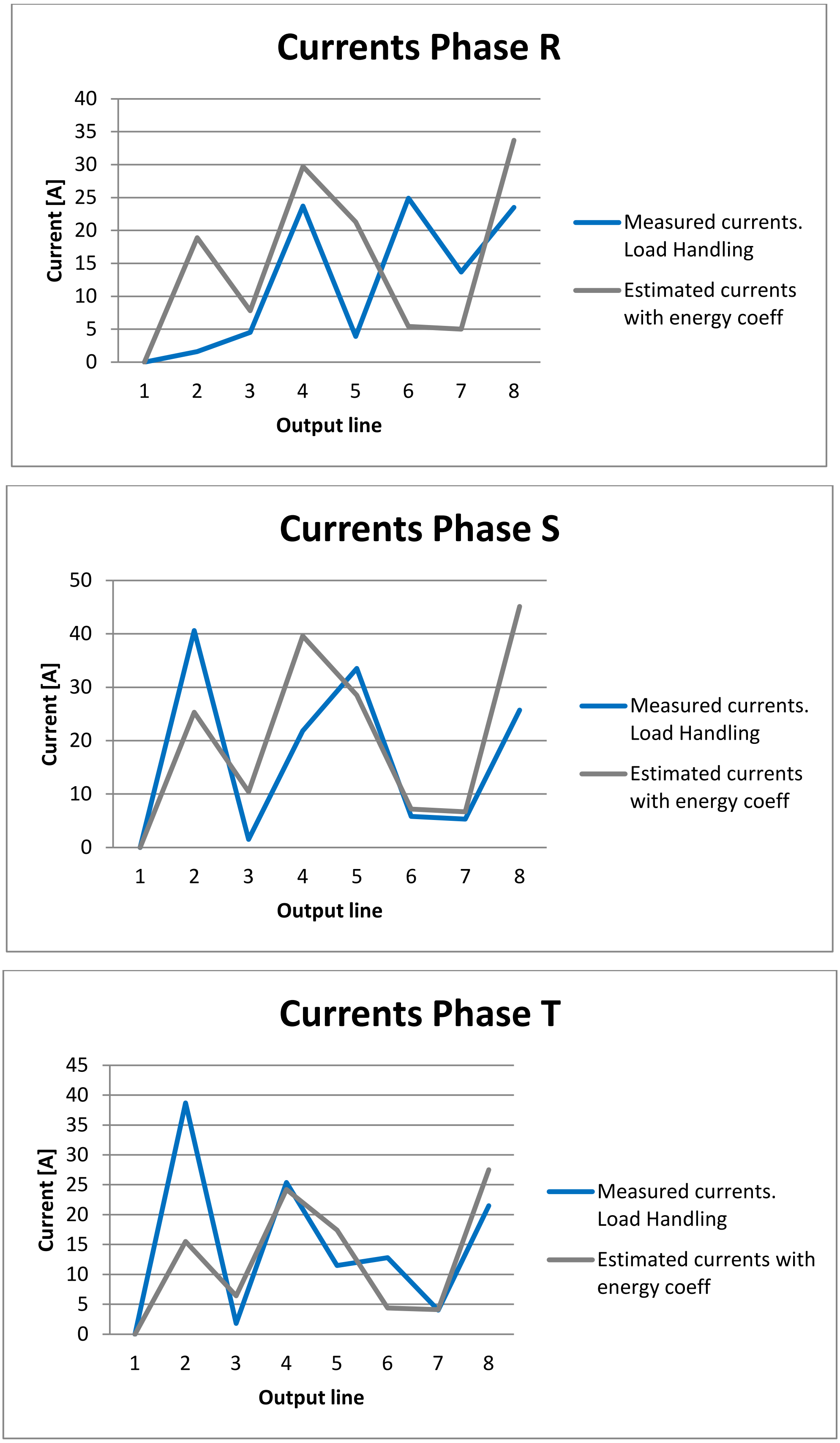


Figure 44. Measured and estimated currents phase R, S, T for 02/03/2016 from 12-13h.

As it can be observed in the figures below, the estimated values and measured are similar. Results from phase S and T are more similar than those of phase R.

After having analyzed in detail three Secondary Substations, some conclusions can be extracted:

- The simplified model represents a good approximation to the measured values of the currents.

- Among the two options to estimate the currents (contracted power coefficients and energy consumption coefficients), the methodology that applies the contracted power coefficients is the most appropriate because it is much easier and fast to be developed than the energy consumption coefficients, the calculation of coefficients is much simpler and the results are very similar compared to the most complex methodology that is applying energy coefficients.

Due to these conclusions, the methodology will be expanded to a wider sample of Secondary Substations, applying the methodology of estimation with contracted power coefficients.

8.4.2.7.4. CASE STUDY 4

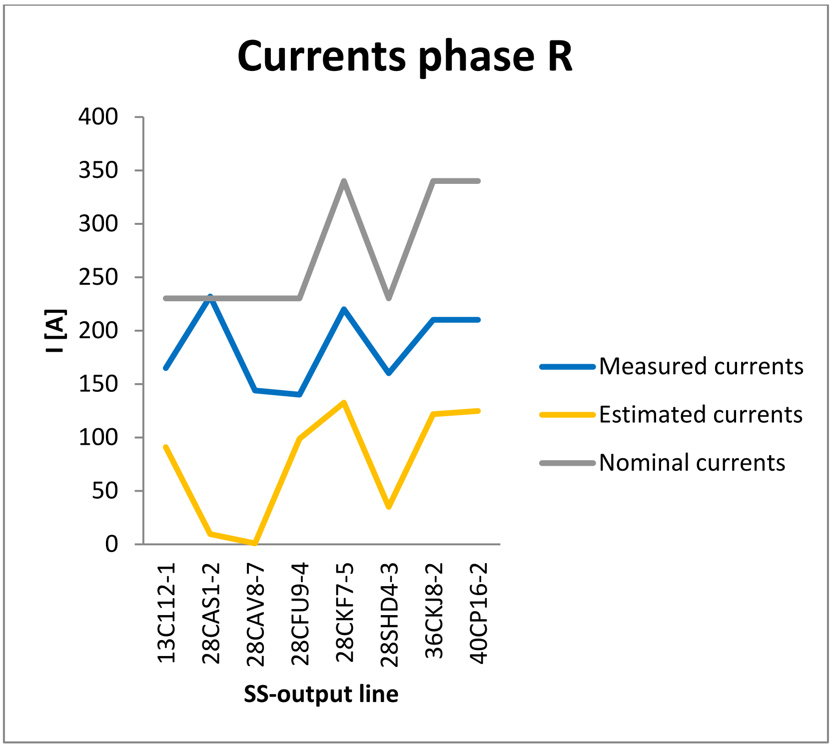
A **sample of 250 Secondary Substations** has been analyzed. In this case, the following calculations were made:

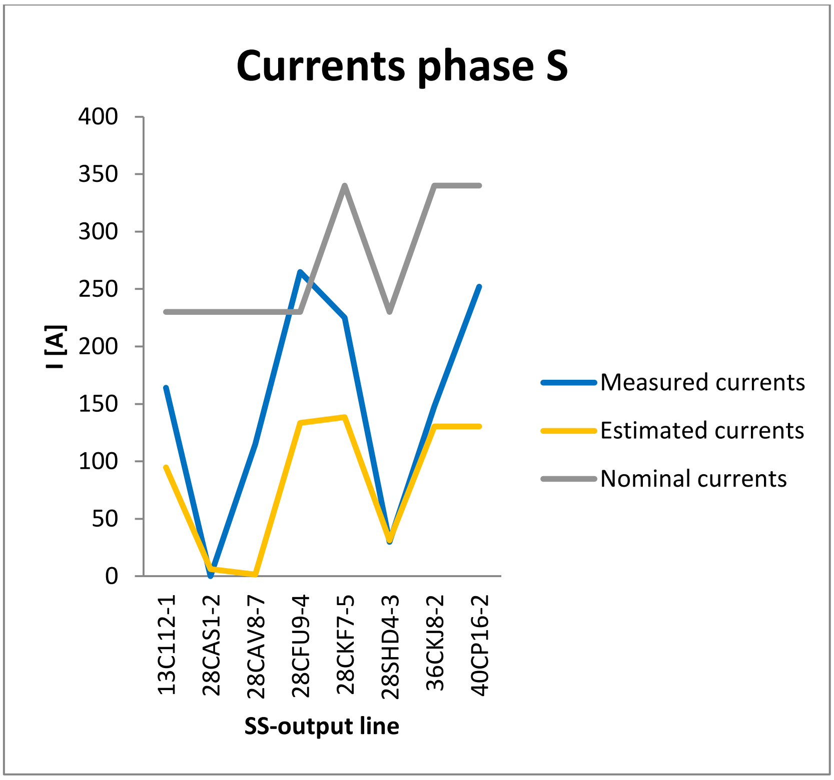
- Estimation of the currents applying the power contracted coefficients per output line and per phase of each Secondary Substation
- Calculation of the maximum nominal current (per output line and per phase of each Secondary Substation according to the type of material of the cable (aluminum or cooper) and its section.

Once these calculations are made, the results were grouped according to the differences among the measured and estimated values of the currents and the nominal values.

The results of the groups are described below.

I. **Group with measured and estimated currents close to the nominal value (differences < 40% of I $_{nominal}$).** There are in total 8 output lines of SS in the sample that has been studied.





