Asturian high voltage power system evaluation: Current and future situations

Ignacio Cortina Gasch

Msc Energy Systems and the Environment

Mechanical Engineering department
University of Strathclyde
Glasgow

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ABSTRACT

Asturias, a Spanish province located in the north coast of the country, is considered as an exporter region in terms of electrical energy due to its favourable characteristics for the exploitation of energy sources such as hydropower, wind power and fossil fuel power.

Despite at present the tight electric power transmission system operating in Asturias withstands current levels of generation, future energy plans for the region could risk power system reliability.

Electrical generation within the region is estimated to increase by 37% by 2011 in terms of new wind farms and combined cycle gas turbines and up to 120 % by 2015 because of the addition of new combined cycle power plants. However, the current transmission system would be unable to manage such dramatic increase of energy through the lines. So it is essential to design a new 400 kV power line grid to transport the energy within Asturian substations and export the surplus to vicinity regions.

The dissertation here presented evaluates the current situation and future horizons of the Asturian high voltage power system. On the one hand, power plants, substations and power lines currently in operation along with current generation and demand trends. On the other hand future projects and upgrades as well as expected generation and demand trends for the following seven years.

In that way, the study carried out models and simulations of the Asturian power system with the aid of Power World simulator in order to later on go through a detailed analysis of the transmission grid overloads over several scenarios of increasing generation and exportation alternatives.

The results obtained from the study show an up to date approach to the electrical energy situation in Asturias nowadays and in a 7 years term. Current and future high voltage power system needs and requirements to make possible all the projected plans for the region.

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1. INTRODUCTION

1.1. A view to the Asturian industry and energy background

The principality of Asturias is a province within the Iberian country of Spain. Geographically located in the north coast of Spain, it faces the Cantabric Sea on the north and the Cantabrian mountains that lead to Castilla on the south.

Asturias has always been characterized by its industrial past. During the last part of the 19th century coal mining began to stand out as the main economy for the region, positioning Asturias as a real competitor for the other countries in that time exporting coal to Spain. That thriving situation would continue all along the first half of the 20th century as Asturias was considered the main supplier of coal for the rest of the Spanish industry. However, over the last decades of the 20th century, the competence from countries such as China or South Africa is so strong that it has caused the closedown of many mines. During the nineties the situation had got worse to a point in which currently the future for the mining industry in Asturias is quite uncertain.

Another industry sector that simultaneously rose was the steel industry. After having evolved gradually over the first years of the 20th century it was not until times of Franco's dictatorship when Asturias was the centre of Spain's steel industry. The then state owned ENSIDESA steel company, now part of Arcelor Mittal Group, created many jobs which resulted in significant migration from other regions in Spain. But once again, over the last years of the 20th century the competency from Asiatic countries drove those industries to important staff reduction policies and a more limited production

Currently the main industrial economy in Asturias is in the energy sector, as opposed to the steel and aluminum industries. Which, although still in constant production, are not as thriving as forty years ago.

Asturias is in terms of electrical energy considered a surplus region. With a population of around 1,000,000 inhabitants and in spite of the several high electric demand industries operating, the current internal consumption of electricity is set to be around a 30% percent of its maximum total production. That means that up to a 70 % of surplus energy could be exported from the region.

Before the Spanish electricity market reform during the 1990s (Spain was the first country to establish a Regional Transmission Organization), Asturian power stations had fixed their generation. The internal demand followed a constant trend so, as said before, generators did not experience important fluctuations in their generation. However, the new wholesale electricity market, based on competing generators which offer their electricity output to retailers, changed completely the management of energy in power plants. With the new system the purchase and sale of electricity is affected using supply and demand to set the price among the several electrical companies. In that way the generation capacity of Asturias power system as well as the exportation and importation of energy between the vicinity regions has became a crucial target for the reliability of the Spanish power system.

Nevertheless, despite of the surplus characteristics of Asturias, the Spanish power system is still considered as importer of energy. In order to meet the increasingly higher demands of energy in the peninsula, Spain is forced to import around 4500 GWh per year from France. [16]

Hence, the future plans for the Asturian power system depend on the increase of electrical generation rates. Hydro power energy is not considered in the plans because this source of energy is completely exploited in Asturias. The addition of new conventional coal fire power plants is also not considered as currently Asturias does not meet Kyoto protocol or have the enormous investment capital necessary in order to have the current plants meeting satisfactory emission levels. And finally the national government and public opinion has placed completely against nuclear power generation. The only exit for future generation alternatives seems to point to:

- On the one hand, the incorporation a large amount of new wind farms, up to 23 according to the government plans.
- On the other hand, diverse combined cycle gas turbine (CCGT) power plants, up to 7 new units which would replace old coal fire units and therefore reduce the gas emissions in a reasonable percentage.

The reason for this controversial anti – distributed generation policy, which contradicts most of the environmental and greens views, can be found in the excellent characteristics of Asturias for the implementation of the above noted generation sources.

In reference to wind power generation, half of Asturias is located on the north western area of Spain, where the wind conditions are the best for the implementation of wind farms. For that reason western areas of Asturias, affected by those high speed winds, are where all the wind farms existing in the region currently operate and also where almost all the future wind farm projects for the region will be located. It is also necessary to state that another factor that triggered the massive exploitation of wind energy were the bonus offered by the EU for the commission of new renewable projects in order to meet a 12 % of renewal energy production by 2010.

In reference to combined cycle gas turbine power plants, the future project of a regasification plant in Musel, Gijon (the main harbour of Asturias), has been the factor that sparked off the large number of CCGT projects for the region.

But, it is not all about advantages. In order to fulfil all those ambitious projects of new generation it will be necessary to overcome some important constraints existing in Asturias power system:

- First, the inexistence of an adequate transmission system to move such a big amount of MW within the region. It will be necessary to increase the power capacity in those transmission lines which run from the substations where the new units are expected to be operating to the substations where the energy is delivered to internal consumers or send away of Asturias as surplus energy.
- Second, the inadequate state of the transmission lines to send energy out of Asturias. Current major transmission power lines which connect Asturias with

the rest of Spain would not resist notable increases of energy to be exported. So it is of the utmost importance to plan new routes for the exportation of energy.

An effective transmission grid, not only within the region but in between bordering regions, is crucial for the security and stability of the power system. The duties of a proper transmission system go beyond the simple transport of energy, it is also essential having enough transport capacity when facing critical situations in which it is necessary to carry on quick regulations of energy between power systems. Furthermore, unexpected overloads of the power lines could lead to the disconnection of generators, fall of lines, cascade falls and even multiple blackouts and outages.

1.2. Aim of the project

The project will firstly describe current situation and future horizons of the Asturian high voltage power system, for later carry out a more detailed analysis of the transmission grid. Discovering current weak points and future problematic situations that could flag up as well as suggest alternatives to overcome those difficulties are other matters here developed.

1.3. Specific objectives

The specific objectives of the project are:

- To model the Asturian high voltage power system firstly for the current (2008) and later for the future (2008 – 2015) situations with the aid of Power World simulation tool.

- To simulate several scenarios of operation and possible contingencies in the grid.

- To study performance and stability of the power system under the proposed situations.

- To analyze one of the major future problems of the region: how to deal the future pushing increase of generation with the limited possibilities of electricity exportation in the Asturian electrical grid.

1.4. Structure of the thesis

The thesis is organized according to the following chapters:

- *Chapter 2: Power system basics*. This chapter reviews the basic knowledge about power systems: Description of the typical structure of a power system as well as an explanation of each one of the stages in which it is split up.

- *Chapter 3: Methodology of the study*. Firstly, working procedure carried out during the study is detailed step by step. Next, necessary simulations are defined in a chronological order. Finally, a brief review of the simulation program used during the study is given.

- *Chapter 4: Asturian electrical network*. This is a descriptive chapter where current situation of the Asturian power system is recounted by giving general information about power plants, substations and power lines. Also a brief introduction to the demand situation is shown.

- *Chapter 5: Study of the current situation (2008)*. This chapter firstly details the necessary data for building the model and how was it obtained. Next, notions about reliability criteria are shown for later analysis. Finally, simulations and analysis of the power system current situation along with some possible contingencies are carried out.

- *Chapter 6: Asturian future electrical network*. As the previous chapter 4, this is a descriptive one where the future plans for the Asturian powers system are expound.

- *Chapter 7: Study of the future situations (2008 – 2015).* In a similar way as in the chapter 5 new models for the future situations are built in this chapter. Simulations and analysis are also carried out for the several plans proposed in the previous chapter.

- *Chapter 8: Conclusions*. A final summarized review of the whole project and situation of Asturian power system is show in this final chapter.

2. POWER SYSTEM BASICS

2.1. Power system structure

Electrical power systems mission consist on the bulk transfer and delivery of electrical energy from the power plants where energy sources are available to several consumers in urban areas, industry parks and other demand points.

Therefore a power system structure can be split up in the following three stages:

- Electricity generation
- Electricity transmission
- Electricity distribution

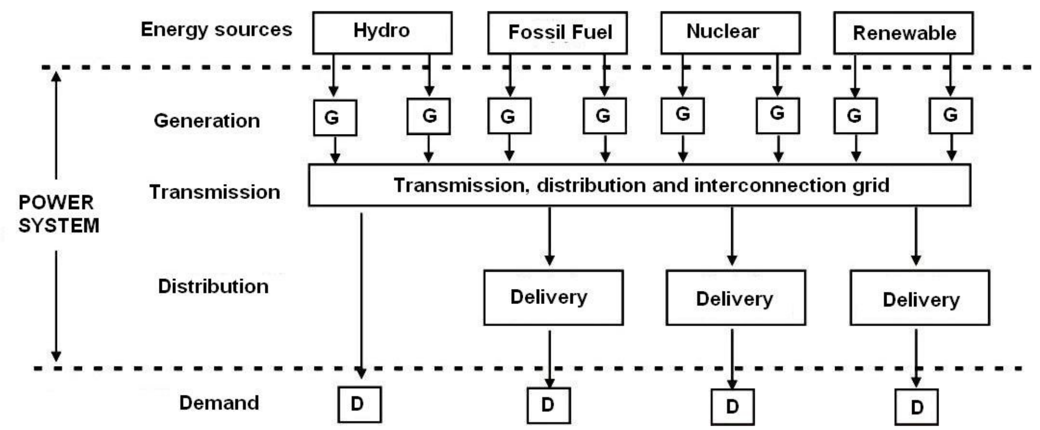


Figure 1. Power system structure [2]

On the first stage power plants generate electricity at voltage levels that normally vary between 6 and 20 kV for later being stepped up to much higher levels (220, 400 kV) in the transformers located within substations attached to the power stations. The reason of those increases in the voltage level is no other than the optimization of energy transport. By increasing voltage levels it is possible to transport large amounts of electricity from remote distances reducing the fraction of energy lost to Joule heating effect.

Normally the transmission grids interconnect all the power plants with a mesh structure of different voltage levels (220 kV or 400 kV) of power lines which merge and diverge in the transmission substations. The fact of allowing electricity to take alternative routes in case of unexpected failures in the power lines gives the power system more reliability.

From those big substations power lines usually go either directly to high demand consumers (Such as in the case of metallurgy industry and similar) or indirectly to the rest of consumers (conventional industry, urban areas, local villages), reducing in that last case their voltage levels in the distribution substations.

In those substations, apart from all the transformers that step up and down voltage levels, there are other important elements for the measure and protection of the transmission power system, as well as communication units which transfer all the variables information to the control centers.

Distribution substations step down voltage levels to 132, 66, 45, 20, 3 kV in order to supply energy to the local grids which can either go directly to medium size industrial consumers or to end consumers. In that last case energy is delivered among the several distribution transformer centres, usually located in the underground or ground floor of the buildings, where electricity is finally stepped down to final consumer levels (380 and 220 kV).

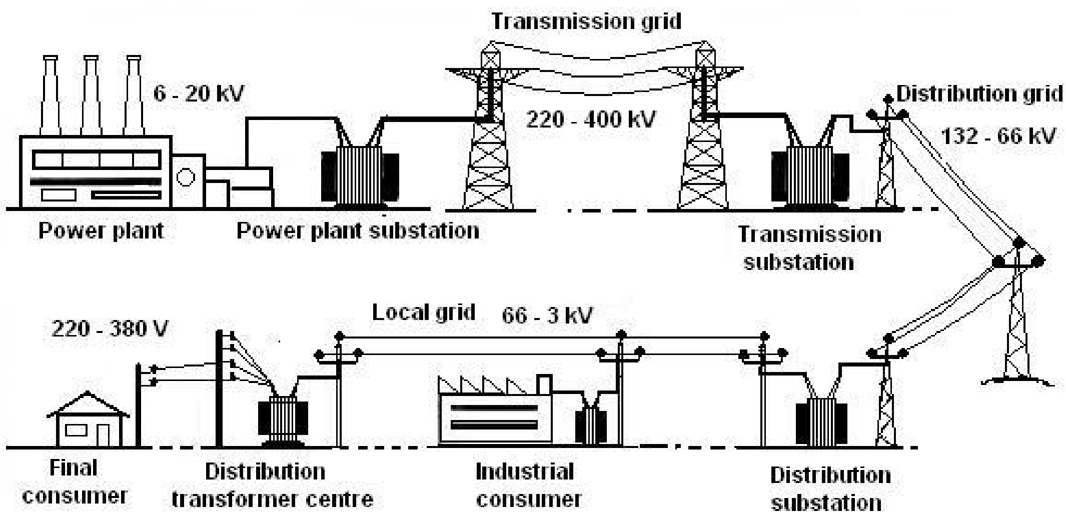


Figure 2. Electrical network structure [17]

Therefore as long as there are not technologies for the massive storage of electricity and generation must equal demand constantly, it is necessary to have proper electric grids interconnecting all the elements and voltage levels that compose the system.