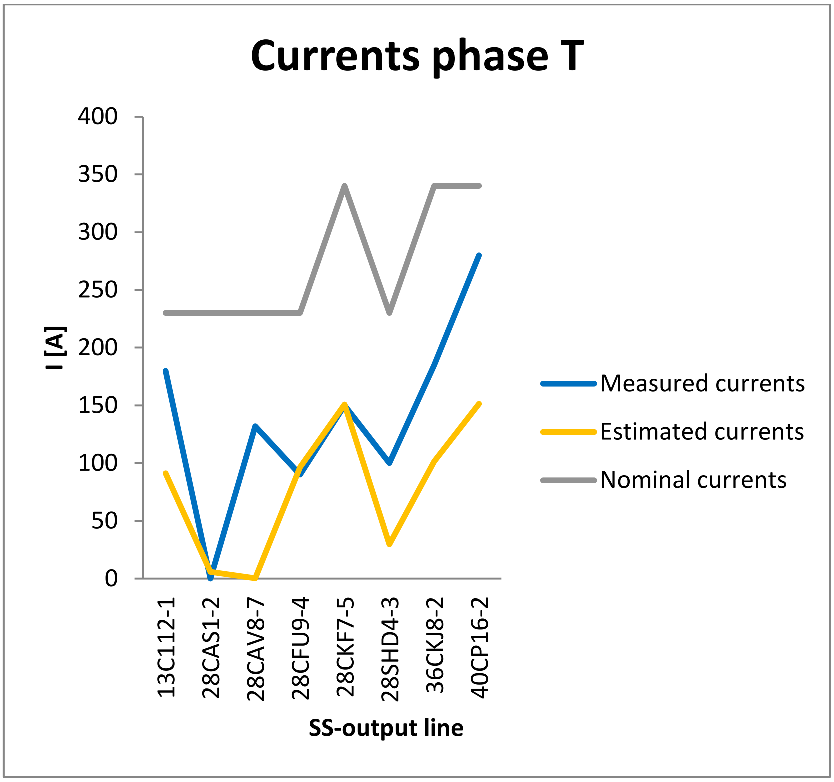
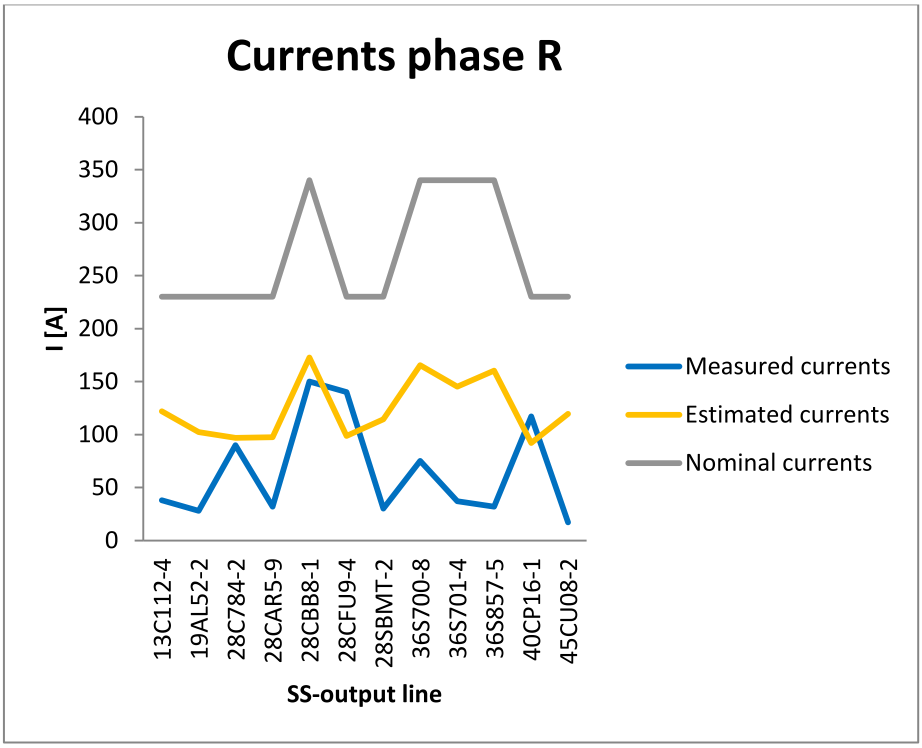
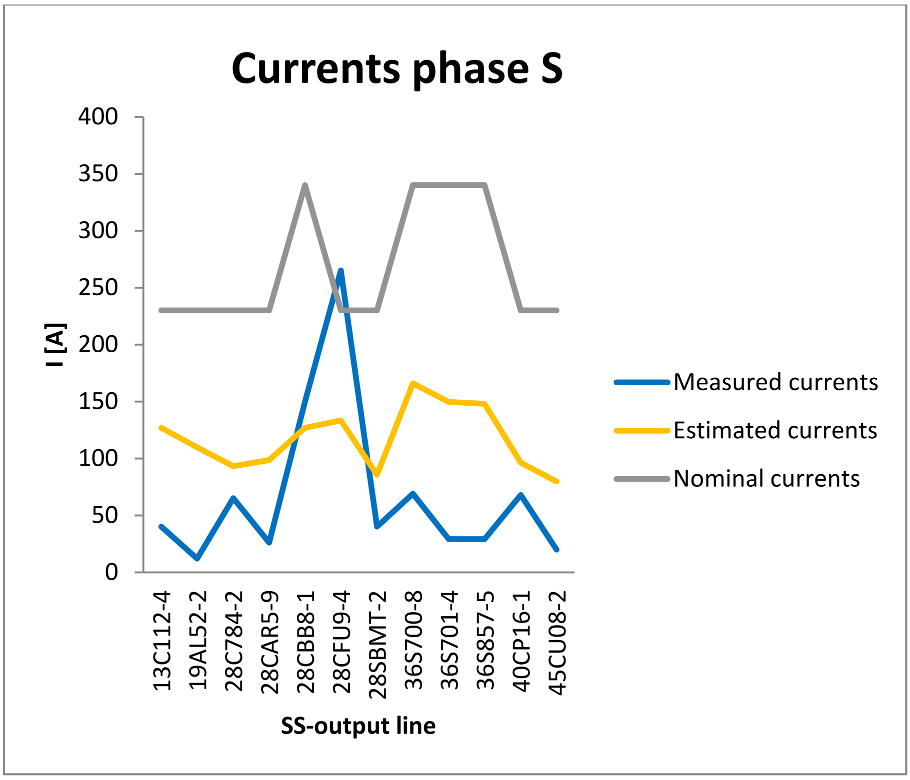


Figure 45. Measured, estimated and nominal current. Source: Own elaboration.

II. **Group with measured and estimated currents lightly close to the nominal value (40%<differences> 60%).** In total there are 12 output lines.





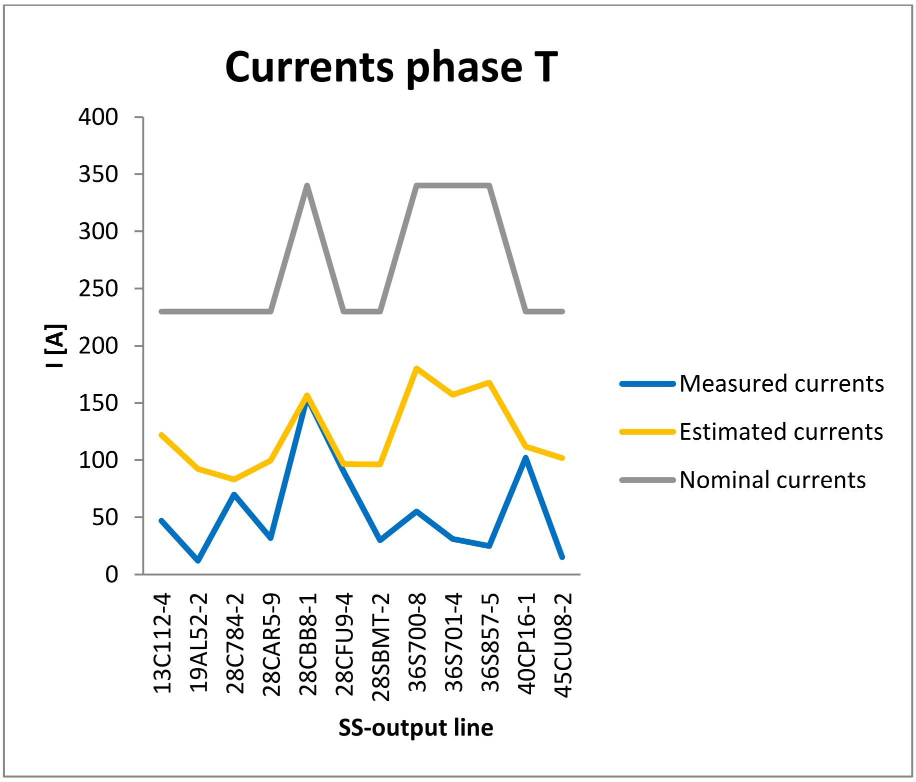
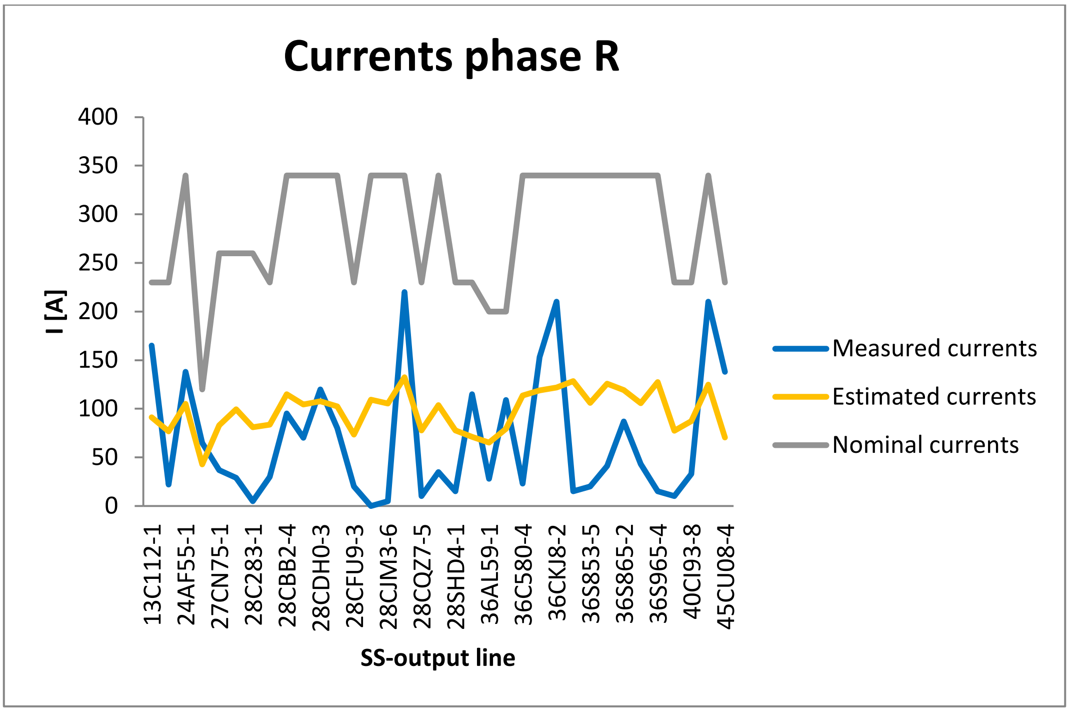
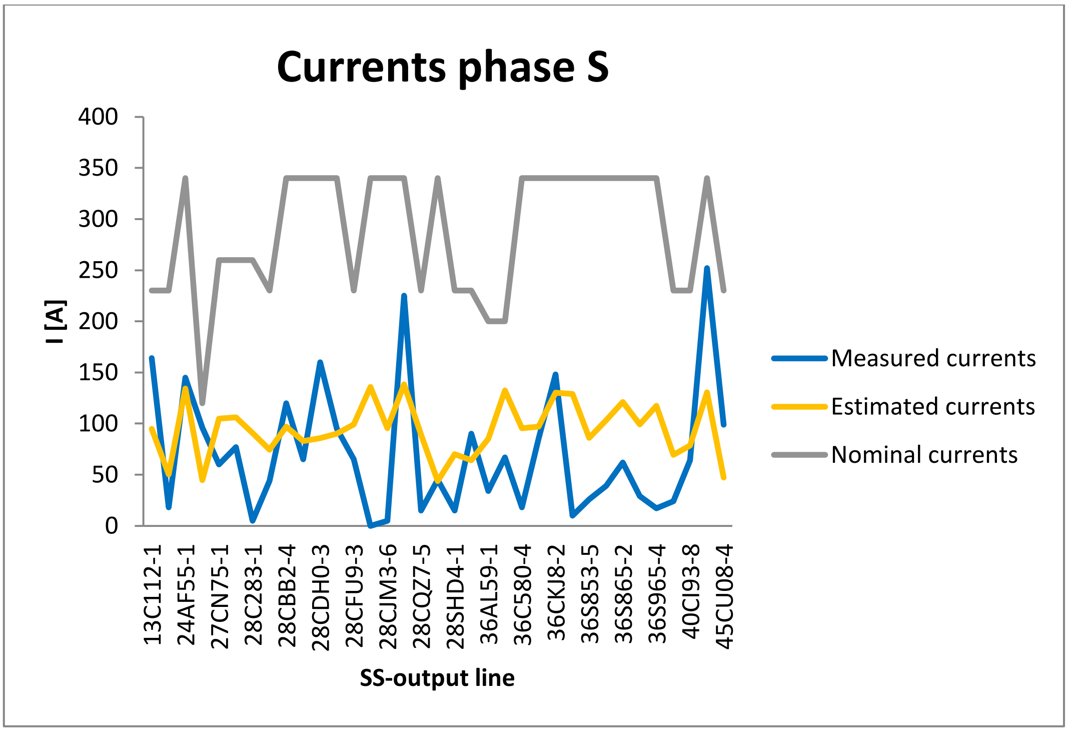


Figure 46. Measured, estimated and nominal current. Source: Own elaboration.

III. **Group with differences among measured and estimated currents and nominal value current in the range of (60%<differences>70%).** In total there are 35 output lines.





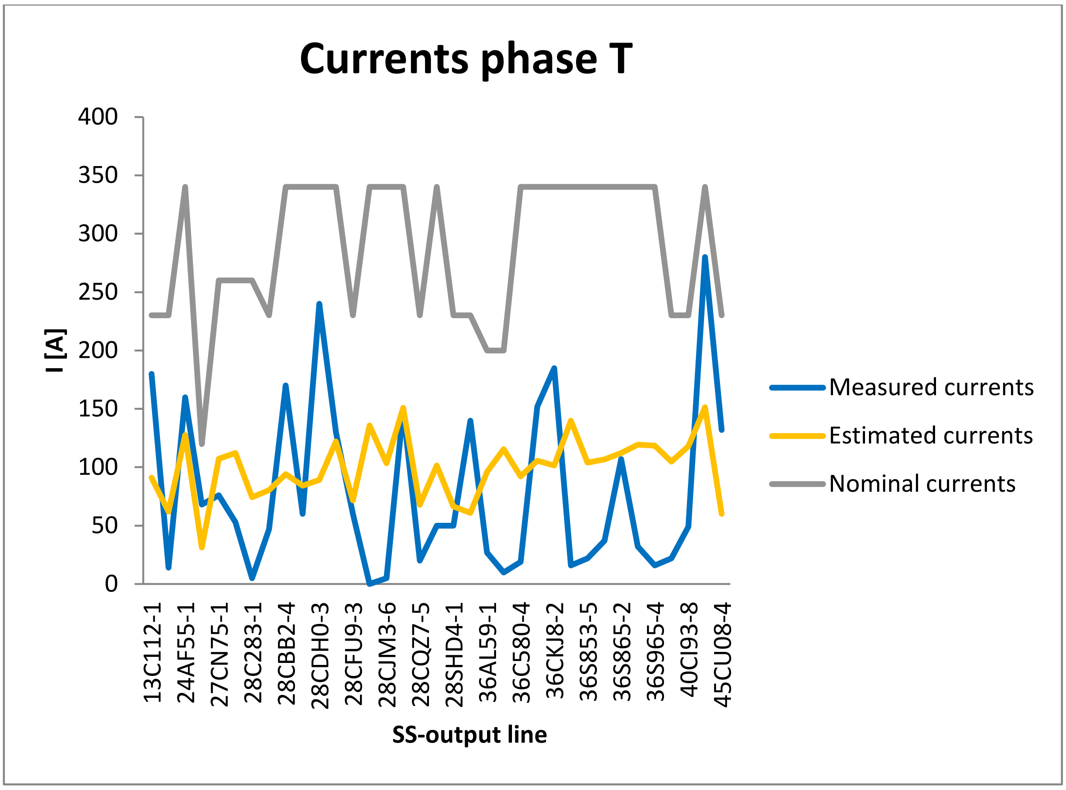
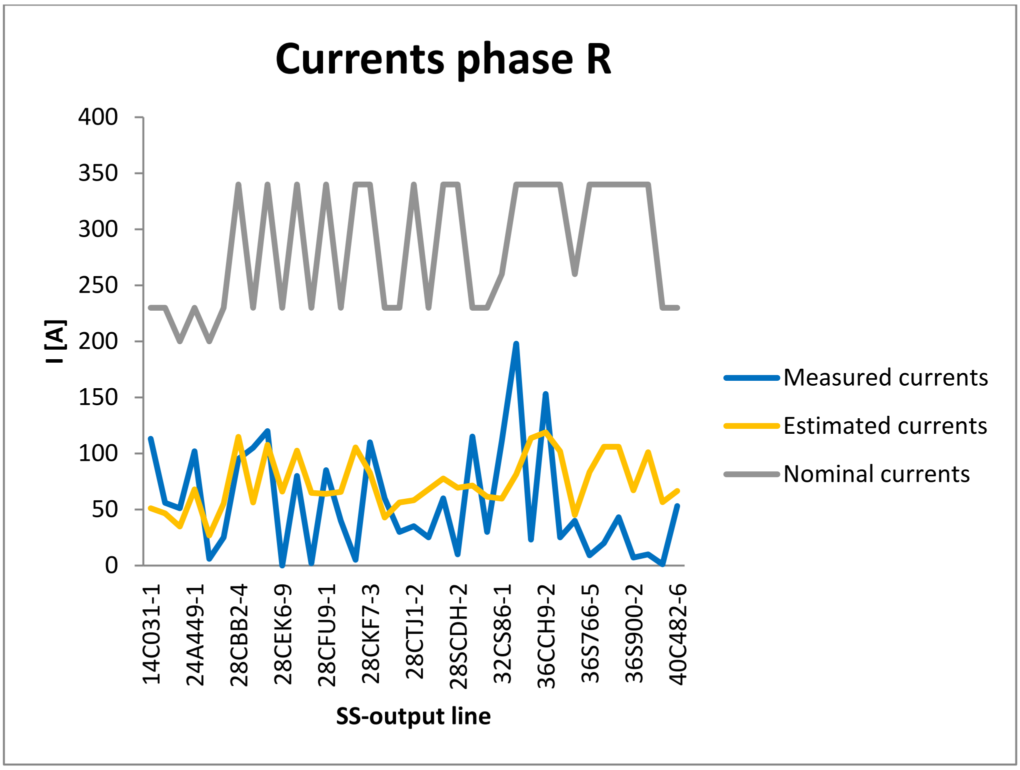


Figure 47. Measured, estimated and nominal current. Source: Own elaboration.

IV. **Group with differences among measured and estimated currents and nominal value current in the range of (70%<differences>75%).** In total there are 37 output lines.