Some of the electrical grid tasks can be summarized as:

- To guarantee the interconnection of the generators and the big demand areas.
- To allow the transmission of the most economical electrical energy generation anytime.
- To constantly guarantee that generation meets demand.
- To contribute to the reliability of the power system (keep voltages and frequencies inside the security margins, avoid outages)

2.2. Energy demand

Electrical demand reflects the amount of energy that is being consumed at a given time by the users of the power system (both industries and end users). Since energy demand and generation are two terms closely related both are measured using the same units. For a high voltage power system the terms typically used are megawatts (MW), which refers to the amount of energy consumed/generated at a given time and megawatts hour (MWh), which refers to the total energy for a period of time.

Depending on the amount of demanded energy, consumers can be split up in the following groups:

- Large industry consumers. They are characterized by their high demands of electricity and thus are directly connected to the transmission grid (normally 220 kV). The most typical cases are the aluminum, iron and steel industry.
- Industry consumers. They usually are factories connected to the distribution grid (132 – 66 kV)
- End consumers. Such as home consumers, offices, shops or small factories connected to the low voltage grid (220 – 380 V)

Electric rates for industry and end users are typically fixed depending on the amount of energy they are consuming. In that way large users tend to get more favorable rates than small users. It will also depend on the time of day they are demanding the energy, day or night rate.

Despite the complex and large number of loads that shape the total energy demand and some facts that can modify demand patterns such as if it is a winter/summer month or if it is a holiday/working day, the final demand curve always follows a typical daily trend. In the following picture it is shown the demand curve for a working day during February in Spain.

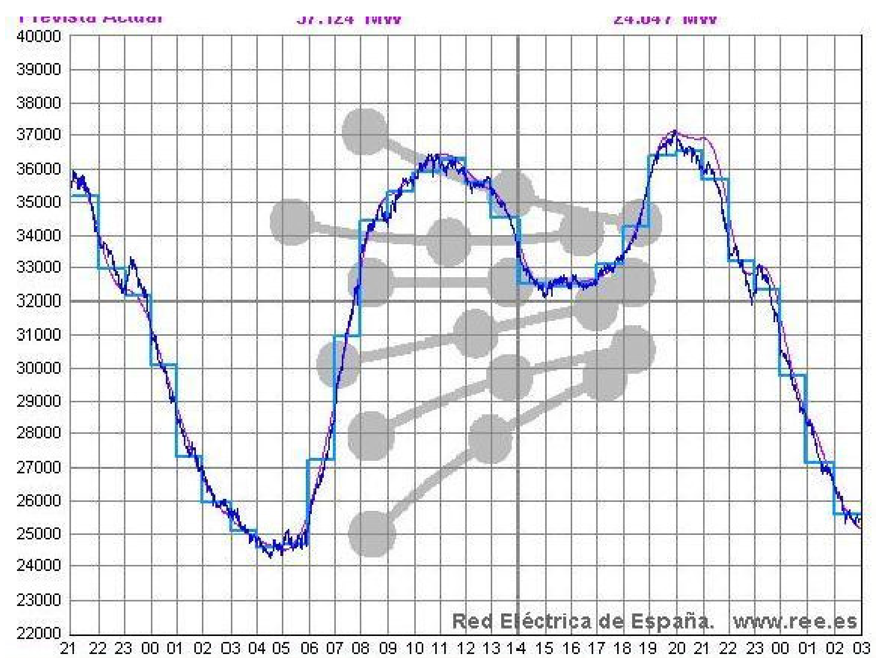


Figure 3. Electrical energy demand curve [18]

In the graph four different demand stages can be distinguished:

- Firstly, a valley load between 00:00 and 07:00 hours which coincides with the time in which most of the people is sleeping and therefore the consumption falls

down. Consumption of energy can be justified by some large industries which keep operating 24 hours.
- Secondly, a first peak load, between 07:00 and 14:00 which coincides with the working day hours in most of the offices and works.
- Thirdly, A second valley hour between 14:00 and 19:00 which represents the time in which people are out of work but have not reach home yet.
- Finally, a second peak load that coincides with the nightfall, when people are coming back home and beginning to turn off all the household appliances and lights.

Bearing in mind the previous demand stages and knowing that some power plants need many hours to start up operating, energy demand management and forecasting is a very important task in order to maintain a quality and safe system.

In the short term predicting demand of electricity for the whole day is important in order to choose which generation is the most economical or when will it be necessary to import or export surplus energy. For example, thermal power plants keep operating constantly supplying energy both, valley hours and peak hours. While other power plants with quicker starting times, such as hydro or combined cycle meet the peak loads.

In a long term the management of demand can help to decide what investments in generation or transmission stages the power system needs.

2.3. Generation

Electricity generation is the first process in the delivery of energy to the customers. Electricity is most of the times generated at a power plant by electromechanical generators driven by steam/gas turbines fueled by chemical combustion or nuclear fission, but also by water and wind turbines. Additionally electricity is generated according to standardized patterns of frequency and voltage.

The most common power plants currently in operation are:
- Hydro electric power plants
- Thermal power plants (including coal, gas and combined cycle)
- Nuclear power plants
- Renewable power plants (Wind farms, biomass, photovoltaic power stations)

2.3.1. Hydro power plants

Hydro power plants use water as an energy source to generate electricity by driving the fluid across a turbine coupled to a generator. There are several types of hydro power plants depending on how the water is harnessed:

The most common type are the dam hydro power plants in which the potential energy of the dammed water drives a Kaplan or Francis turbine at the bottom of the dam. Another similar type are the pumped storage hydro power plants, where electricity is produced in high peak demand hours or consumed during low demand hours by pumping water to higher reservoirs.

When the hydroelectric power plants have no reservoir they are called run-off-the-river plants, since it is not possible to store the water. In this case the water usually runs down the mountain across a large pipe which ends in a turbine room where the water impact against the blades of a Pelton turbine.

A last type of hydro generation, is that from small scale hydro electric plants. They are usually committed in areas that formerly used waterwheels. They can be divided into mini-hydro, when the generation is around 1MW and micro hydro, when the generation is up to 100 kW.

Among the advantages of those power plants are the elimination of the cost fuel, the minimum cost of operation and the lack of greenhouse gas emissions.

Some disadvantages can be found on the high initial costs, the long period of time needed to make them profitable and the environmental damage to surrounding ecosystems.

2.3.2. Thermal power plants

In a thermal power station water is heated by the combustion of any fossil fuel (coal, fuel oil or natural gas), which then turns into steam and spins a steam turbine which drives an electrical generator. After passing through the turbine the steam is condensed either in a condenser tower or thanks to the river or sea water.

Another type of thermal power plants are those in which the waste heat from a gas turbine is used to raise steam to be recirculated through a second turbine in the so called combined cycle. The main characteristic of those power plants is its higher overall efficiency.

The main advantage of those power stations is the high amount of energy that can be generated, always necessary to meet the base demand of electricity.

On the other side the disadvantages can be listed as:

- Firstly, the typical low efficiency of a conventional thermal power station. Normally it is between 38 % and 48 %, limited as all heat engines by the laws of thermodynamics.
- Secondly, the low adaptability for coupling and decoupling to the electrical network. The times necessary to turn on/off the boiler are around seven hours. That led the plant engineers to consider sometimes the possibility of having the thermal power plants operating even when it is not necessary to generate electricity.
- Thirdly, the contribution to the increasing air pollution due to high emissions of greenhouse gases.

2.3.3. Nuclear power plants

The principle of operation is quite similar to the previous thermal power plants; in fact some classifications include those as another type inside thermal power plants.

However, in nuclear power plants heat is provided by nuclear fission inside the nuclear reactor core.

The nuclear fission process consists on an atomic nucleus which is hit by a neutron, then it forms two or more smaller nuclei as fission products, releasing energy and neutron which will trigger further fission and so on. The nuclear chain reaction is strictly controlled in order to harness the energy released to heat water and drive a turbine that generates electricity.

The electricity generated by power plants, like in the case of coal fire power plants, supplies the constant values of base demand as they can not be regulated to stop or begin working depending on the pick demands.

There are many pros and cons when debating the commissioning of new nuclear power plants. On the one hand, those proponents of the nuclear energy suggest that nuclear power is a sustainable source that reduces carbon emissions and increases energy security by decreasing dependence on foreign oil. On the other hand, critics state that nuclear power is potentially dangerous. As possible hazards they point to the problem of storage of radioactive waste and the possibilities of severe radioactive contamination by unexpected accidents.

2.3.4. Renewable energies

The majority of renewal energies are powered by the sun, directly harnessing the solar radiation in photovoltaic process or indirectly in form of wind and ocean currents. Despite some references consider hydro power as a renewable energy, the renewable power plants here considered are:

- Wind farms
- Biomass
- Photovoltaic

There are many others such as geothermal, biofuels, wave power or marine current but their global generation levels are much lower than the previous listed. Besides, they only operate in certain countries where their natural resources are available.

2.3.4.1. Wind power

Wind power is the conversion of wind energy into electricity using wind turbines. Initially wind turbines were used to provide electricity to isolated locations, currently wind turbines are implemented in large scale form of wind farms connected to the electrical grid.

Some of the advantages of this form of energy are: it is clean, easy to implement, has small environmental impact. However, it has a major drawback: the intermittency of wind sometimes creates problems when using wind power to supply big amounts of demand.

2.3.4.2. Biomass

The ambiguous term biomass refers to the use of wood, plants, waste or crops which are specially grown for electricity generation. Direct combustion in power plants burn the biomass fuel directly in boilers that heat water to make steam circulating through a turbine that spin a generator as it happens in a conventional thermal power plant. Another possibility is that offered by biomass gasification, where biomass is converted into gas methane that can then fuel steam generators, combustion turbines, combined cycle technologies or fuel cells.

Environmentally, biomass is considered as a "carbon neutral fuel" as it is part of the carbon cycle: Carbon from the atmosphere is converted in biological matter by photosynthesis. Then, burned carbon goes back into the atmosphere as carbon dioxide so plant matter can be used as a fuel that can be constantly replaced by new growth.

2.3.4.3. Photovoltaic

This technology consists on the conversion of sunlight directly into electricity by chemical processes happening on solar cells. This seems to be a future thriving alternative for the generation of energy as the manufacture of photovoltaic arrays has expanded dramatically in recent years. One of the main problems of this technology is the high capital cost of installation and material. However, some important PV power plants with outstanding peak powers of around 20 MW are currently operating in Spain and Germany.

2.4. Transmission

Electric power transmission process refers to the bulk transfer of electricity from the power plants generation areas to the populated and industrial demand areas. As most of the times power plants (such as hydroelectric) are located hundred of miles away from the consumer centres and the amounts of power involved are typically large, transmission power system works at high voltage levels of 220 KV or 400 kV to reduce the losses in the power line wires.

Another important duty of the transmission system is to interconnect the whole power system and give reliability to the global grid when large amounts of energy need to be transmitted to other regions of the power system.

Transmission networks are designed as efficiently as feasible was possible. Typically transmission lines use a three phase AC current system. An alternative is high voltage direct current (HVAC) but it is the only possibility when:

- Transmitting large amounts of power over very long distances. In the situation of interconnecting remote areas the transmission of energy using direct current instead of alternating current can be more economical due to the reduction of energy loss in the resistance of the wires.
- Interconnections between asynchronous grids. For technical reasons DC power facilitate transmission when interconnecting countries with different voltages or frequencies.
- Undersea cables. Where high capacitance causes additional losses in AC wires.

According to the Spanish regulations (Real Decreto 1955/2000) the main components that defined a transmission power system are:

- Power lines with voltages of 220 kV and above.
- Power lines interconnecting different countries, no matter the voltage level.
- Substations and all the relevant machinery (transformers, reactances, circuit breakers…) with voltages of 220 kV and above.

- Communication, control and protection devices
- Buildings and constructions necessary for the operation of the substations.

2.4.1. Substations

Substations can be found either in the generation, transmission or distribution stages. The main duties of a transmission substation are:

1. Interconnect two or more transmission lines.
2. Transform voltage from high to low or the reverse using transformer.
3. Connect and disconnect power lines.
4. Control and monitor power flow quality of the system. (Voltages and frequencies must keep between fixed values)

Substations content the following main elements:

- Transformers, to step up/down voltages
- Circuit breakers, used to interrupt any short circuits or overload currents
- Instrument transformers, necessary for the measure of currents and voltages
- Switches, for the safe operation of the workers.
- Reactances, which regulate voltage levels.
- Bus bars, where all the power lines drain electricity for redistribution.