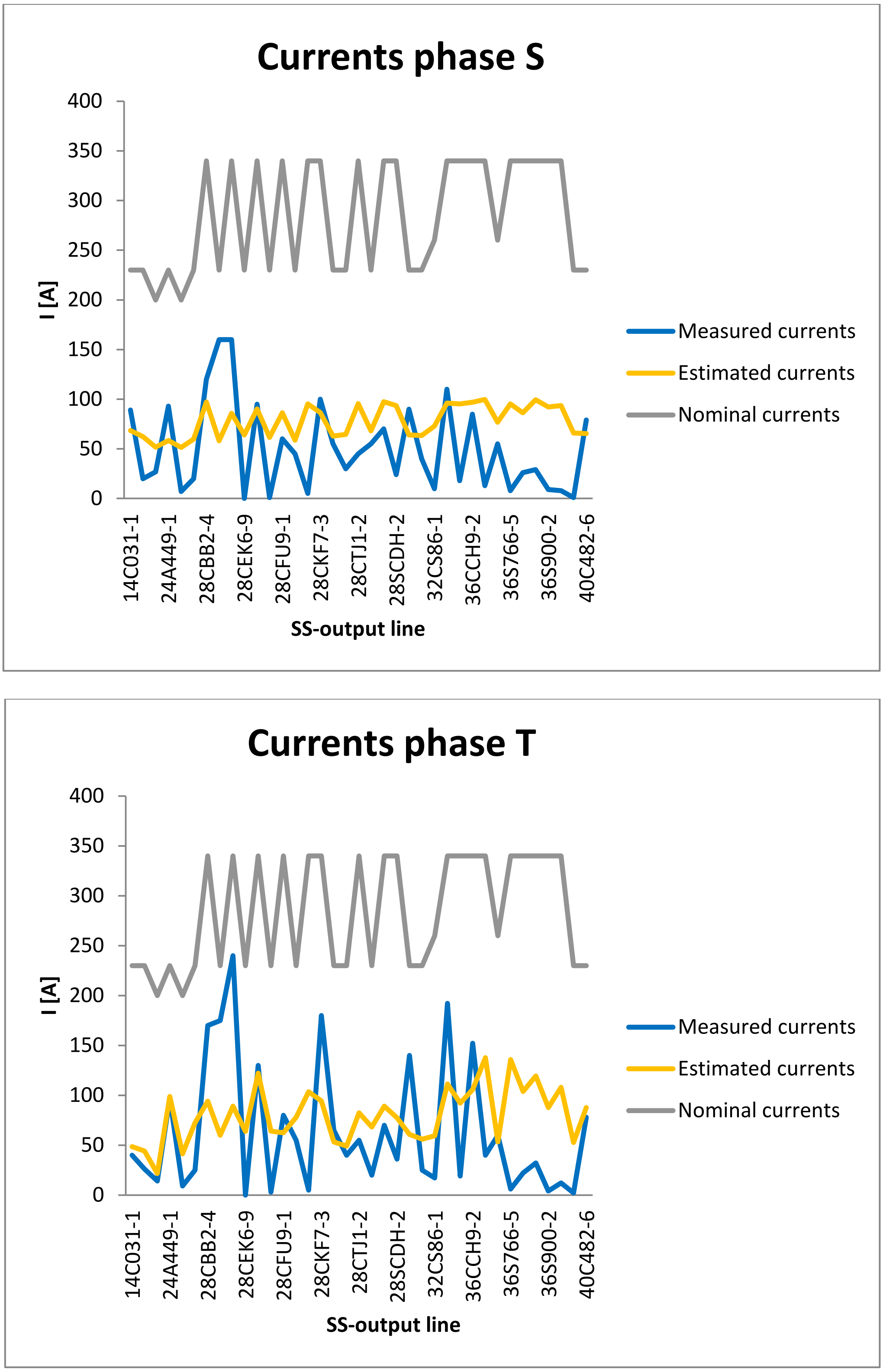
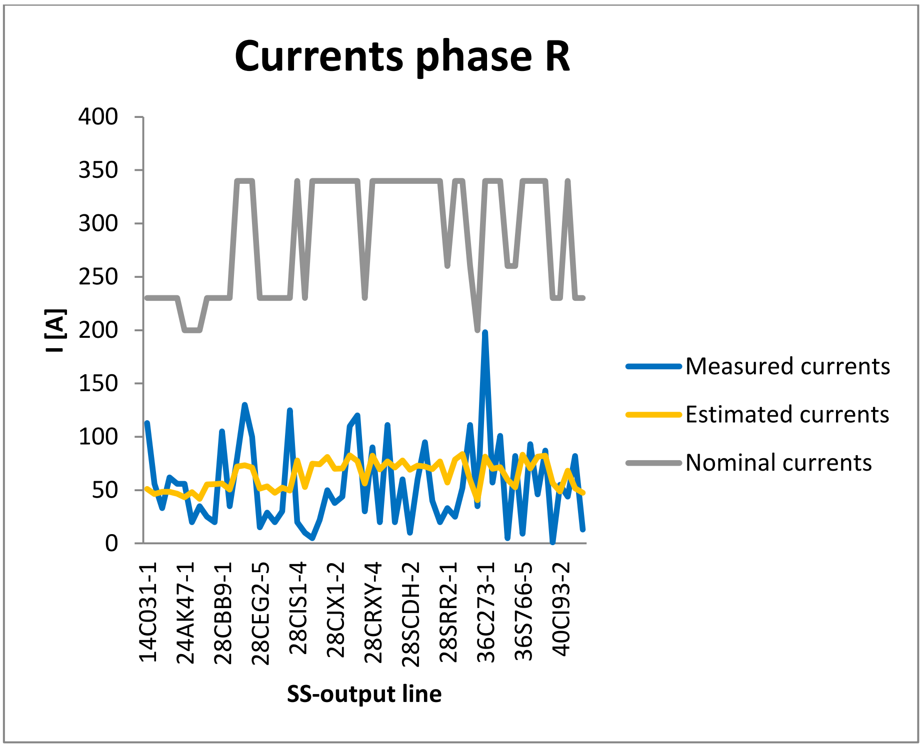
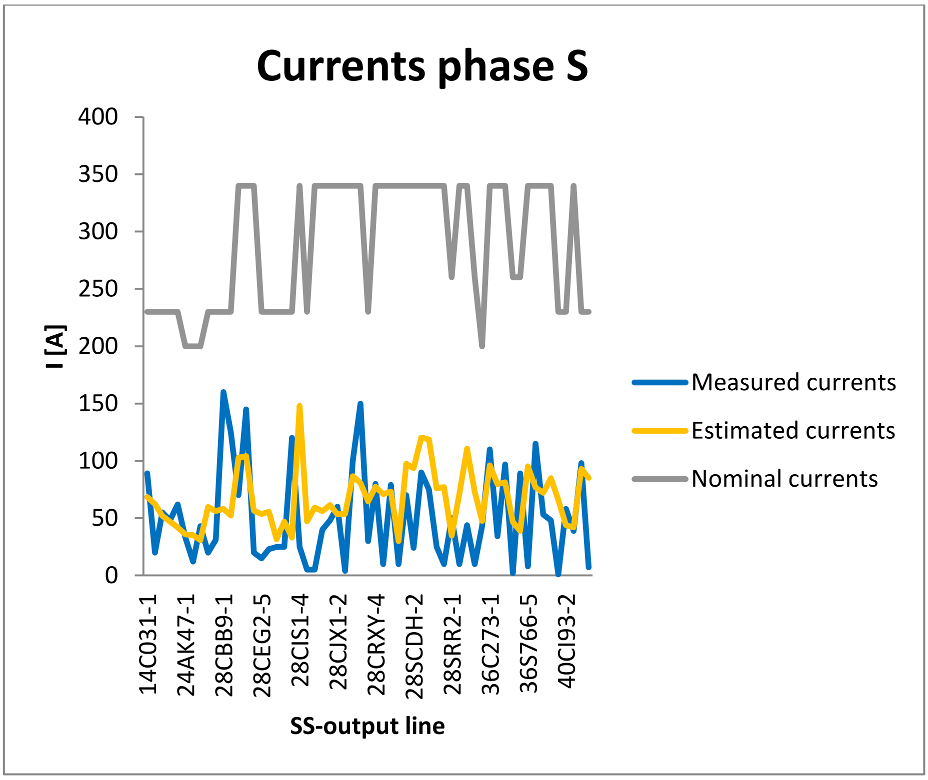


Figure 48. Measured, estimated and nominal current. Source: Own elaboration.

V. **Group with differences among measured and estimated currents and nominal value current in the range of (75%<differences>80%).** In total there are 60 output lines. Some of those output lines are shown in the following figures.





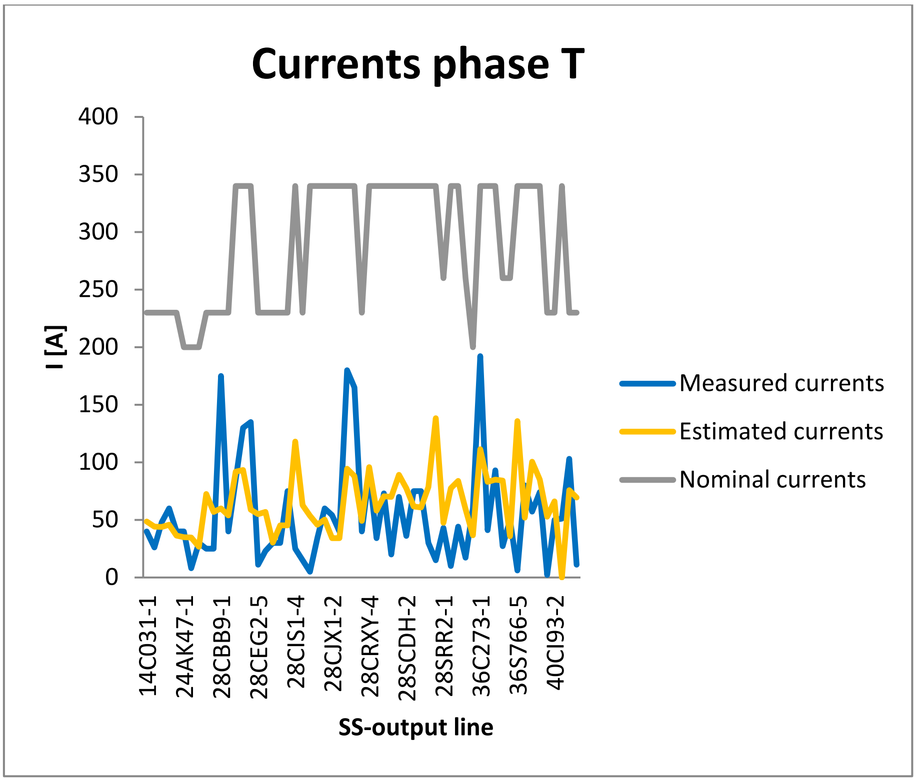


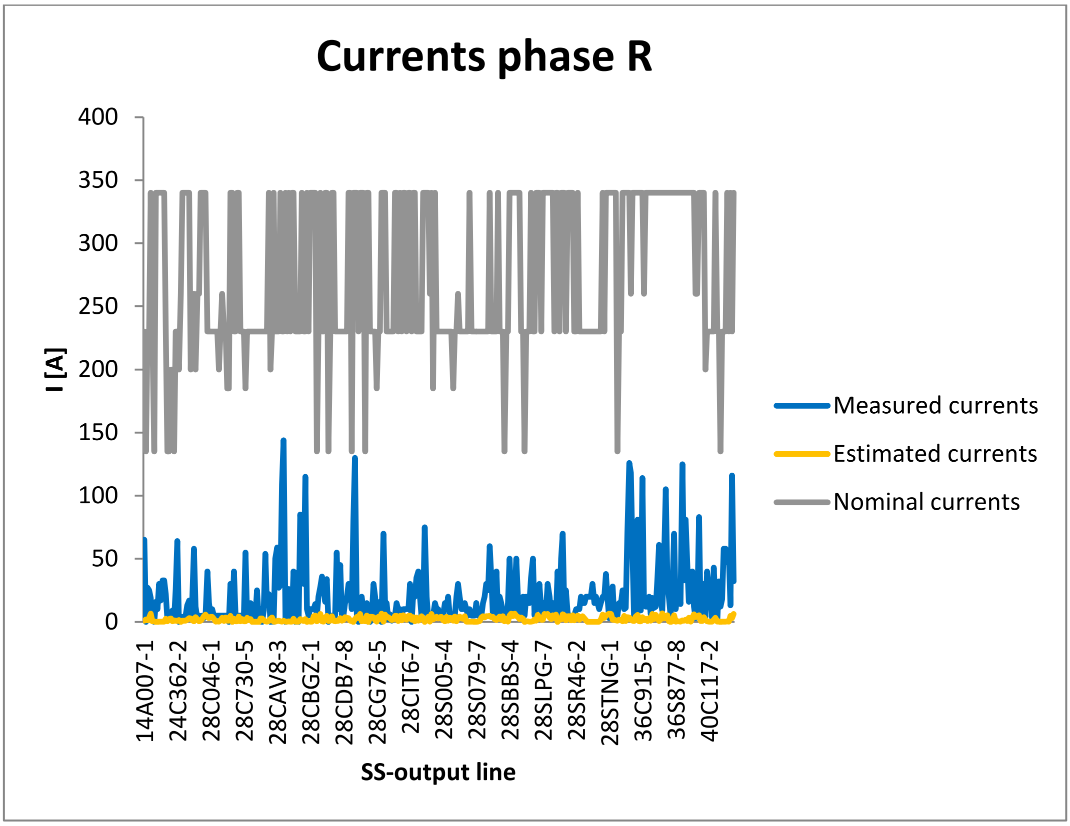
Figure 49. Measured, estimated and nominal current. Source: Own elaboration.