Substation design does not follow standardized patterns, as there several options depending on the number of input / output power lines, number of transformers, lay out of the elements.

2.4.2. Power lines

Power lines operating in the transmission grid range from 220 kV and above. The reason of using those levels is no other than reducing losses in the wires due to Joule heating. For a given amount of power, a higher voltage reduces the current and thus the resistive losses in the conductors according to the formula “$P_{loss} = I^2 R$” where the major component of power loss is due to ohmnic losses in the conductors and is equal to the product of the square of the current and the resistance of the wire.

However there is a limit, at extremely high voltage levels (more than 2000 kV) corona discharge losses are so large that they can offset the lower resistance loss in the line conductors.

Very related with the power lines it is always the controversial issue about the effect of the electromagnetic fields. Some research has found that that exposure to elevated levels of magnetic fields such as those originates by transmission lines may be implicated in some diseases such as children leukemia.

2.5. Distribution

Distribution is the last stage of an electrical power system just before final consumption. It includes three voltage levels:

- High voltage: 132 kV – 66kV
- Medium voltage: 66 – 1kV

- Low voltage: Belo 1000 V

High voltage (below 132 kV) power lines leave from transmission substations to distribution substations through an interconnected network named distribution grid. In between, power lines may supply some industries demanding high voltage electricity.

Distribution substations are considerably smaller that transmission ones as they work with lower voltage levels. However, their main duties are basically the same: Interconnect transmission lines, transform voltages, connect and disconnect power lines, control and monitor power flow.

Power lines leaving distribution substation with medium voltage levels (66 – 1 kV) shape a local grid also known as radial network because its structure is not as interconnected as in previous stages. Those power lines can go directly to factories or to end consumers. But end consumers must receive low voltage electricity levels so the last transformation takes place in the either distribution transformer centres (for the case of urban areas) or pole-mounted transformers (for the case of rural areas).

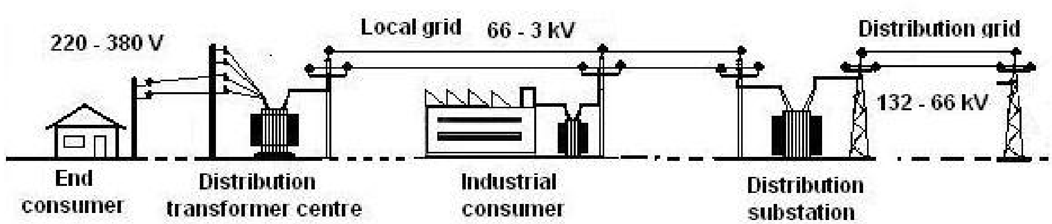


Figure 4. Distribution network [17]

2.6. Monitoring and protection

In order to maintain a reliable and safe power system it is necessary to carry out two important control activities in power plants, power lines and substations:

- Monitoring
- Protection

Monitoring means to be aware of the state of a system, so in the systems here studied, high voltage power systems, two stages of monitoring are distinguish:

First stage of monitoring takes place in a control centre where SCADA (Supervisory Control And Acquisition Data) is managed. In that stage all the basic components of the power system (power plants, power lines and substations) are controlled from a central computer system which monitors in real time power system variables such as generation in power plants, load flows in the lines, voltage levels in the substations or frequency distortion.

Those SCADA control centres take care of the power system general reliability.
The working procedure is the following: Firstly, SCADA receives all the power system variables from remote locations. Then, after studying the current situation of the system and simulating alternatives, SCADA offers the engineers the possibility to operate the system by remote control. In that way, they can order increases in the generation of

certain power plants or open/close lines in substations. All of that with the only purpose of maintaining a safety in power system.

Second stage of monitoring takes place in the power plants. It offers two possibilities of control:

- Speed regulation: Speed regulators duty consist of having generation meeting demand constantly. So if a generator slow down or speeds up due to an overall power imbalance frequency slightly varies. In order to bring frequency back to standard values speed regulator modifies the steam or water intake in the turbine.
- Voltage regulation: Voltage levels must remain between certain operation margins in order to have a secure system. Voltage levels can raise or fall depending on the reactive power of the system. So in situations such as a very high demand of reactive power or when capacitor banks supply to much reactive power, voltage regulators modify excitation current of the generators in order to have them generating more or less reactive power.

Power system protection deals with the protection of the electrical power system from faults by isolating the faulted part from the rest of the network. The most typical electrical fault is the short-circuit, an excessive electric current (over current) when it takes a different path from the one intended. Normally due to the accidental connection between two nodes of the circuit or due to the connection to ground.

Therefore, protection is carried out in power plants and substations:

- In power plants, electrical protection consist on measurement devices, alarms and tripping relays which take care of the generator.

- In substations, electrical protection take care of the whole high voltage grid (transformers and power lines) and consist on relays, circuit breakers and switches.

3. METHODOLOGY OF THE STUDY

3.1. Working procedure

The working procedure developed during the study of the current and future situations of the Asturian power system followed the next steps:

1. General description of the electrical network
2. Modeling the network
3. Power system simulation
4. Analysis of the results

3.1.1. General description of the electrical network.

Firstly for the current situation and later on for the future ones, general information about substations, generation, demand and power lines, (existing or predicted) were detailed in this introductory step of the study.

3.1.2. Modelling the network

As a general idea about the electrical network was already gained, the purpose of the second step of the project working procedure was to obtain detailed data necessary for building the model as well as built the model itself.

3.1.3. Power system simulation

Once the model was ready, next step consisted on carry on a series of diverse simulations depending on the situation of study. In that way the situations under study were the following:

- Current situation: Summer 2008
- Future situations:
  - Horizon 2011
  - Horizon 2015

Therefore the simulations carried out were the following:

- Current situation: Year 2008 simulations:
  - Standard situation
  - Contingencies situation (3 contingencies in power lines)
- Future situation:
  - Year 2011 simulations: (4 scenarios of new 400 kV power lines)
  - Year 2015 simulations: (3 scenarios of new power plants)

3.1.4. Analysis of the results

Load flow calculation was the analysis tool used for examining the electrical network. Results from the model simulation provided:

- Voltage profiles for the nodes
- Load percentages in power lines and transformers

Which were examined to verify the compliance or violation of the reliable operation conditions. In other words, voltage in the nodes must meet a permissible voltage range while load in the lines must remain below a maximum load limits.

3.2. Simulation tool

The simulation tool used for the modelling and simulation of the project case of studies was Power World Simulator, and interactive package for the operation of high voltage power systems.

Some of the features of the program are:

- User friendly interface: The Simulator allows visualizing the system through colorful and consistent one-line diagrams.
- Animated one line diagram: Simulator animates power lines flow as arrows along the line the size of which is proportional to the magnitude of the flow. Also provides pie chart that indicate the flow as a percentage of the line
- Interactive one line diagram: Circuit breakers that allow opening or closing lines, loads and generators with automatic recalculation of the system.
- Model Explorer: It offers spread sheet like views of power system data and tabulations. It allows sorting and filtering the data as well as copy to or from other applications.
- Numerous solution options: Full AC or DC solution; Single solution option or continuous; Convex cost curves; Post-power solution actions.
- Simulation control options: Specify maximum iterations; Step through the power flow solution by single iterations.
- Contingency analysis tools: Management, creation, analysis, and report list of contingencies and associated violations.

4. ASTURIAN ELECTRICAL NETWORK

As already said in the introductory chapter the present Project is centred on the study of Asturias, a region mainly characterized for being exporter in terms of energy.

To clarify the term "exporter", a map of the northern regions of Spain together with the energy exchanges among themselves (in GWh) is represented in the figure 5 shown below:

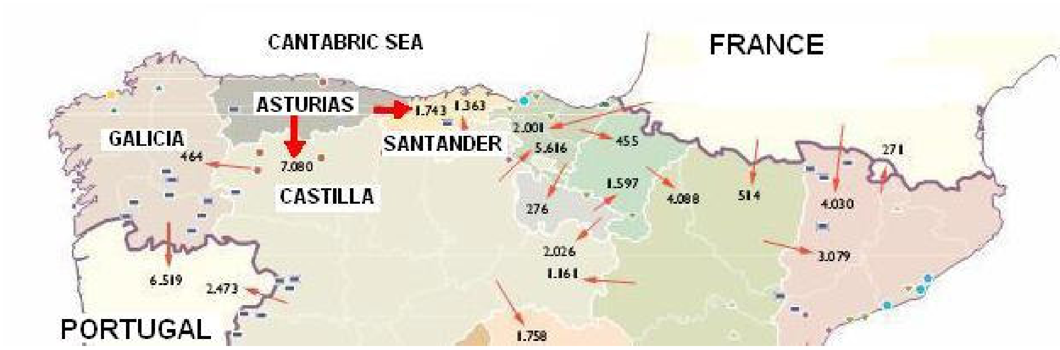


Figure 5. Energy exchanges in the north of Spain [2]

So Asturias holds a surplus of Energy that needs to send away to nearby regions:

Asturias → Castilla	7080 GWh
Asturias → Santander	1743 GWh

Table 1. Power flows between Asturias and border regions

4.1. Electrical companies in Asturias

Most of the electrical grid in the region is controlled by HC Energia, a company founded at the beginning of the 20th century with the aim of harnessing the energy from some waterfalls existing in the hilly areas of Asturias.

Nowadays HC Energia, subsidiary of EDP (Energia de Portugal) is in charge of the generation, transport (up to 220 kV) and distribution of electricity in Asturias. Transportation of 400 kV voltage level used to be also managed by HC Energia. However since the last decade, the recently created national organization Red Electrica España (REE) is in charge of the regulation and control of high voltage power lines over the whole national grid in Spain.

It also needs to be mentioned that the distribution of electricity in the North West area of the region and three councils in the south are controlled by Enel – Viesgo (E on).

Finally, there is a small third electrical company named Electra de Carbayin, which controls the council of Bimenes.

The map of Asturias with all its councils and the action area of each electrical companies working in Asturias is represented in the following figure 6.

Figure 6. Electrical companies working in Asturias [2]

4.2. Electrical areas in Asturias

In order to explain the electrical infrastructures currently existing, Asturian electrical network was divided in seven geographical areas: North West, South East, North (Aviles), North (Gijon), Centre (Oviedo), East and South.

In the following figure 7 the seven areas were sketched over the electrical-geographical map of the region:

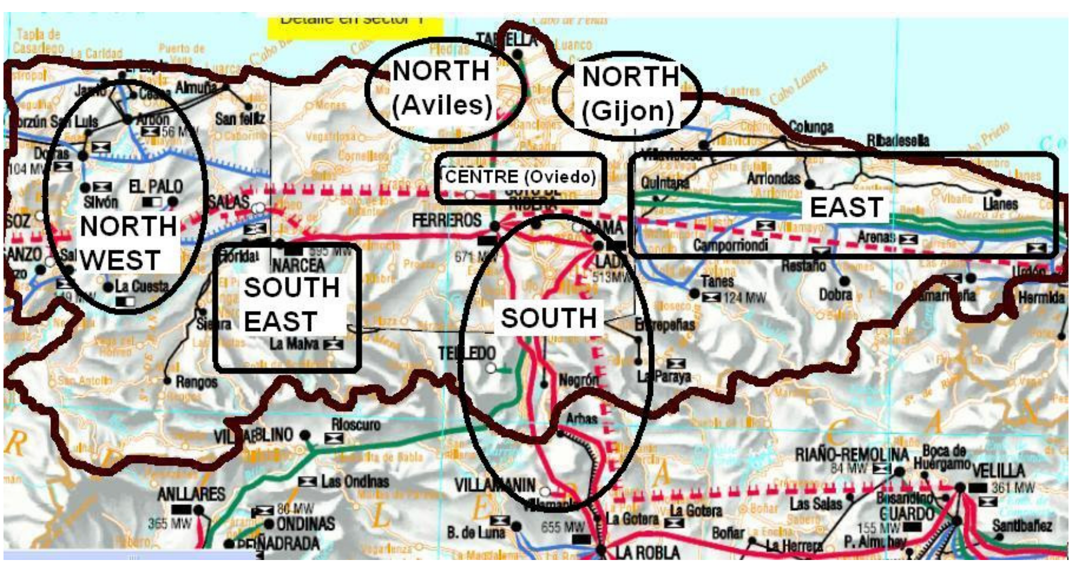


Figure 7. Electrical areas in Asturias [3]

- North West: This area is far from the main cities, the only electrical demand is due to some small towns and villages. However, it is characterized by favourable wind conditions. This fact led to the erection of some wind farms over the last eight years. Another point to emphasize in this area is the Hydro power plant of Salime which was the second biggest in Europe when finished during the fifties.

- South East: Referring to demographic population, as in the previous case, this area is characterized by many scattered villages around its forests and mountains. The large number of rivers that spring from those mountains made possible the construction of many hydro power plants years ago.

- North (Aviles): Aviles is the third biggest city in Asturias with a population of 83,500 inhabitants. It is located by the side of an estuary and characterized as an industrialized city. It holds many high energy demand industries such as the steel industry Arcelor-Mittal, the aluminum industry Alcoa or the chemistry DuPont.