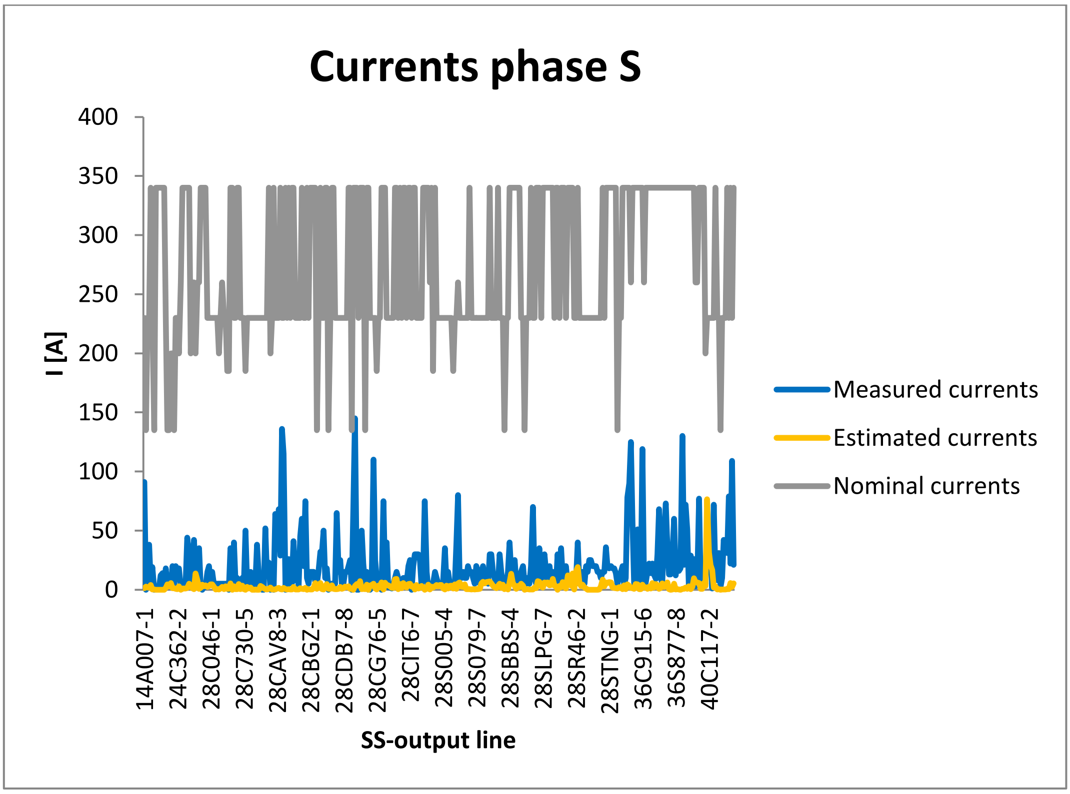
VI. **Group with differences among measured and estimated currents and nominal value current in the range of (80%<differences>85%).** In total there are 115 output lines.

VII. **Group with differences among measured and estimated currents and nominal value current in the range of (differences>85%).** In total there are 1367 output lines.

VIII. **Group with differences among measured and estimated currents and nominal value current in the range of (differences>95%).** In total there are 753 output lines.

IX. **Group with differences among measured and estimated currents and nominal value current in the range of (differences>98%).** In total there are 364 output lines. Some of those output lines are shown in the figures below.





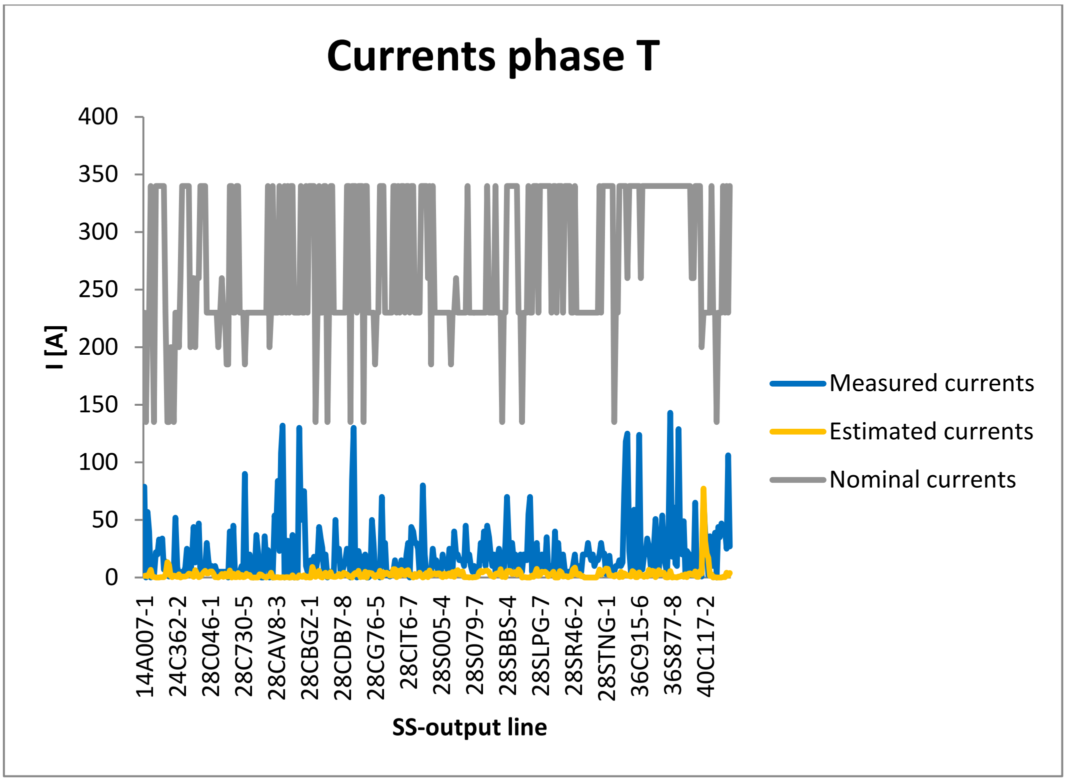


Figure 50. Measured, estimated and nominal current. Source: Own elaboration.

The summary of the grouped output lines regarding the differences with respect to the nominal current can be observed in table 26.

Differences with respect to nominal current	Number of ouput lines
<40%	8
40%-60%	12
60%-70%	35
70-75%	37
75%-80%	60
80%-85%	115
85%-95%	673
>95%	753

Table 26. Groups of output lines. Source: Own elaboration.

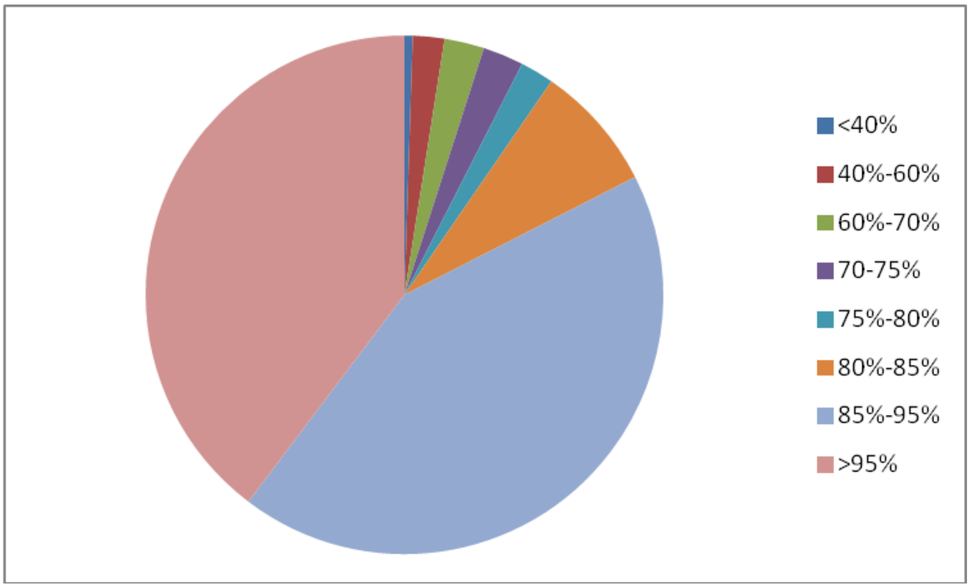


Figure 51. Group of output lines regarding differences of currents with respect to nominal current. Source: Own elaboration.

It can be observed in the previous figures that most of Secondary Substations' output lines operate below their nominal current with a wide range of difference, 82.5% of the Secondary Substations of this case study operate above 85% difference of its nominal current.

Thanks to the methodology followed, it is possible to detect the Secondary Substations that are more critical. This methodology tries to predict the failure before it actually happens by directly monitoring the machine during normal operating condition, so that maintenance activities can be undertaken the moment they are needed.

Therefore, Gas Natural Fenosa will move from a **conventional preventive maintenance**, in which maintenance is developed in some Secondary Substations that are pre-determined based on a number of factors including experience, age, manufacturers recommendations, etc. It is assumed that a machine component will degrade within a time period that is common for its type. The methodology followed for the estimation of currents will allow Gas Natural Fenosa to change the conventional maintenance for a **predictive maintenance**. Predictive maintenance is a **condition based maintenance** that uses direct monitoring of the operating condition to determine the actual mean-time-to-failure or loss of efficiency that would be detrimental for network operation.

Predictive maintenance is a philosophy or attitude that simply stated uses the actual operating condition of plant equipment and systems to optimize network operation.

Improvements in quality, profitability and productivity can result when predictive maintenance is used on capital-intensive assets.

8.5. OTHER APPROACHES TO IMPROVE MAINTENANCE

As it was explained before in 3.3., the least sophisticated maintenance is put in place where the bigger number of assets and interruptions are higher and where the observability is lower.

However, the deployment of digital equipment in the distribution network has increased the level of observability in LV network, so it is possible to establish a condition based maintenance also in MV and LV. In order to achieve it, it is necessary to develop lifespan models for the analysis of the collected data and the forecasts of failures.

8.5.1. RELIABILITY CENTERED MAINTENANCE

In the majority of cases, the general philosophy for maintenance followed by distribution companies, in particular, by Unión Fenosa Distribución, is based on the combination of corrective, preventive and predictive maintenance.