- North (Gijon): Gijon is the biggest city in Asturias with a population of 279,000 inhabitants. It holds an important harbour currently under expansion for the erection of a future regasification plant that will fuel the future combined cycle power plant to be built in the region during the following seven years. It still keeps part of what used to be another big steel industry complex, Uninsa. Also a big coal fired power plant refrigerated by the sea water characterizing this area.

- Centre (Oviedo): Oviedo is the capital of Asturias with a population of 220,000 inhabitants. This town lacks industry, most of the economy of the city is oriented to the tertiary sector services. On the outskirts of the town it is located Corredoria substation, which distributes and delivers most of the energy in the 132 kV voltage level throughout Asturias.

- East: The east of the region has no remarkable industry, just some small towns and a large amount rivers that serve as settlement for many hydro power plants such as Dobra, Camarmeña, Camporriondi and Tanes.

- South: The south of the region is characteristized by having a thriving coalfield area during the last century (Nalon and Caudal coaldfields). Despite most of the mines closed over the last fifteen years some industries and mines continue with their modest production in the present days. Mainly because of the mining boom experienced in this area of Asturias during the fifties and sixties, it counts with three coal fired power plants Soto, Lada and La Pareda.

4.3. Substations

Here is a classification of the different types of substations existing in Asturias:

- Transmission substations: Their aim is to interconnect large power lines (400 and 220 kV voltage levels) and sometimes supply energy to big industry consumers.
- Distribution substations: Their aim is to reduce voltage levels from transmission power lines (400 and 220 kV) in order to deliver energy through distribution power lines (50 and 20 kV) to consumers.

- GIS (Gas insulated substations): This type of substation is four times smaller in comparison with a conventional one. They are completely enclosed using sulphur hexafluoride as insulator mean. This feature make them the best option when the room is very reduced, case of ground floors or building basements.
- Power plant substations: These substations are just at the side of power plants. Their aim is to step up voltage levels and so reduce losses and cost in the transmission of the generated energy.
- Industry substations: Very similar to power plant substations but in this case the objective is to step down voltage levels for the use of large amounts of energy. These substations usually are property of the factory they are supplying.

In the following table 2 all the substations existing in Asturias above the 132 kV voltage level are shown along with a description of their voltage level, area of location and a brief explanation about the type of substation they belong to according to the previous classification:

Name	Voltage levels	Area	Specifications
Corredoria	132	Centre(Oviedo)	Main distribution substation
San Esteban	132	Centre(Oviedo)	Distribution and GIS
Puente SanMig	220	East	Transmission substation
Siero	132 / 220	East	Transmission substation
Tanes	132	East	Hydro power plant substation
DuPont	132	North (Aviles)	Chemistry industry substation
Maruca	132	North (Aviles)	Steel industry substation
Tabiella	132 / 220	North (Aviles)	Transmission and distribution substation
Trasona	132	North (Aviles)	Distribution substation
Aboño	132 / 220	North (Gijon)	Coal fire powerplant substation
Carrio	132 / 220	North (Gijon)	Transmission and distribution substation
Castiello	132	North (Gijon)	Distribution and GIS
Pumarin	132	North (Gijon)	Distribution substation
Uninsa	220	North (Gijon)	Steel industry substation
Arbón	132	North West	Hydro powerplant substation
Cuesta-Palo	132	North West	Wind farm substation
Curiscao	132	North West	Wind farm substation
Doiras	132	North West	Hydro powerplant substation
Pico Gallo	132	North West	Wind farm substation
Salime	132	North West	Hydro powerplant substation
La Pereda	220	South	Coal fire powerplant substation
La Robla	400	South	Transmission substation
Lada	132 / 400	South	Coal fire powerplant substation
Langreo	132	South	Distribution substation
Soto	132 / 220 / 400	South	Transmission and powerplant substation
Ujo	132	South	Distribution substation
Villablino	220	South	Transmisión substation
La Barca	132	South West	Hydro powerplant substation
Miranda	132	South West	Hydro powerplant substation
Narcea	132 / 400	South West	Coal fire powerplant substation
Proaza	132	South West	Hydro powerplant substation

Table 2. Asturian substations

4.4. Generation

The three main types of power stations operating in Asturias are:

- Hydro power stations
- Coal fire power stations
- Wind farms

New emerging power plants such as PV panels, biomass or cogeneration plants were left behind in the present study for not presenting a considerable amount of energy generated in comparison with the total.

4.4.1. Hydro power stations

Due to Asturias topography and climate conditions (it is a mountainous and rainy region) dozens of small Hydropower plants are scattered around the South and East of the region. However all the hydro power plants with less than 10 MW of rated power were left aside for the work considered in the present study.

The hydro power plants considered for the model were:

Name	Maximum capacity (MW)	Area
Camporriondi	15	East
Dobra	14	East
Camarmeña	13	East
Salime	112	East
Arbon	56	North west
Doiras	42	North west
Silvon	63	North west
Tanes	125	North west
Proaza	48	South west
La Barca	54	South west
Miranda	65	South west

Table 3. Asturian hydro power plants [4]

The hydro power plants shown above are represented in the following map of Asturias:

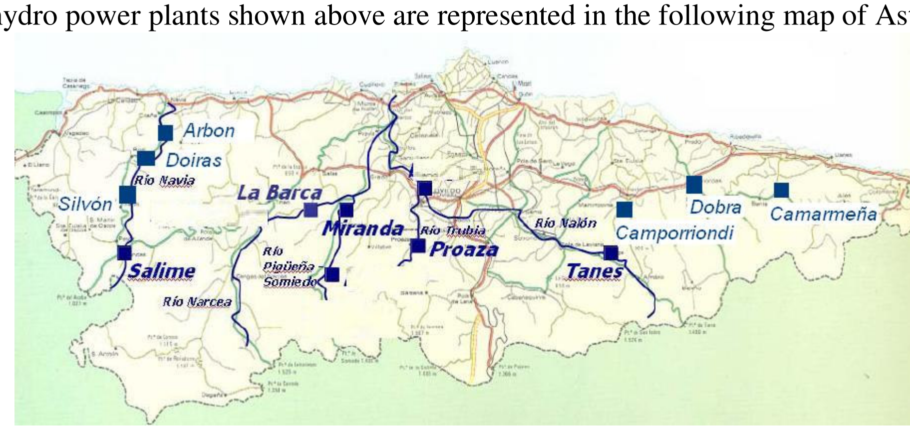


Figure 8. Asturian hydro power plants [19]

Some of the most important power plats are explained more in detail over the following lines.

4.4.1.1. La Barca hydro power plant

This power station property of HC Energia was built in 1966. The first two generators started working in 1967 and a third one later in 1974. It is placed in the course of Narcea River, one of the most important in the region. The typology of the power plant corresponds to a typical arch gravity hydroelectric dam made of concrete and seated in between the natural walls of two rocky mountains. The dam is sixty meters high and the length of the reservoir is around eight miles.

Rated power	55.3 MW
Effective head	58 m
Turbine model	Francis
Number of turbines	Three
Mean energy generated per year	135000 MWh

Table 4. La Barca hydro power plant [19]

4.4.1.2. Miranda hydro power plant

This power station presents a run off the river typology with a 385 meter fall. It was built in 1962; in this same year the four generators coupled to Pelton turbines began working. In that case no big dams are necessary because the water is taken from small reservoirs existing up in the mountain and diverted through a subterranean pipe to the turbine building inside the mountain.

Rated power	64.8 MW
Effective head	385
Turbine model	Pelton
Number of turbines	4
Mean energy generated per year	250000 MWh

Table 5. Miranda hydro power plant [19]

4.4.1.3. Salime hydro power station

The project of this impressive hydroelectric arch gravity dam power station began to take shape after the conclusion of the WW II, but it was not until 1953 when the overambitious dam was inaugurated. At that time it was the second biggest in Europe. The first position was held by another one already working in Russia. Due to the rugged landscape of the location the previous works to the erection were very complex. It was even necessary to build a 24 miles cable railway to carry all the clinker cement from the nearest harbour.

Rated power	112 MW
Effective head	114
Turbine model	Francis
Number of turbines	4
Mean energy generated per year	350000 MWh

Table 6. Salime hydro power station [19]

4.4.1.4. Tanes hydro power station

This hydroelectric power station was built between 1970 and 1978. It has two reservoirs up river. While the second one has only a capacity of 2.8 Hm3 the first one, just upriver the turbine room, has a capacity of 25.3 Hm3. Other important characteristics of this power station are: First, it is the only one in Asturias that has pumping system. Second, the main reservoir store and supply water to the whole central region of Asturias.

Rated power	123 MW
Effective head	102 meters
Turbine model	Francis
Number of turbines	2
Mean energy generated per year	85000 MWh

Table 7. Tanes hydro power station [19]

4.4.1.5. Proaza hydro power station

Proaza hydro power station was constructed in 1968 by the electrical company HC Energia. It runs off the river Nalon river basin and present 138 meter fall pipe which carry the water from an upper reservoir to the turbine room where two Francis turbines coupled tow 14 MW generators are installed.

Rated power	48 MW
Effective head	138 meters
Turbine model	Francis
Number of turbines	2
Mean energy generated per year	100000 MWh

Table 8. Proaza hydro power station [19]

4.4.1.6. Prianes hydro power station

Finally Priañes power station is an old one constructed in 1952. By that time it was composed of two generators. In 1967 a third group turbine-generator was installed. The water harnessed in the turbines comes from the Nora river reservoir which is also used to supply water to the close village of Priañes.

Rated power	18.43 MW
Effective head	18 meters
Turbine model	Kaplan
Number of turbines	3
Mean energy generated per year	60000 MWh

Table 9. Priañes hydro power station [19]

4.4.2. Coal fire power stations

the basis of electrical generation in Asturias are thermal power plants. All of them are coal fire power plants, mainly due to the mining past history of the region. The two main coalfields of the region are:

- Narcea coalfield in the south west
- Nalon and Caudal coalfield in the south

Power plants currently operating in Asturias are:

Name	Maximum capacity (MW)	Area
Aboño	930	North (Gijón)
Soto	675	South
Narcea	595	South West
Lada	505	South
La Pereda	50	South

Table 10.Asturian coal fire power stations [2]

Asturian coal fire power plants along with asturian coalfields are represented in the following map:

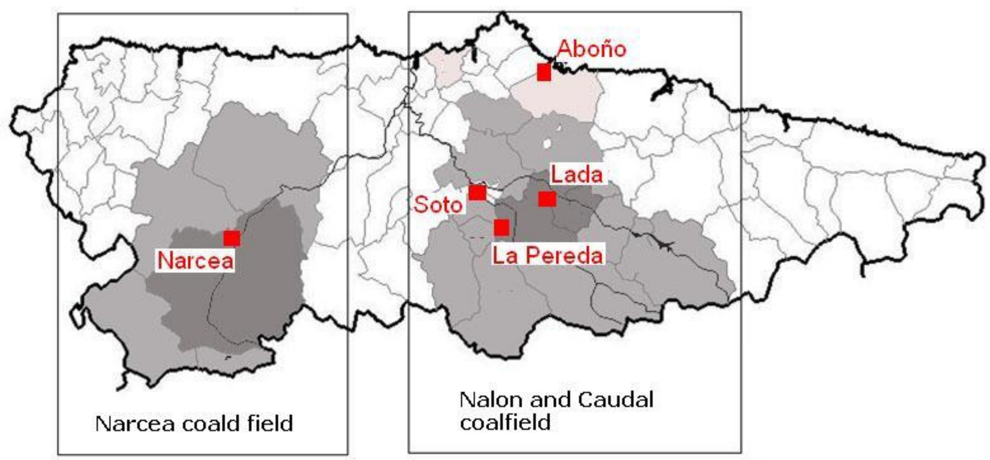


Figure 9. Asturian coalfields [20]

4.4.2.1. Aboño coal fire power station

The conventional coal fire power station of Aboño is located 6 miles away from the city of Gijon and just 2 miles from the harbour. The proximity to the main harbour made the erection of a cooling tower unnecessary. The cooling process is carried out thanks to the proximity to the sea water.

Generation unit	Power output (MW)	Commision date
Aboño I	380	1974
Aboño II	545	1985

Table 11. Aboño coal fire power station [2]

4.4.2.2. Soto coal fire power station

Soto coal fire power station is located 5 miles away from Oviedo, the capital of Asturias. Despite being constructed by a riverbank the cooling process is carried out thanks to a cooling tower in order to avoid overheating the water of the river Nalon.

Generation unit	Power output (MW)	Commision date
Soto I	70	1967
Soto II	255	1967
Soto III	350	1984

Table 12. Soto coal fire power station [2]

4.4.2.3. Narcea coal fire power station

This power station is the only one existing in the southwest coalfield of Asturias. Originally it was designed to burn the coal surplus extracted from this area. However, over the last years, due to the decrease in the extraction of coal from the mines, the power station had to modify its structure in order to begin admitting imported coal.

Generation unit	Power output (MW)	Commision date
Narcea I	65	1965
Narcea II	166	1969
Narcea III	365	1984

Table 13. Narcea coal fire power station [2]

4.4.2.4. Lada coal fire power station

Despite the fact this power station is criticized by the Green Party due to the increased contamination in the area. It is importance over the last years was crucial for the welfare of the mines in Asturias. As this power station harnesses the bituminous coal that comes from the main coalfield existing in the south of Asturias.

Generation unit	Power output (MW)	Commision date
Lada I	155	1967
Lada II	350	1981

Table 14, Lada coal fire power station [2]

4.4.2.5. La Pereda coal fire power station

La Pereda is a small power station constructed by Hunosa, the main mining company in Asturias. As Hunosa is not a consolidated electrical company La Pereda is a very small power station with just one 50 MW generator. However it is under planning a future expansion to a new combined cycle generator.

Generation unit	Power output (MW)	Commision date
La Pereda	50	1974

Table 15. La Pereda coal fire power station [2]

4.4.3. Wind farms

The number of wind farms currently operating in Asturias is 11, however there are 35 proposals in process for the construction of new wind farms over the following years that would increase the current capacity of 291 MW to around 1000 MW. The favourable wind conditions existing in the western areas of the region have encouraged many companies to study the area and prepare several wind farm projects.

So far the wind farms currently operating in the region are shown in the following table:

Name	Company	Towers	kW (generator)	Maximum capacity (MW)	Area (County)
Pico Gallo	Northeolic	37	660	24.42	North West (Tineo)
Penouta	Parque eolico de Penouta	9	660	6	Noth West (Boal)
Cuesta	Sinae energia y medio ambiente	12	750	9	North West (Salime Allande)
Palo	Sinae energia y medio ambiente	59	660	38.9	North West (Salime Allande)
La Bobia	Terranova energy corp	58	600	34.8	North West (Illano)
San Isidro	Terranova energy corp	58	600	34.8	North West (Illano)
El acebo	Sinae energia y medio ambiente	27	750	20.2	North West (Grandas Salime)
Bodenaya	Northeolic	18	1000	18	Sout West (Salas)
Curiscao	Sinae energia y medio ambiente	63	690	42.5	North West (Salas y Valdes)
Belmonte	Barbao	53	660	35	South West (Belmonte)
Baos y Pumar	Sinae energia y medio ambiente	41	750	30.6	North West (Salas, Cudillero y Valdes)

Table 16. Asturian wind farms [4]

Wind farms are also represented in the map of Asturias shown in the following figure:

Figure 10. Asturian wind farms [7]

Some wind farms such as "La Bobia and San Isidro" or "Cuesta and Palo" are represented together due to the close distance between each other and also because they are owned by the same company.

4.5. Demand

Since Asturias is an energy exporting region, first distinction within demand of electrical energy can be made between internal and external demands. The energy surplus, available to meet external demand (72.7 %), can be up to more than twice the internal consumption (27.3 %). In that way external demand is organized as follows:

- Doiras: A 5 % of the total 72.7% surplus is sent to the west bordering region (Galicia) through Doiras substation which is already in the border.
- Puente San Miguel: A 20 % of the total surplus energy is sent to the east border through the double circuit 220 KV power line Siero – Puente San Miguel.
- Villablino: Another 5% of the total energy surplus is sent to the south-western border through the 220 kV line La Pereda – Villablino.
- La Robla: Finally, most of the energy to be evacuated from Asturias (up to 70 % of the total surplus) follows the southern route to the rest of the peninsula. The lines used for this purpose are the 400 kV lines Soto – La Robla and Lada – La Robla. [21]

In the following figure 11 a pie chart shows the final energy demands from Asturias and from neighbouring regions:

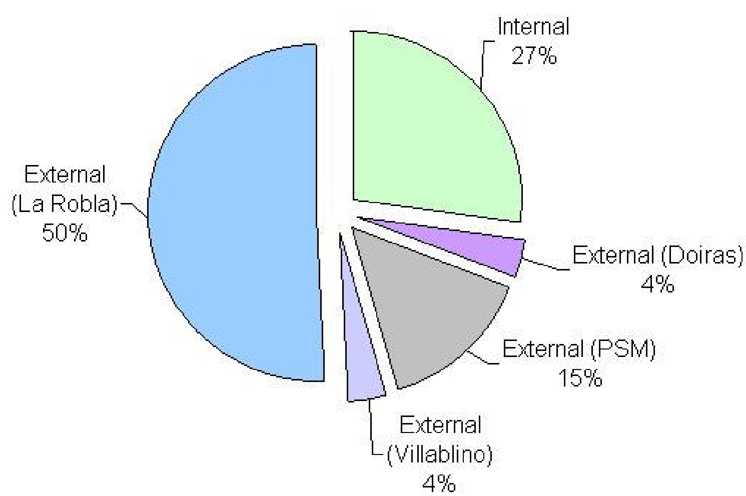


Figure 11. Internal / External energy demand in Asturias

The internal demand of energy (27.3 %) was divided in two major groups:

- On the one hand, Industrial demand, which represents approximately a 70% of the internal consumption with strong demand in the following nodes:
    - Aszinc (10.65%), which supplies energy to the chemistry industry Asturiana de Zinc.

- La Granda (3.59%), which supplies energy to the aluminum industry Alcoa.
- Uninsa (10.34%), which supplies energy to the steel industry Arcelor Mittal.

- On the other hand, home, tertiary sector and transport demands representing the remaining 30 %.

In the following figure 12, the pie chart shows the division existing within the internal demand of energy in Asturias:

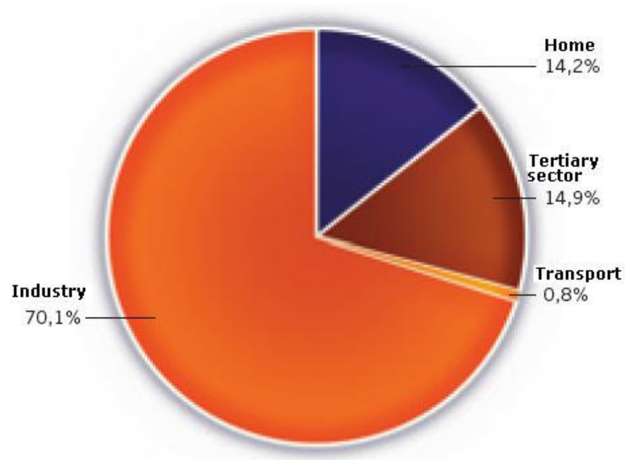


Figure 12. Internal energy demand in Asturias [6]

4.6. Power lines

Asturian power lines interconnecting generation and demand points through the substations previously shown are represented in the following tables according to their voltage level:

400 kV Power lines		
From	To	Duty
Soto	Lada	Interconnect South 400 kV substations
Narcea	Soto	Transport generation from Narcea Coal fire power plant
Soto	La Robla	Evacuate of energy towards the south of Asturias
La Robla	Lada	
220 kV Power lines		
From	To	Duty
Tabiella	Carrio	Transport energy from the Noth (Gijon) generation area to North (Aviles) demand area
Tabiella	Carrio	
Tabiella	Soto	Transport not consumed energy from North to South areas
Carrio	Uninsa	Supply energy to Metallurgy industries
La Pereda	Soto	Evacuate energy towards the south of Asturias
La Pereda	Villablino	
Aboño	Carrio	Transport energy from generation substation of Aboño to distribution substation of Carrio
Aboño	Carrio	
Carrio	Soto	Transport energy from North to South for later evacuation
Siero	Puente SanM	Evacuate energy towards the east of Asturias
Siero	Puente SanM	
Siero	Soto	Transport energy from South to East for later evacuation
132 kV Power lines		
From	To	Duty
Trasona	DuPont	Supply energy to Chemistry industry
Pumarin	Castiello	Supply energy to Gijon city
Salime	Cuesta-Palo	Interconnect wind farms
Arbon	Pico Gallo	Interconnect wind farms
Corredoria	Tabiella	Distribute energy from Centre to local consumption in the North (Aviles)
Corredoria	Tabiella	
Langreo	Lada	Supply energy to residential areas and small industry
Ujo	Doiras	Transport energy from the North West to the South for later evacuation
Ujo	Pico Gallo	
Pumarin	Tanes	Transport of energy from Tanes Hydro power to North (Gijon)
Castiello	Corredoria	Distribute energy from Centre to local consumption in the North (Gijon)
Langreo	Corredoria	Distribute energy from Centre to local consumption in the South
Tabiella	Trasona	Supply energy to Metallurgy industry
San Esteban	Proaza	Transport of energy from Proaza Hydro power to Centre (Oviedo)
Arbon	Doiras	Transport energy from Arbon hydropower for later evacuation towards the West
Carrio	Aboño	Transport energy from generation substation of Aboño to distribution substation of Carrio
Ujo	Siero	Transport energy from South to East for later evacuation
La Barca	Narcea	Transport energy from La Barca hydropower to Narcea Substation for later 400 kV transport
Pumarin	Corredoria	Distribute energy from Centre to local consumption in the North (Gijon)
Corredoria	San Esteban	Interconnect distribution substations

132 kV Power lines		
From	To	Duty
Soto	Ujo	Distribute energy to local consumption in the South
Narcea	Trasona	Transport energy from South West to North (Aviles)
Curiscao	La Barca	Transport energy from North West wind farms to South West for later evacuation
Soto	San Esteban	Distribute energy from South to local consumption in the Centre area
Tabiella	Maruca	Supply energy to Metallurgy industry
Tabiella	Maruca	
La Barca	Trasona	Transport energy from South West to North (Aviles)
Ujo	Lada	Distribute energy to local consumption in the South
Cuesta-Palo	Corredoria	Transport of energy of North West wind farms to the Centre area
Salime	Corredoria	
Corredoria	Siero	Transport energy from Centre to East for later evacuation
Miranda	Corredoria	Transport of energy of South West hydro power plants to the Centre area
Lada	Soto	Interconnect South substations

Table 17. Asturian power lines

5. STUDY OF THE CURRENT SITUATION (2008)

5.1. Acquisition of reliable data for the model

In the previous chapter, general aspects of generation, transmission, distribution and demand stages of the Asturian electrical power system were presented. However, in order to build the model for the simulations it is necessary to found a reliable source offering more detailed information related to:

1. Technical data of from power lines and substations (power line capacities, length, resistance parameters…)
2. Real time load flows in power plants and consumption areas (power outputs, load demands…)

The source consulted to obtain the data was Red Electrica España (REE).

REE is the national company in charge of the global working of the Spanish electrical network. The duties of the company could be summarized as:

- Transport of high voltage electricity (220 kV – 400 kV) throughout the country.
- Interconnections with vicinity countries (France, Portugal and Morocco)
- Control and operation of the Spanish electrical network from its central offices in Madrid.

REE website has a section named "e.sios" where it is possible to access and download real time data about the whole Spanish power system. The procedure followed to obtain this data is explained as follows:

1. Once log in the website http://esios.ree.es , there is an upper toggle bar with an option called "Publicaciones OS".
2. After clicking, another toggle bar turns up on the left side with an option called "Casos PSS/E".
3. After clicking, a field for the search of monthly publications pop ups in the centre of the screen. When selecting a month a list with daily files is shown on the web site.
4. Those files in .zip format contain all the power system data for the related day.

In the following figure the process detailed above is shown as it looks on the website:

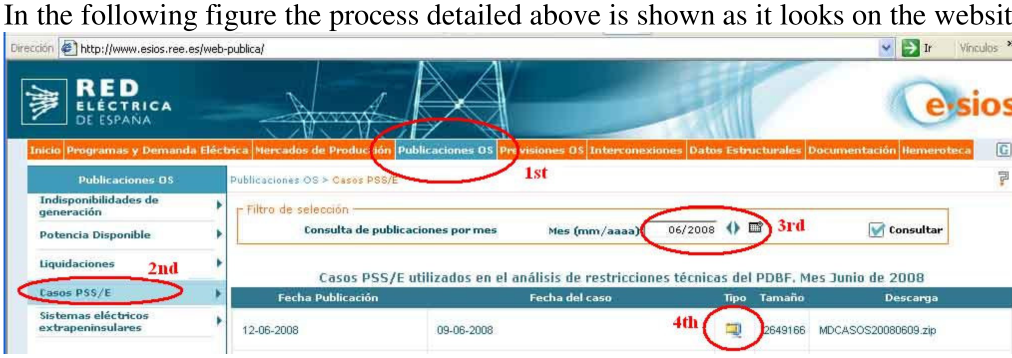


Figure 13. REE website capture

These files are suitable for working with SIEMENS transmission system analysis and planning program PSS/E. However they can also be opened with any word processor. The only disadvantage when opening the files with a word processor is found in the way the information is shown, as the data is difficult to identify. Nevertheless, the data can be easily distinguished with the aid of a PSS/E user guide.

The lengthy information supplied in those files is related to the whole Spanish electrical grid. So for the present study just information related to Asturias was taken into consideration.

The essential information picked up from the files for elaboration of the Asturian model was:

- BUS DATA (Substations information): Nodes number, names, voltage levels, location.
- LOAD DATA (Demand information): Demand nodes, Load values, nature of the load.
- GENERATOR DATA (Generation information): Generation nodes, power generation, maximum generation, type of generation.
- BRANCH DATA (Power lines information): Origin and end of each line, length, voltage levels, power capacity, load flow, line parameter.
- TRANSFORMER DATA (Transformers information): Nodes interconnected voltage levels, power capacity, load flow, transformer parameters.