This methodology, although it is correct, suffers from the possibility of evaluating the "real" function of the assets inside the system operation and the effect that their unavailability would have in the operation. In addition, an improvement on maintenance strategies would reduce the operating cost.

Reliability Centered Maintenance (RCM) is defined as process that combines and uses inspection, diagnosis and analysis of power systems as elements that allows to take decisions over the adequate type of maintenance that should be applied (corrective, preventive or predictive) according to the level of criticality and functionality of the equipment.

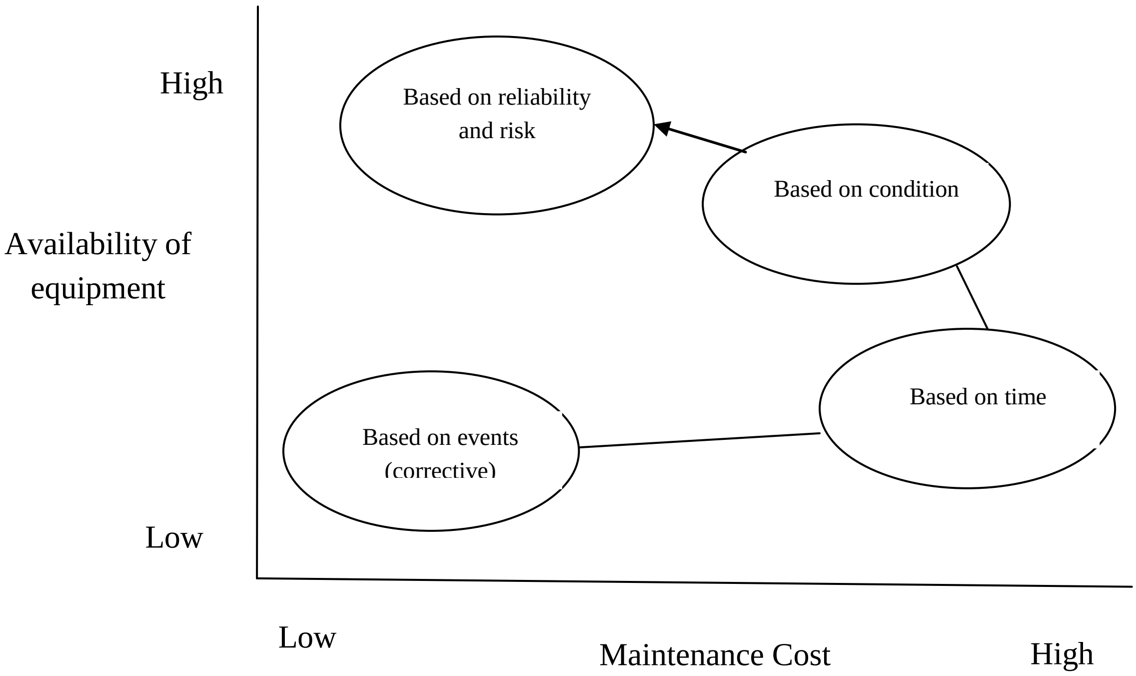


Figure 52 .Maintenance development. Source: (Daniel Galván Pérez, 2014).

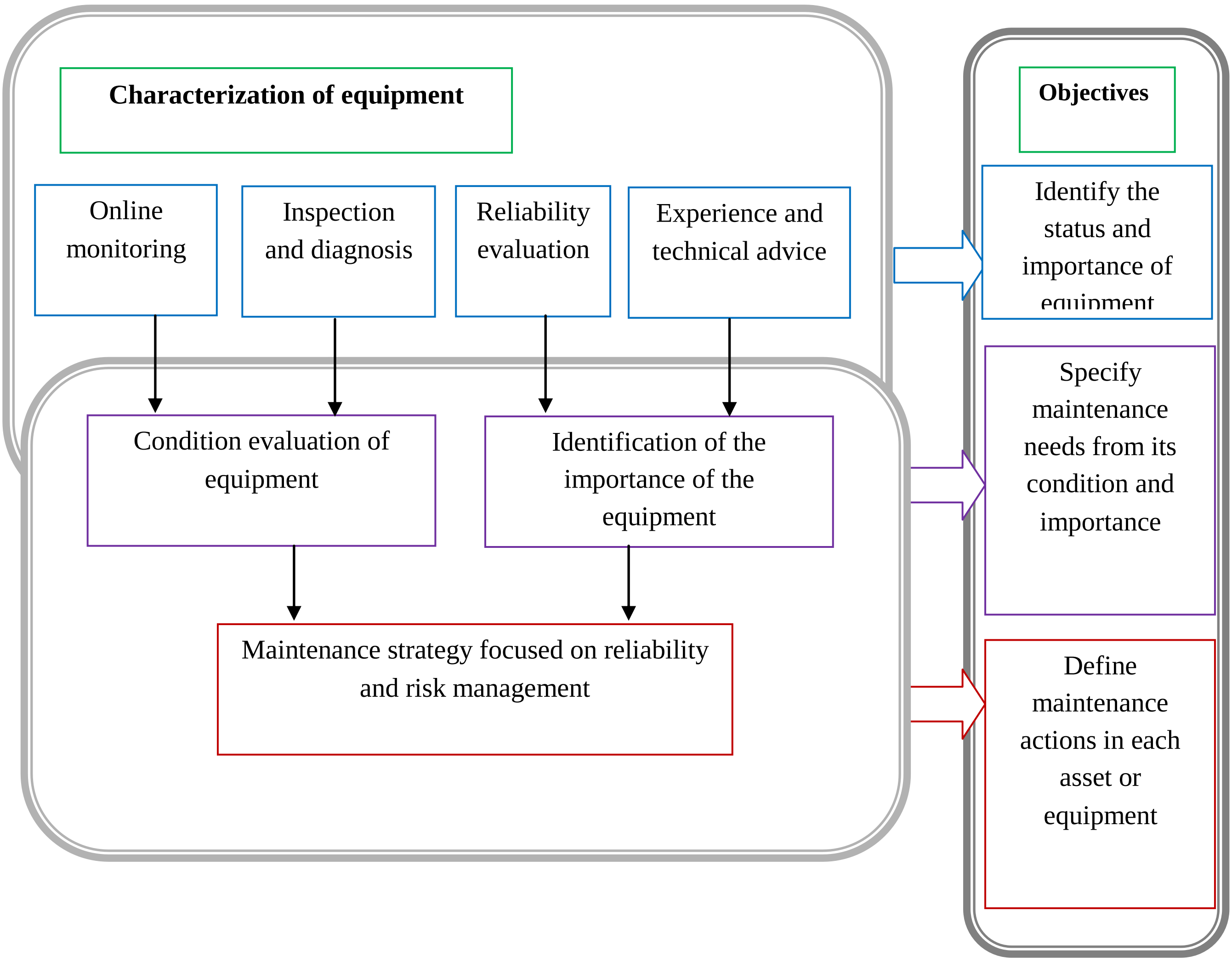


Figure 53. Development of strategy RCM. Source: (Daniel Galván Pérez, 2014).

As it can be observed in figure 53, the implementation of RCM process is based on a characterization of equipment (assets).

The process of evaluation of the asset condition will be done by a diagnosis and physical audit of the elements. In this case, the factors that should be taking into account when evaluating the condition are:

- Age of equipment
- Yearly operations
- Operating mechanism
- Operative experience with similar equipment
- Diagnosis results
- Maintenance crew experience

Regarding the importance of the equipment, the results obtained from the theoretical analysis of exploitation/planning will be used. The factors that measure the importance of equipment are:

- Failure rate
- Time to repair
- Economic impact: Non supplied energy, penalties from regulation
- Social impact

The main results obtained from the application of the RCM maintenance strategy are:

- Establish the investment priorities, planning the maintenance topology according to the balance between importance and condition of the equipment. Therefore, some elements will be exclusively on corrective maintenance, others on preventive or Time Based Maintenance and others on predictive maintenance.
- The simultaneous evaluation of the costs of maintenance and its effect on reliability and quality of supply allows to determine the optimization potential of the available resources.
- As the type of maintenance is set and the time to act is known. it is possible to improve the human resources-use curve that are needed for maintenance.

8.6. OTHER RESULTS TO IMPROVE MAINTENANCE

More than one visit for maintenance was done at 46% of the total number of Secondary Substations of Gas Natural Fenosa during last year. The number of visits recorded in 2015 was 30559 visits. The most important activities of maintenance that were developed in those visits are:

- Revision and regulation
- Revision and conservation (cleaning)
- Conservation and regulation
- Revision, conservation and regulation

The number of visits of Secondary Substations has a direct impact over the total number of incurred transport hours.

The aggregation of maintenance activities will allow to reduce the transport cost.

In order to calculate the cost of transport reduction, several **estimations** are done:

- Estimation of an incurred cost of transport equal to 36€/h
- No corrective maintenance is taken into account because it cannot be planned

- It is considered a maximum of two visits per Secondary Substation that are grouped.

The total cost of transport for the total number of visits during 2015 and the reduction after grouping the maintenance activities can be observed in the figure below.

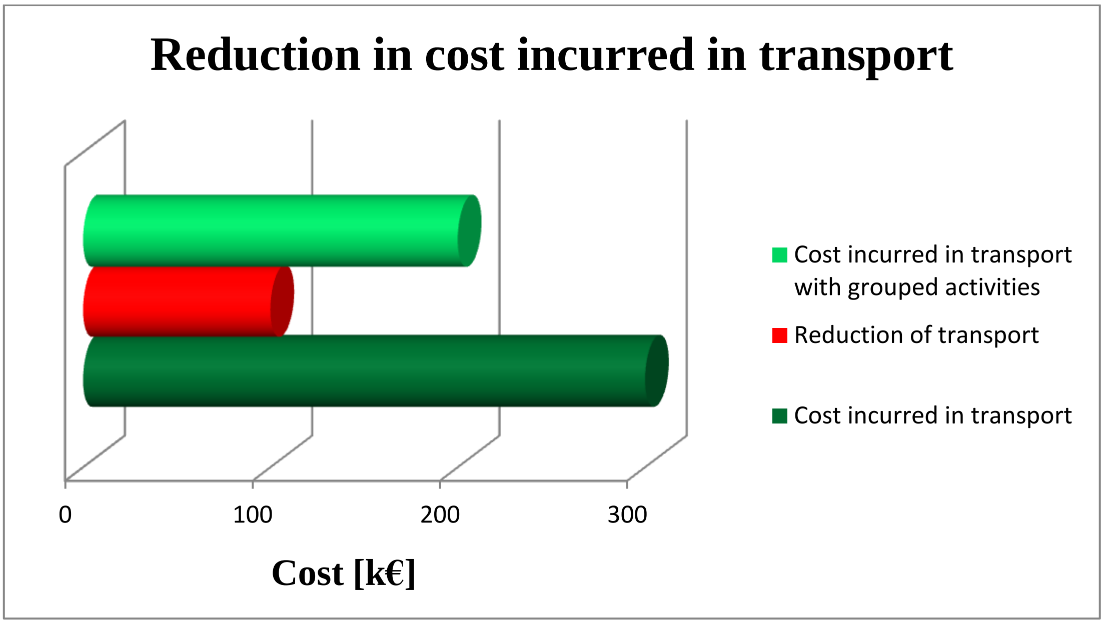


Figure 54. Reduction in cost incurred in transport. Source: Own elaboration.