5.2. Modelling the network

First of all, before going in depth with the modelling procedure, main characteristics of the network to be modeled for simulations of the current situation (summer 2008) need to be outlined:

- <u>According to voltage levels</u>: 132 kV, 220 kV and 400 kV voltage levels were considered for the modelling of the network. Those voltage levels are represented in substations and power lines. Lower voltage levels such as 50 and 20 kV were rejected as those lines are mainly used for the distribution of energy in between localities and the connection of small hydro power stations with less than 5 MW of power installed.

- <u>According to demands</u>: Considerable industrial demands, general consumption from main urban areas and external export are the demands taken into account for the model.

- <u>According to generation</u>: The power stations represented in the model are most of the hydro power plants (all over 10MW), all the coal fire power plants and all the wind farms in operation so far.

Over the following pages it is described which data was essentially necessary supply to Power World simulator when building the model of the current situation. It is also detailed the data itself in tables as well as what assumptions and simplifications were considered for the model under study.

The elements included in Power world model were:

- Buses
- Loads
- Generation
- Power lines
- Transformers

5.2.1. Bus data

Bus is the term used by Power World when referring to the nodes representing voltage levels of a substation. That is the reason why in the following tables some nodes were represented two of three times, because they could refer to either 132 or 220 or 400 kV for the substation in question.

It was necessary to introduce the following data into Power World when laying out the nodes:

- Node Number, which is assigned by REE
- Node Name, it usually coincides with the name of the substation
- Voltage Level, each of the voltage levels in the substation

The nodes considered in the present study are listed in the following table:

Node Number	Node Name	Voltage (kV)	Area
1040	Corredoria	132	Centre (Oviedo)
1158	San Esteban	132	Centre (Oviedo)
21160	Puente SanMiguel	220	East
1159	Siero132	132	East
21185	Siero220	220	East
1180	Tanes	132	East
1044	DuPont	132	North (Aviles)
1081	Maruca	132	North (Aviles)
1177	Tabiella132	132	North (Aviles)
21200	Tabiella220	220	North (Aviles)
4447	Aboño132	132	North (Gijon)
24125	Aboño220	220	North (Gijon)
1018	Carrio132	132	North (Gijon)
21025	Carrio220	220	North (Gijon)
1021	Castiello	132	North (Gijon)
1098	Pumarin	132	North (Gijon)
1189	Trasona	132	North (Gijon)
61215	Uninsa	220	North (Gijon)
1001	Arbón	132	North West
2001	Cuesta-Palo	132	North West
61216	Curiscao	132	North West
1043	Doiras	132	North West
2018	Pico Gallo	132	North West
1155	Salime	132	North West
21117	La Pereda	220	South
11030	La Robla	400	South

Node Number	Node Name	Voltage (kV)	Area
1072	Lada132	132	South
11035	Lada400	400	South
1075	Langreo	132	South
1162	Soto132	132	South
21195	Soto220	220	South
11065	Soto400	400	South
1204	Ujo	132	South
21240	Villablino	220	South
1064	La Barca	132	South West
1090	Miranda	132	South West
1099	Narcea132	132	South West
11050	Narcea400	400	South West
1129	Proaza	132	South West

Table 18. Power World model nodes [21]

The most logical way to place the nodes in the one lien diagram was to follow the geographical location of the substation they represented.

In this way, and taking also into account the seven electrical areas considered in the previous chapter (North West, South West, North-Gijon, North-Aviles, Centre-Oviedo, South and East) Power World one-line diagram looks as it is shown in the following figure 14:

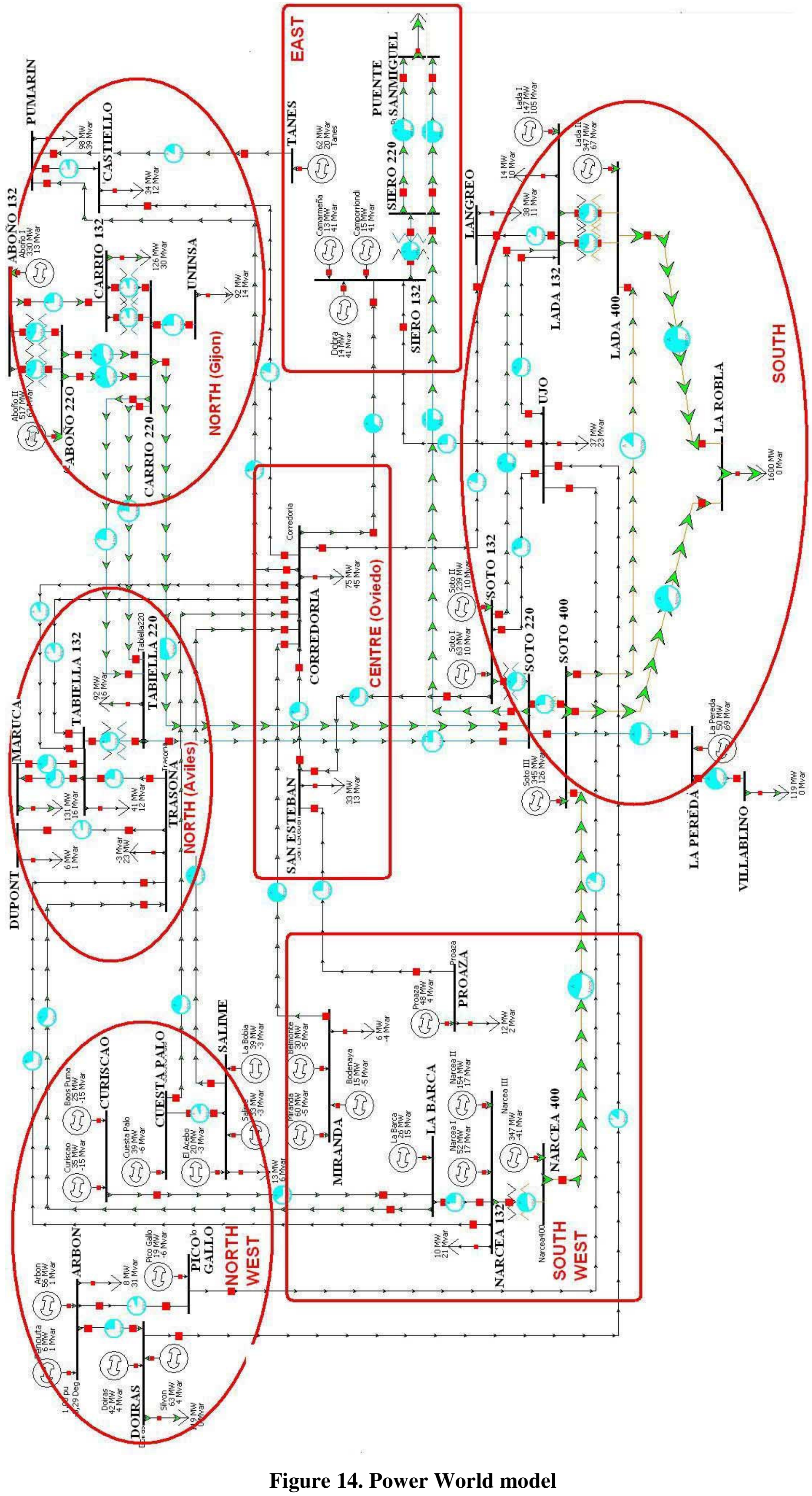


Figure 14. Power World model

5.2.2. Load data

Energy demand was set considering a peak demand hour (11.30am) of a week day during the summer month of June. Loads were grouped together and named according to the node they were attached. This simplification involves loosing some information related to the different consumers they could represent, as it is not specified if it is industrial or home demand. Nevertheless, the type of demand was specified in the last column of the table 19.

It was necessary to introduce the following data into Power World when laying out the loads:

- Bus Number
- Bus Name
- MW Value: Real power demand
- Mvar Value: Reactive power demand

The loads considered in the present study are listed in the following table:

Node Number	Load / Node Name	Voltage (kV)	Area	Load (MW)	Type of demand
11030	La Robla	400	South	**1659**	**External**
21160	Puente San Miguel	220	East	**474**	**External**
1081	Maruca	132	North (Aviles)	**131**	**Industrial (chemistry)**
1018	Carrio	132	North (Gijon)	**126**	**Industrial (aluminum)**
1043	Doiras	132	North West	**118**	**External**
21240	Villablino	220	South	**118**	**External**
1098	Pumarin	132	North (Gijon)	**98**	**Industrial / home / tertiary**
61215	Uninsa	220	North (Gijon)	**92**	**Industrial (steel)**
21200	Tabiella	220	North (Aviles)	**92**	**Industrial / home / tertiary**
1040	Corredoria	132	Centre (Oviedo)	**75**	**Home / tertiary**
1177	Tabiella	132	North (Aviles)	**41**	**Industrial**
1075	Langreo	132	South	**38**	**Industrial / home / tertiary**
1204	Ujo	132	South	**37**	**Home**
1021	Castiello	132	North (Gijon)	**34**	**Home / tertiary**
1158	San Esteban	132	Centre (Oviedo)	**33**	**Home / tertiary**
1189	Trasona	132	North (Aviles)	**23**	**Industrial**
1072	Lada	132	South	**14**	**Home / tertiary**
1155	Salime	132	North West	**13**	**Home**
1129	Proaza	132	South West	**12**	**Home**
1099	Narcea	132	South West	**10**	**Home**
1001	Arbon	132	North West	**8**	**Home**
1090	Miranda	132	South West	**6**	**Home**
1044	DuPont	132	North (Aviles)	**6**	**Industrial**

Table 19. Power World model loads [21]

Layout of the Asturian electrical grid one-line diagram modeled with Power World is shown again in the following figure 15, but highlighting now the external demand (in red) and internal demand (in blue):

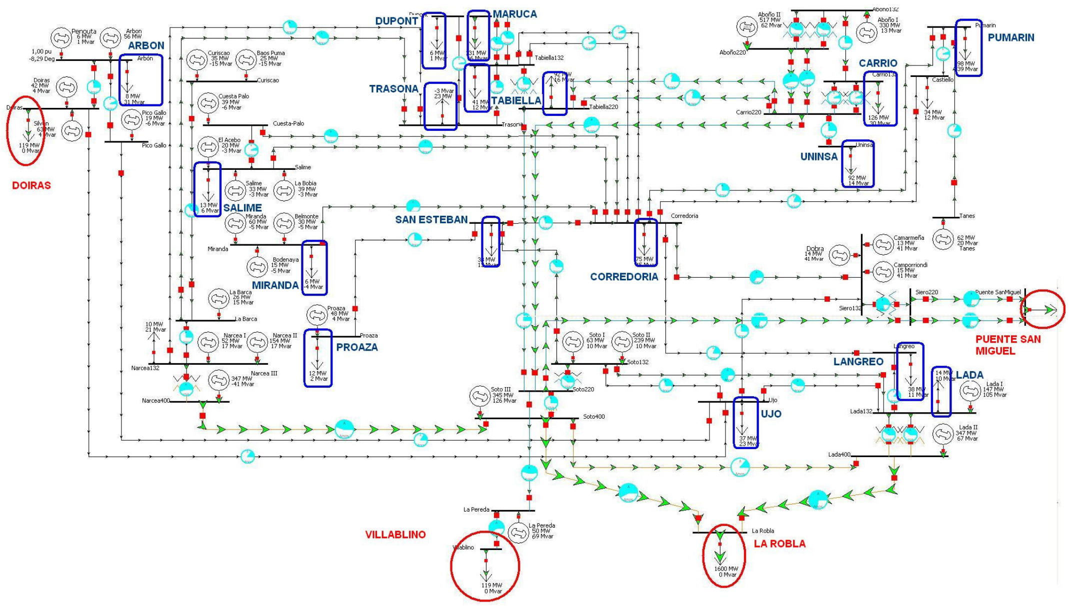


Figure 15. Power world model loads

5.2.3. Generator data

It was necessary to specify the following data when entering generator values in Power World:

- Bus Name
- Bus Number
- MW Output: Real power being generated during the simulation.
- Max MW Output: Maximum power output from the generator.
- Mvar Output: Reactive power being generated during the simulation (despite this is only an initial value as the reactive power is fixed by Power world after the load flow simulation)
- Unit type: The type of unit the generator represents, such as combined cycle, steam, hydro, wind farm…

Rest of fields were left as default.

The power plants considered in the model under study were coal fire, hydro and wind farms. Leaving apart small hydropower plants (below 10MW) and other renewal energies not yet consolidated in the region such as the small scale PV panels or biomass plants.