The total reduction in cost incurred in transport represents a 33.33%.

Several lines of action can be taken in order to group or cluster the maintenance activities:

1) Identification of planned/remaining activities on each Secondary Substation
2) Going further in the types of activities that need several visits and supervision needs
3) Planning of simultaneous maintenance of derivative activities (regulation, adequacy, etc.)
4) Monitoring of the maintenance activities. Need of approval to execute an additional visit over the Secondary Substations that have already been addressed during the year

8.7. CONCLUSIONS OF THE RESULTS

After calculating the estimated currents and comparing them to the real measured values, it has been verified that real and estimated values differ within an acceptable range. With the simplified model it is possible to do it better than it has been done until now with the conventional maintenance at Gas Natural Fenosa.

A decision has been made with the work that has been done: Gas Natural Fenosa will develop the estimation of currents in order to reduce significantly the conventional maintenance revisions that were done periodically to Secondary Substations.

Before	Now
• Traditional Load Handling has been made periodically and over a few sample of Secondary Substations. • There was a sporadic and isolating reading at the moment of metering the currents in the feeders.	• Estimated Load Handling is done over the total number of Secondary Substations. • It is done continuously, 24 hours a day, every day of the year and provide higher accuracy.

Table 27. Comparison between traditional Load Handling and estimated Load Handling. Source: Own elaboration.

As a result of my work in **Gas Natural Fenosa**, the company **is starting to do the maintenance** in those Secondary Substations that are determined by the **estimated Load Handling** to be more critical and subject to have problems.

The continuous analysis of the currents in Secondary Substations allows creating indicators and histograms that represent the status of the distribution assets in relation to the nominal values.

The deployment of remote management and telemetering is of real importance in order to increase the impact of the methodology followed to estimate de current. Currently, the 50 percent of the Secondary Substations of Gas Natural Fenosa do have remote management and telemetering. The methogology in short term can allow to monitor the 45 percent of the Secondary Substations (Fenosa, 2016).

Increasing the level of remote control and telemetering of supply points is very important as well. Approximately, 61 percent of Secondary Substations have more than 80% remote management supply points, as it can be observed in the following figure.

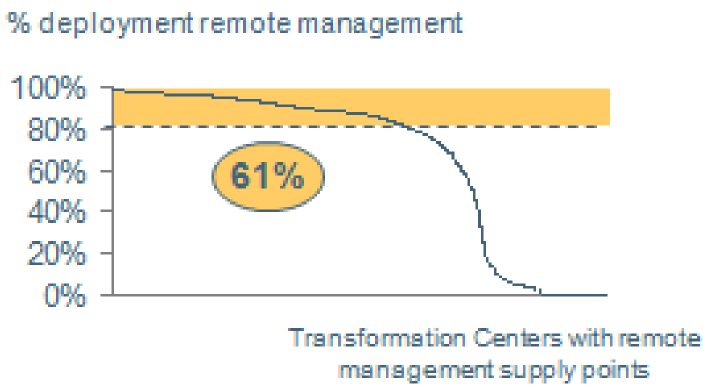


Figure 55. Deployment (%) remote management. Source: Gas Natural Fenosa.

There are several advantages provided by the properly estimation of currents in Secondary Substations:

- Reduction of the recurrent physical maintenance supervision (load handling) of the Secondary Substations. It would only be necessary for specific cases.

- Reduction of corrective maintenance: The continuous monitoring of Secondary Substations will allow to establish alarms depending on operating patterns in order to predict failures in critical points of the network.

- The continuous monitoring will also allow to reduce incidences associated to failures due to current imbalances or overcurrents between 25% and 50% (Fenosa, 2016).

9. CONCLUSIONS

9.1. SUMMARY OF THE PROBLEM

Secondary Substation Maintenance at Gas Natural Fenosa is being done in an instantaneous and sporadic way. The measures that crew maintenance members take on LV output lines oscillate a lot. In addition, not all the Secondary Substations are being measured and revised. Under traditional Maintenance the currents that are measured at one particular moment are very volatile and the punctual value may not be representative.

The figure below represents the change of maximum, minimum and mean active power each hour, registered by the supervisor's meter. Depending on the moment that the measure is taken, the obtained values can be very different.

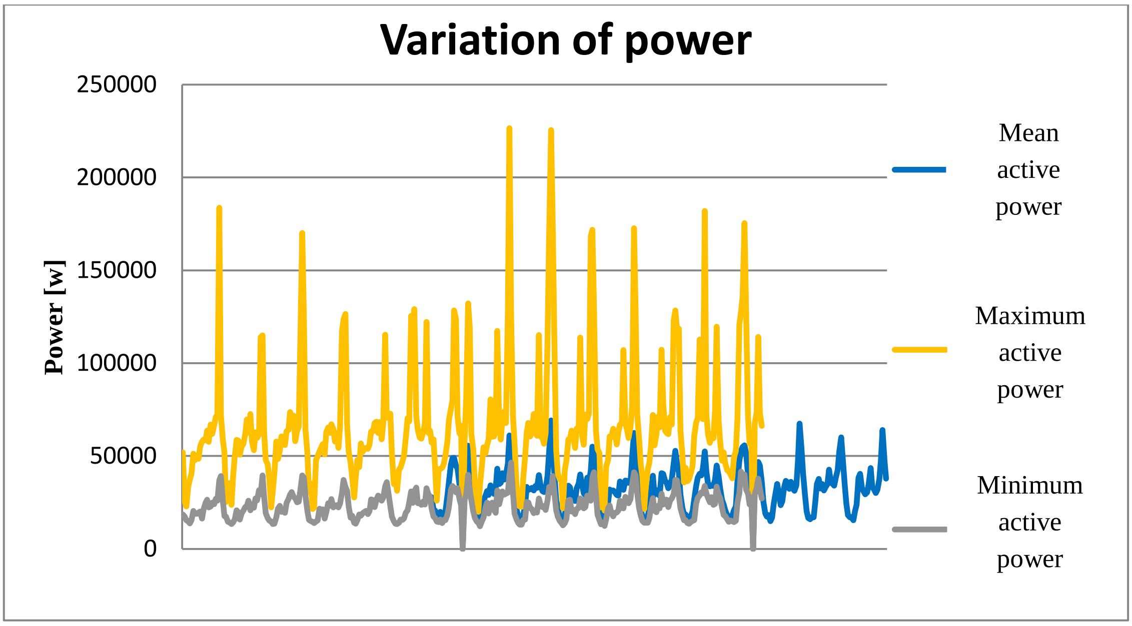


Figure 56. Variation of active power. Source: Own elaboration.

In order to improve the maintenance of Secondary Substations, a solution has been proposed. The methodology described in the Thesis allows to estimate the currents in LV feeders that are measured in the conventional way. With these estimated measures, it is possible to supervise the daily status and operation of all Secondary Substations and detect those that are more critical and that should be taken into consideration for maintenance revisions or operations.

In summary, this will allow to move from a preventive maintenance to a **predictive maintenance**. The benefits of predictive maintenance are, first of all, its ability to drastically reduce machine downtime by providing the most up-to-the-minute condition data for assets. By streaming real-time data into a system directly from the machine itself, maintenance personnel can see when problems are forming and address them early, before they can cause costly downtime. Compared to preventive maintenance, predictive maintenance offers the most proactive form of maintenance possible.

9.2. MAIN FINDINGS

Digitalization has changed the way things are done in distribution companies. DSOs have to make use of the information that digital devices provide in order to improve their systems and the way they operate the network. Maintenance systems are changing because they receive much more information and data each day, most are hourly data that it is important to manage efficiently in order to improve the systems.

The new solution that will take Gas Natural Fenosa to develop maintenance not only will reduce Operation and Maintenance costs but, with all the information, much more things could be done.

The estimated savings in Maintenance due to this new maintenance for Secondary Substations is about 1 million Euros in approximately two years.

Visits to Secondary Substations will be reduced up to 60%, only those that are detected as most critical will be subjected to maintenance.

9.3. FURTHER RESEARCH

The analysis of the estimated currents in the Secondary Substations could be useful to define indicators and alarms to monitor the state of the Secondary Substations and their output lines.

The probability of failure of the assets due to to overcurrents and phase imbalances could also be studied.

The analysis of the severity and failure probability of Secondary Substations will be the base to do an advanced segmentation. The objectives of the segmentation are:

- Set several categories of Secondary Substations that will allow to establish the **optimal frequencies of maintenance**. For instance:

    - **Cleaning** of those Secondary Substations with higher incidence index for filth and flooding.
    - **Extraordinary revision** of Secondary Substations as a consequence of a high level of risk for the network or for the people.
    - **Extraordinary revision** of Secondary Substation for Festivals/Parties as a consequence of an event in a municipality that demands the explicit presence of the company.

- **Improve the decision-making** on Secondary Substations. Probability failure and severity methods will be applied to optimize the decision-making. For instance:

    - Most critical Secondary Substations to monitor possible flooding through **sensors**.

    - Deployment of **video cameras** to revise the status of the Secondary Substations in specific cases due to alarms or other events.

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13. ANNEXES

13.1. ANNEX I: SMART METERING DEPLOYMENT IN EU

Around 72 % EU customers are expected to be equipped with electricity smart metering systems by 2020, based on the Benchmarking Report findings. In fact, Finland, Italy and Sweden have already ended their nation-wide smart metering deployment, presenting 23 % by 2020 (JRC, 2014).

Figure 57 shows an overview of the electricity smart metering national roll-outs in EU based on the data available by the EU Member States, as of July 2013.

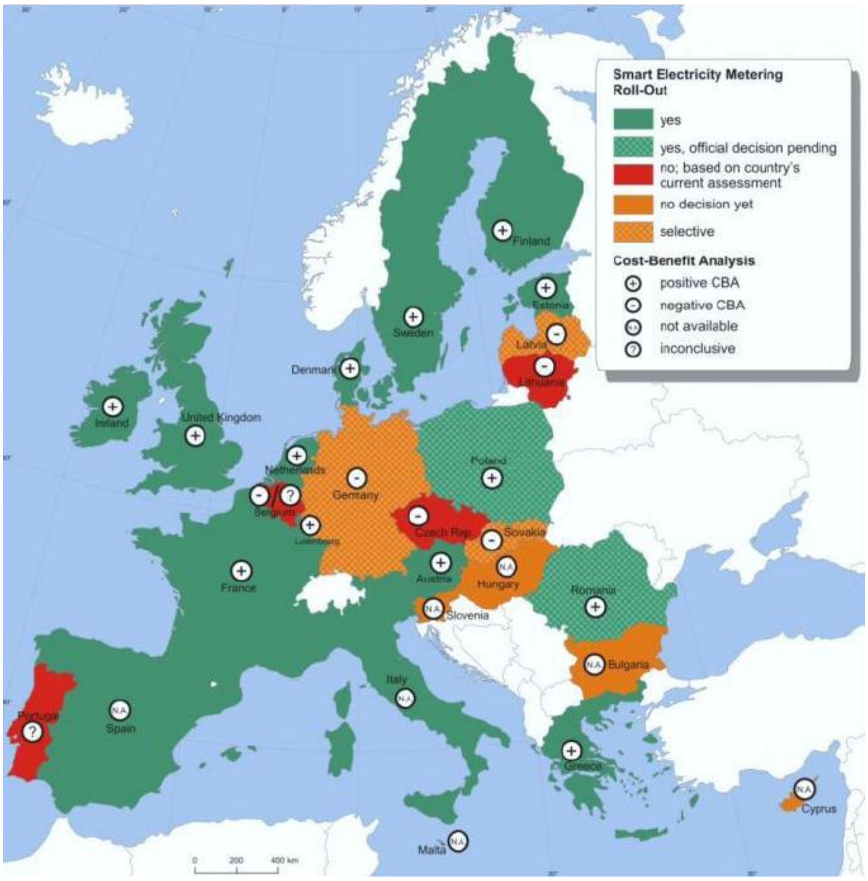

Figure 57. Overview of CBA outcomes for nation wide roll-out of electricity smart meters in Member States by 2020, based on data available in July 2013.

13.2. ANNEX II: SMART METERING COST BENEFIT ANALYSIS (CBA) IN EU

According to the benchmarking analysis of the long term economic assessment of costs and benefits due to nation-wide roll-out of smart electricity systems in EU, the results of the CBAs regarding key roll-out parameters diverge across Member States. This can be explained by different local realities and starting conditions reflected in the CBAs, and the inclusion of additional features in the smart metering systems considered.

Most of EU Member States addressed savings in electricity consumption as one of the main benefits associated with the deployment of smart metering. As a conservative estimate, an average value of 2,6% and 3% considering countries which have already started the deployment.

Peak load shifting of electricity consumption is considered another important benefit (from 1% to 9,9%). This is explained because of the different ways of consumption, energy efficiency programs, pricing mechanisms, etc.

The second most observed benefit among Member States is the savings on meter reading costs and electricity network losses reduction (technical and commercial losses).

Regarding costs, the capital and operational cost of the smart meter is the major one, followed by the cost due to data communication. The cost per metering point vary greatly across EU countries. Available data indicate that a smart electricity metering system could cost on average €252 per customer with a wide standard deviation of €189.

Smart metering systems are expected to deliver an overall benefit per customer of €309 (±€170) for those Member States that have completed or will be proceeding with the roll-out by 2020 along with average energy savings of 3 % (JRC, 2014).

Smart Metering and consumers

According to the smart metering roll-out plans of the EU Member States, there is a clear evidence to benefit the electricity consumer by means of effective smart metering deployment and successful strategies for consumer's engagement. In particular, there are six ways the adoption of smart metering systems can benefit the electricity customer, that is shown in figure 58.

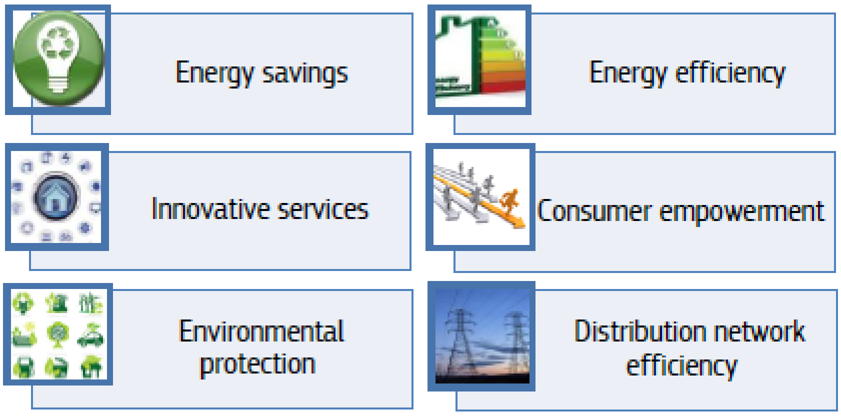

Figure 58. Benefits of Smart Meters to consumers. Source: (JRC, 2014).

- **Energy savings**

The deployment of Smart Meters do not lead automatically to energy savings; however, effective use of its potential can bring benefits to all players involved, being the first one the electricity consumer.

It is very important to understand and motivate the consumers with provision of clear and easily accessible information about their consumption. The way the data is presented may have an important impact on their energy savings.

- **Energy efficiency**

Smart metering deployment may lead to energy aware of consumer in the purchase of more energy efficient appliances and more efficient use of the electric energy.

Energy efficiency can also result due to more efficient use of the electricity network, leading to reduced technical network losses. On the same note, demand response and peak load shifting using distribution network tariffs that reflect real network conditions will account for electricity cost reduction for the consumer.

- **Innovative services**

Information collected from Smart meters can help suppliers or other market players create innovative services, such as home energy management and demand response, which can be tailored to consumers' needs and offer energy savings and higher efficiency to consumers.

The availability of detailed consumption data will create significant new opportunities to companies in offering services and products on appliance diagnostics, more refined automation of heating and hot water controls and the analysis of heating patterns.

- **Consumer empowerment**

Smart metering deployment will increase consumer awareness on the time and amount of electricity consumed as well as enabling easier and quicker switch between suppliers. This enables consumers to choose from different offers to better adapt their consumption patterns and therefore drive prices down.

While greater level of competition may result in lower electricity prices, quantification of this benefit at the current stage of smart metering roll-out across Member States is difficult to quantify, and therefore it has been identified as a qualitative benefit in Member States, such as UK and Netherlands.

- **Environmental protection**

The effective deployment of smart meters can provide additional value to society. As a result of energy savings and higher efficiency in network operation, CO2 emissions will be reduced.

Smart metering systems also help to promote micro-generation and electric vehicles, making the consumer aware of its CO2 emission footprint.

- **Distribution network efficiency**

The benefits for distribution companies are the reduction of losses and the increase in network observability, which is specially important in Low Voltage network. Furthermore, Smart Metering deployment will also help DSOs to improve quality of supply and increase reliability while providing a better service to the final customer at lower distribution network costs.

13.3. ANNEX III. DIGITALIZATION OF NETWORKS AND DSOS

- **Smart Meter Roll-Out (Finland)**

Following the national legislation issued in 2009, DSOs in Finland had to install smart meters with hourly measurement to at least 80% of all metering points on their grids by the end of 2013. At the moment, more than 97% of the 3.3 million connection points in Finland are equipped with a smart meter. From each meter, hourly-recorded consumption values are transferred to DSO databases, usually during the night after the day of consumption. On the same day, hourly data is sent both to the metering points' supplier and to the relevant consumer via an online portal or electronic message.

Accurate hourly data is used in balance settlement and customer billing. Smart meters in Finland must be equipped with two-way communication capabilities to ensure the possibility of controlling the loads connected to the meter. Two-way communication enables many other useful functions. Most metering points can be disconnected and reconnected remotely and read any time from the DSO's control room or customer service department. DSOs also receive power quality data, which makes the operation of the network more efficient. Smart meters can help detect outages immediately.

Information about outages is also sent to the relevant connected customer by SMS. In addition to consumption measurement, the same smart meter is capable of recording production that is fed to the network from the metering point. The hourly time series of consumption and production are separated and can be sent to different market players. Many suppliers in Finland buy surplus electricity from small-scale producers/prosumers.

There are several service providers in Finland that use hourly data to provide energy efficiency services or procurement of electricity for big consumers with several metering points. When a consumer requests the hourly data, it will be sent in a standardized electronic format to a 3rd party appointed by the consumer.

The DSOs will not charge the consumer for this service. The consumer needs to contact the service provider and agree on the terms of service and set up a power of attorney. The service provider will then contact the DSO relevant to the metering point to agree on data exchange party ID and other receiver details. When distributing data to third parties, the DSO must ensure that consumer authorisation is granted. A valid power of attorney is needed to ensure privacy.

- **Towards a Digital DSO, ERDF (France)**

Smart Meters & Smart Grids for Energy Transition

With the Linky smart meter and smart grids, ERDF will address the challenges of energy transition (integration of intermittent renewable energy capacities connected to the distribution grid, EV charging stations and demand response). ERDF is rolling out 35 million smart meters (2015 – 2020) and is investing in smart grid demonstrators in France and in Europe (18 demonstrators) to prepare smart grid industrialization (Boillot, 2014).

Digital Program for Energy Transition and Consumers' Empowerment

In 2014, ERDF launched a company-wide digital program to reach best digital standards with four main actions:

- Digital relationships with consumers and local authorities: Reaching the best level of digital standardsfor all consumers

- Building a relationship with digital standards with local authorities and market participants and adapt it over time

- Digital network management: Developing predictive maintenance on transformers and related MV substation

- Making data the second most important asset of future - Establishing a predictive and real time management planning from source stations to low voltage (LV)

- Culture & Collaboration: Making ways of working more flexible and cross-functional, leveraging enterprise social network to strengthened collaboration

- Digital innovation and Mobile experience: Offering an optimal mobile experience aligned with external best practices (devices and usages) giving rise to an environment that is genuinely open to innovation

- Data operation: Developing a big data capability allowing to manage, analyse, enrich and publish metering data

Data for Consumers

ERDF is promoting an open data approach and developing services for local authorities and private consumers. As a regulated entity, ERDF is well positioned to guarantee data protection (personal, industrial and commercial data) and neutral market facilitation.

- ERDF is committed to an open data process. The company publishes online raw data in partnership with Etalab and the French government on the website data.gouv.fr
- ERDF will make daily consumption data available to consumers. An easy and user-friendly web portal has been created where consumers can consult their data (time intervals of 30 minutes, 1 hour, 24 hours). With consumers' consent, data will be communicated to third parties (retailers, aggregators) which propose commercial services