COAL FIRE POWER PLANTS GENERATION						
Power Station	Unit name	Node name	Voltage (kV)	Max. Power Output (MW)	Power output (MW)	Area
ABOÑO	Abono I	Abono	132	380	330	North (Gijon)
	Abono II	Abono	220	543	525	
LA PEREDA	La Pereda	La Pereda	220	50	50	South
LADA	Lada I	Lada	132	155	147	South
	Lada II	Lada	400	350	347	
NARCEA	Narcea I	Narcea	132	65	52	South West
	Narcea II	Narcea	132	166	154.2	
	Narcea III	Narcea	400	364	347	
SOTO	Soto I	Soto	132	70	62.8	South
	Soto II	Soto	132	255	239	
	Soto III	Soto	400	350	346	

Table 20. Power World model generators (coal fire) [21]

Most of the power plants are located in the North (Gijon) and South areas:

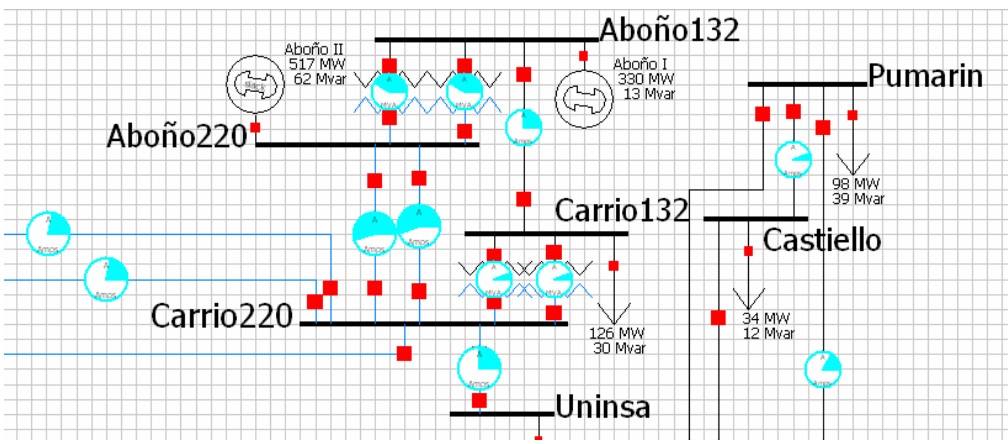


Figure 16. Power world model generators (North -Gijon)

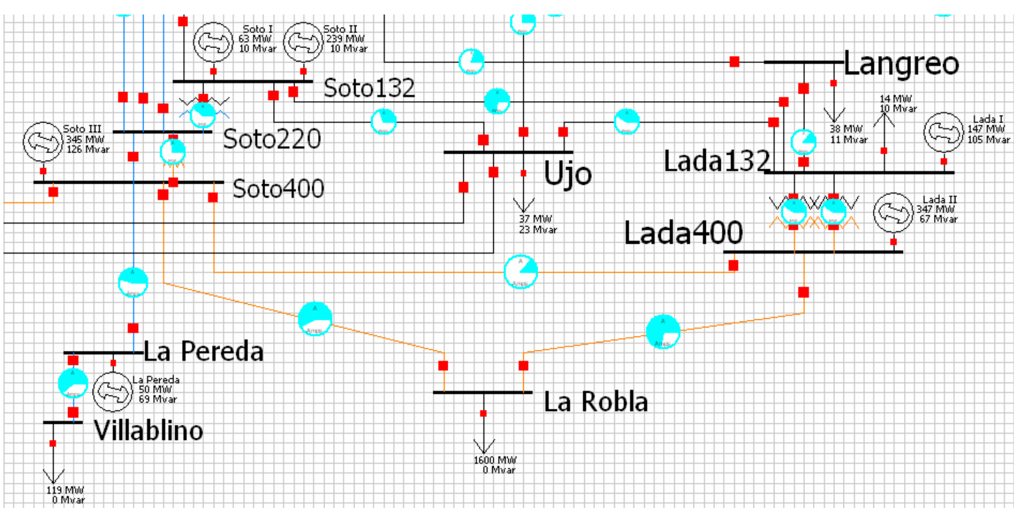


Figure 17. Power world model generators (South)

HYDRAULIC POWER PLANTS GENERATION					
Power Station	Node name	Voltage (kV)	Max. Power Output (MW)	Power output (MW)	Area
Proaza	Proaza	132	48	48	South West
Arbon	Arbon	132	56	56	North West
Camporriondi	Siero	132	15	15	East
Dobra	Siero	132	14.4	14	East
Camarmeña	Siero	132	13	13	East
Doiras	Doiras	132	42	42	North West
Silvon	Dorias	132	63	63	North West
Tanes	Tanes	132	125	62	East
La Barca	La Barca	132	54	26	South West
Salime	Salime	132	112	33	North West
Miranda	Miranda	132	65	60	South West

Table 21. Power World model generators (hydro) [21]

Hydro power plants can be found either in the east or west of the region.

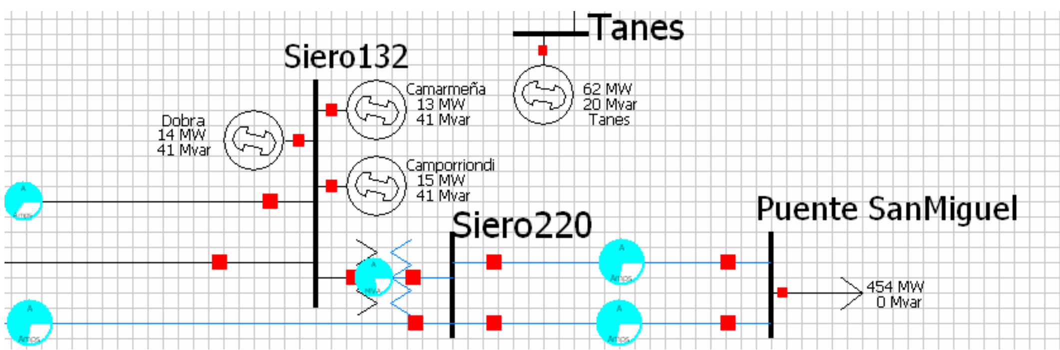


Figure 18. Power World model generators (East)

WINDFARMS GENERATION					
Wind farms	Node name	Voltage (kV)	Max. Power Output (MW)	Power output (MW)	Area
Pico Gallo	Pico Gallo	132	24	19	North West
Penouta	Arbon	132	6	6	North West
Cuesta - Palo	Cuesta Palo	132	48	39	North West
La Bobia-San Isidro	Salime	132	67	39	North West
El Acebo	Salime	132	20	20	North West
Bodenaya	Miranda	132	18	15	South West
Curiscao	Miranda	132	43	35	South West
Belmonte	Miranda	132	35	30	South West
Baos - Pumar	Miranda	132	31	25	South West

Table 22. Power World model generators (wind farm) [21]

Finally, wind farms mostly can be found in the west.

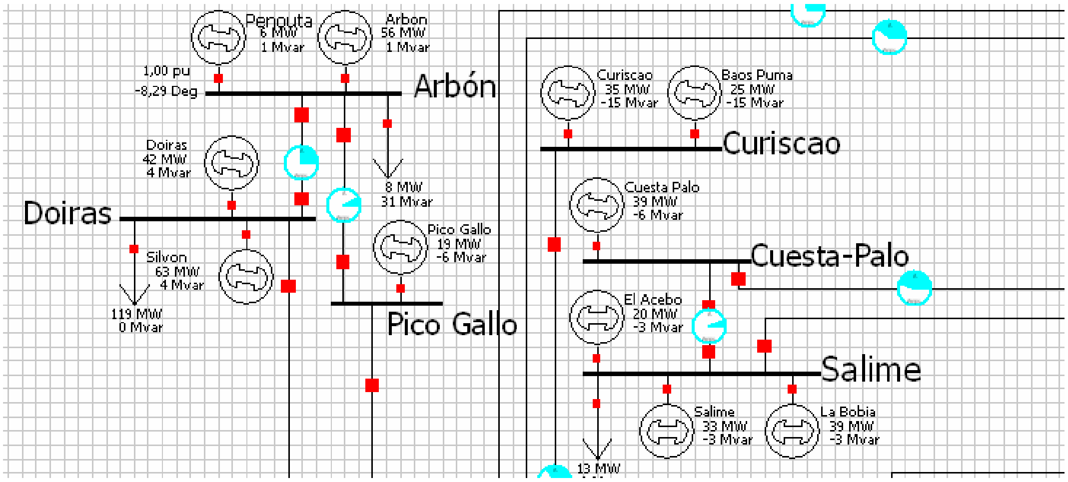


Figure 19. Power World model generators (North West)

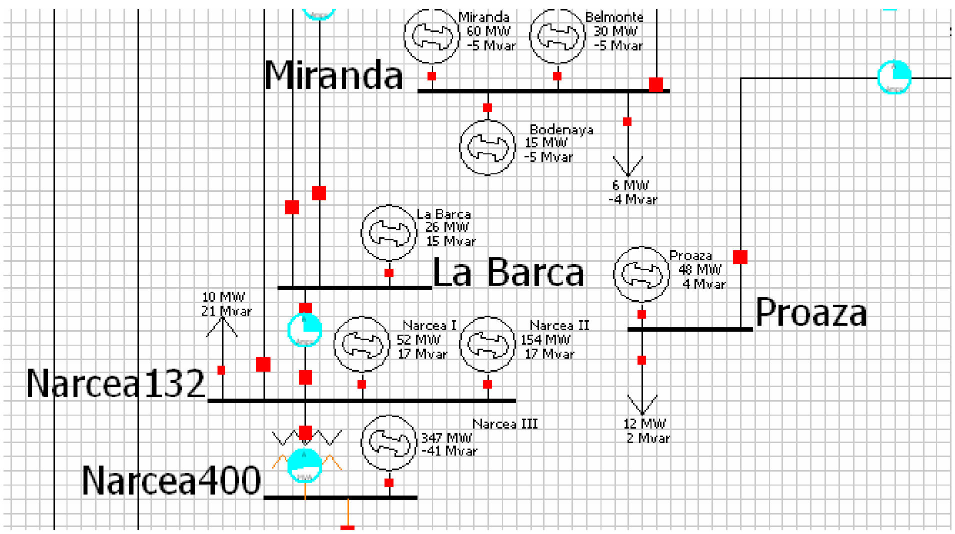


Figure 20. Power World model generators (South West)

5.2.4. Branch data

It was necessary to specify the following data when entering power lines in Power World:

- From / To Bus: Initial and final node of the line
- Voltage level
- Length: In miles
- R Series resistance: Per unit impedance parameters
- X Series reactance: Per unit impedance parameters
- B shunt charging: Per unit impedance parameters
- MVA limits: Capacity of the line

Lines represented in the model along with their characteristics are shown in the following table 23:

From	To	Voltage (kV)	Capacity (MVA)	Length (miles)	R (pu)	X (pu)	B
Trasona	DuPont	132	280	2.49	0.00139	0.00653	0.0207
Pumarin	Castiello	132	190	3.11	0.0019	0.0101	0.0044
Salime	Cuesta-Palo	132	100	18.64	0.0551	0.55096	0.03
Arbon	Pico Gallo	132	200	21.75	0.01994	0.03994	0.01
Corredoria	Tabiella	132	280	23.61	0.00698	0.06979	0.0043
Corredoria	Tabiella	132	280	23.61	0.00698	0.06979	0.0043
Langreo	Lada	132	280	1.55	0.0017	0.009	0.0042
Ujo	Doiras	132	200	62.14	0.0812	0.15124	0.0655
Ujo	Pico Gallo	132	200	49.71	0.09129	0.19294	0.035
Pumarin	Tanes	132	380	37.28	0.00888	0.06861	0.0292
Castiello	Corredoria	132	146	15.53	0.01526	0.06037	0.0156
Langreo	Corredoria	132	190	11.18	0.00579	0.03134	0.0073
Tabiella	Trasona	132	275	2.49	0.00162	0.00763	0.004
San Esteban	Proaza	132	150	12.43	0.01065	0.03728	0.0079
Arbon	Doiras	132	200	11.18	0.01889	0.03519	0.0152
Carrio	Aboño	132	595	1.68	0.00308	0.03081	0.015
Ujo	Siero	132	110	15.53	0.02087	0.04813	0.016
La Barca	Narcea	132	132	4.97	0.0097	0.031	0.0109
Pumarin	Corredoria	132	190	18.64	0.00579	0.03134	0.0073
Corredoria	San Esteban	132	190	3.73	0.00372	0.02015	0.0047
Soto	Ujo	132	110	5.59	0.01128	0.03765	0.0074
Narcea	Trasona	132	132	40.39	0.0374	0.1199	0.0423
Curiscao	La Barca	132	200	18	0.01994	0.03994	0.01
Soto	San Esteban	132	164	2.49	0.00215	0.0117	0.0005
Tabiella	Maruca	132	190	4.35	0.00978	0.04451	0.0097
Tabiella	Maruca	132	190	4.35	0.00978	0.04451	0.0097
La Barca	Trasona	132	132	31.07	0.0354	0.1135	0.0401
Ujo	Lada	132	110	12.43	0.013	0.02465	0.0099
Cuesta-Palo	Corredoria	132	100	62.14	0.05836	0.28365	0.04
Salime	Corredoria	132	150	74.56	0.05894	0.20339	0.0455
Corredoria	Siero	132	150	15.53	0.00434	0.01472	0.0028
Miranda	Corredoria	132	150	18.64	0.0213	0.07456	0.0158
Lada	Soto	132	122	9.94	0.007	0.0268	0.011
Tabiella	Carrio	220	636	8.7	0.00112	0.0101	0.0244
Tabiella	Carrio	220	636	8.7	0.00112	0.0101	0.0244
Tabiella	Soto	220	470	21.75	0.00579	0.05785	0.0546
Carrio	Uninsa	220	366	1.24	0.00034	0.00291	0.0333
La Pereda	Soto	220	220	4.97	0.00312	0.01089	0.0159
Aboño	Carrio	220	640	0.62	0.00017	0.00165	0.02
Aboño	Carrio	220	640	0.62	0.00017	0.00165	0.02
Carrio	Soto	220	636	21.75	0.00253	0.02213	0.0549
La Pereda	Villablino	220	200	43.5	0.01891	0.06557	0.0944
Siero	Puente SanM	220	340	90.1	0.0182	0.08832	0.2537
Siero	Puente SanM	220	340	90.1	0.0182	0.08832	0.2537
Siero	Soto	220	510	9.94	0.00118	0.00875	0.0234
Soto	Lada	400	1210	10	0.00036	0.00343	0.0962
Narcea	Soto	400	1210	31.07	0.00081	0.00848	0.2413
Soto	La Robla	400	1540	52.82	0.00126	0.01336	0.3805
La Robla	Lada	400	1030	52.2	0.00171	0.01498	0.4056

Table 23. Power World model power lines [21]

5.2.5. Transformer data

Defining transformers followed almost the same process as when defining a power line. Transformers represented in the model along with their characteristics are shown in the following table 24:

Bus	Voltage step	Capacity (MVA)	R (pu)	X (pu)
Carrio	132 / 220	270	0,00071	0,04690
Carrio	132 / 220	270	0,00071	0,04690
Tabiella	132 / 220	270	0,00071	0,04862
Soto	132 / 220	350	0,00050	0,04478
Lada	132 / 220	300	0,00110	0,06494
Lada	132 / 220	300	0,00110	0,06494
Aboño	132 / 220	225	0,00021	0,04798
Aboño	132 / 220	225	0,00021	0,04798
Narcea	132 / 220	350	0,00066	0,03988
Siero	132 / 220	150	0,00150	0,05737
Soto	220 / 220	600	0,00040	0,02356

Table 24. Power World model transformers [21]

5.3. Power system security: reliability criteria and operation conditions.

Before moving on to the next sections of the project, dedicated to the simulation and analysis of the power system it is necessary to explain the reliability criteria established for the appropriate operation of the power system under study.

The guidelines applied in this case were obtained from the operation criteria standards prepared by REE.

REE reliability criteria was set down taking into account original design and planning of the electrical network in order to make possible a better use of the system.

As REE was established in 1984 many of the oldest power lines operating in Spain were not design by REE but by other local companies with different operation criteria. Over the last years those local companies have sold all their transportation infrastructures (220 kV – 400 kV power lines and substations) to REE according to the regulations currently in force. So REE carried out the unification of all the reliability standards elaborated by the former owner companies.

Maintaining a reliable system involves keeping into margins the following electrical variables:

- Voltages in the nodes
- Loads in power lines and transformers

5.3.1. Operation states

Four possible operation states or situations can be distinguished in the general operation of an electric power system:

- Standard state: All the control variables meet the operation margins established and satisfy reliability criteria.

- Alarm state: In this case, control variables are adequate however reliability criteria is not meet when facing a contingency.

- Emergency state: In this situation at least one or more system variables show values out of the standard state margins. This situations ends up in local outages.

- Restoration state: Arises after a regional or national black out. The main object in this situation is to restore quickly but step by step supply service in the affected area. [9]

Figure 21. Power system operation states

5.3.2. Contingency types

Three different kinds of contingencies can be distinguished in a reliability analysis:

- Simple failure: Of any of the elements in the power system, either generator, or power line, or transformer or reactance)
- Simultaneous failure: In the two circuits of a double power line as long as they are sharing the same pylons during at least 30 km of the route.
- Special situations: When after a contingency the implementation of the operation criteria needs an excessive time. For example, the coupling of a coal fire power plant generator is considered as a failure. [9]

5.3.3. Acceptable operation margins for the control parameters

Depending on the situation of the system there are different operation margins for the control parameters:

Standard operation of the system

- Voltage: Voltage control procedures for the standard situation will meet the restrictions set by the design margins.

- Load: Load levels will not be greater than the nominal capacity from transformers or thermal capacity from power lines defined for the different seasons of the year.

Contingency type I: Simple failure
Power system must keep the following parameters in order to avoid simple failures:
- Referring to power lines, there will not be steady state overload. However, it could be accepted up to a 15% in transient overloads (20 minutes max length). Referring to transformers, there will not be steady state overload but it could be accepted a maximum overload of a 10% (in winter). These limits can vary in each transformer depending on manufacture features.
- Voltages that guarantee a stable situation should be between the next limits:

Voltage Level	Minimum	Maximum
400 kV	380 kV	435 kV
220 kV	205 kV	245 kV
132 kV *	120 kV	145 kV

Table 25. Operation margins (simple failure) [9]

Contingency type II: Simultaneous failure
- Referring to power lines and transformers, there will not be overload greater than 15%
- Voltages that guarantee a stable situation should be between the next limits:

Voltage Level	Minimum	Maximum
400 kV	375 kV	435 kV
220 kV	200 kV	245 kV
132 kV *	115 kV	145 kV

Table 26. Operation margins (simultaneous failure) [9]

* 132 kV voltage level is not reflected in the guidelines from REE so those values were supposed taking in to consideration maximum and minimum voltage values from higher voltages levels.

5.4. Simulations and analysis of the current situation.

In the present section of the current situation (2008) study, several simulations were carried out:

- Firstly, for the case of a standard situation (no contingencies).
- Secondly, for the case of some contingencies in the weak points of the network discovered over the analysis of the standard situation.

Results obtained from the simulations were represented in form of tables and snap captures from Power World animated one line diagram for discussion and analysis.

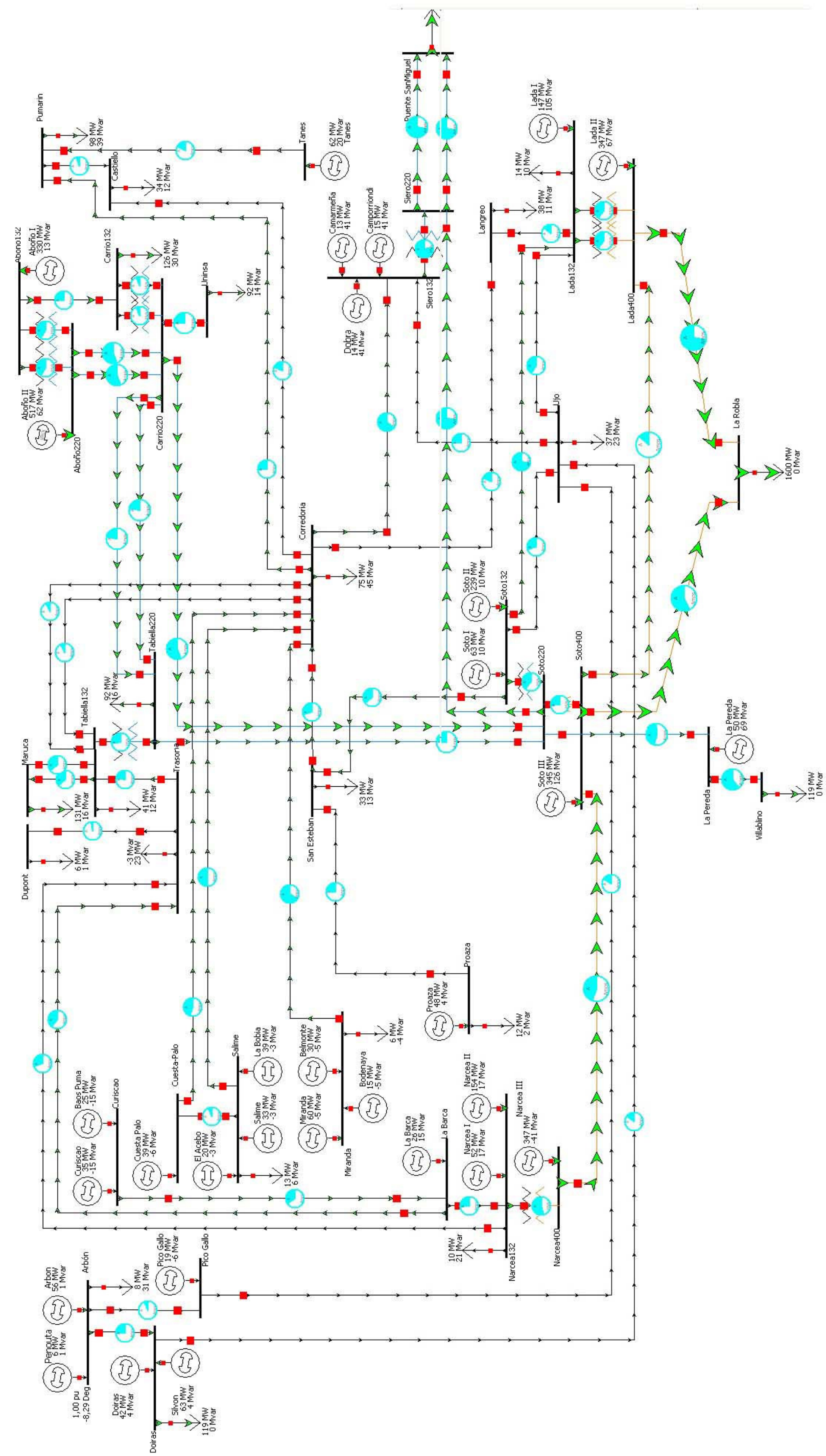


Figure 22. Current situation simulation screen

5.4.1. Standard Situation

The analysis carried out with the results from the simulation of the Asturian power system under a standard situation was based on a comparison between the load flows in each power line. Special attention was given to those overloaded lines or close to overload that could lead to future contingencies in the power system.

Results obtained from the simulations were sort out according to three different transmission line voltage levels (132, 220 and 400 kV).

Each of the following result tables details the following information:

- Origin and end of each line;
- Load levels in MW, Mvar and MVA;
- Maximum load MVA limit of the line;
- Percentage of load in the line in comparison with the total tolerated load.

5.4.1.1. 132 kV power lines running under a standard situation

132 kV Lines charge level						
From	To	MW (from)*	Mvar (from)	MVA (from)	MVA Limit	% of MVA Limit
Trasona	DuPont	6	-1,3	6,1	280	2,2
Pumarin	Castiello	9	1,5	9,1	190	4,9
Salime	Cuesta-Palo	5,3	-2	5,6	100	5,6
Arbon	Pico Gallo	10,8	-5,8	12,3	200	6,1
Corredoria	Tabiella	20,3	4,7	20,8	280	7,5
Corredoria	Tabiella	20,3	4,7	20,8	280	7,5
Langreo	Lada	-11,9	-36,6	38,5	280	13,8
Ujo	Doiras	-28,8	13,1	31,7	200	15
Ujo	Pico Gallo	-28	10,5	29,9	200	15,9
Pumarin	Tanes	-61,6	-19,7	64,7	380	17,4
Castiello	Corredoria	-25,3	-9,6	27	146	18,9
Langreo	Corredoria	-26,1	25,6	36,6	190	19,3
Tabiella	Trasona	-61,3	-1,1	61,3	275	22,6
San Esteban	Proaza	-35,9	-2	35,9	150	24,1
Arbon	Doiras	43,2	-23,4	49,2	200	24,6
Carrio	Aboño	-145,7	-5	145,8	595	24,7
Ujo	Siero	21,3	-16,8	27,1	110	24,7
La Barca	Narcea	33,4	-10,8	35,1	132	26,6
Pumarin	Corredoria	-45,3	-20,3	49,6	190	26,6
Corredoria	San Esteban	-52,4	-17,8	55,3	190	29,4
Soto	Ujo	33,3	-1,2	33,4	110	30,3
Narcea	Trasona	40,3	-2,2	40,4	132	30,6
Curiscao	La Barca	60	-29,3	66,8	200	33,4
Soto	San Esteban	49,7	29,5	57,8	164	35,3
Tabiella	Maruca	65,9	9	66,6	190	35,6
Tabiella	Maruca	65,9	9	66,6	190	35,6
La Barca	Trasona	51,7	-4,4	51,9	132	39,3
Ujo	Lada	32,2	-30,8	44,6	110	40,7

132 kV Lines charge level						
From	To	MW (from)*	Mvar (from)	MVA (from)	MVA Limit	% of MVA Limit
Cuesta-Palo	Corredoria	-43,1	6,3	43,6	100	44,5
Salime	Corredoria	-70,4	19,3	73	150	49,8
Corredoria	**Siero**	50	-82,5	96,5	150	**65**
Miranda	**Corredoria**	98,6	-11,5	99,3	150	**66,2**
Lada	**Soto**	-85,7	23	88,7	122	**72,7**

Table 27. Simulation results for 132 kV power lines

*Minus sign shows that the power flows in the opposite direction

According to the previous results table, 132 kV power lines which could lead to future constrains in the grid expansion were:

- Lada – Soto. The 72,7% overload showed in Lada - Soto could be a possible critical point in the future expansion of power system. However both substations (Lada and Soto) are also interconnected by a 400 kV line with just a 13,3 % overload and the transformers connecting 132 – 400 kV voltage levels in each substation were below the 50% load level.

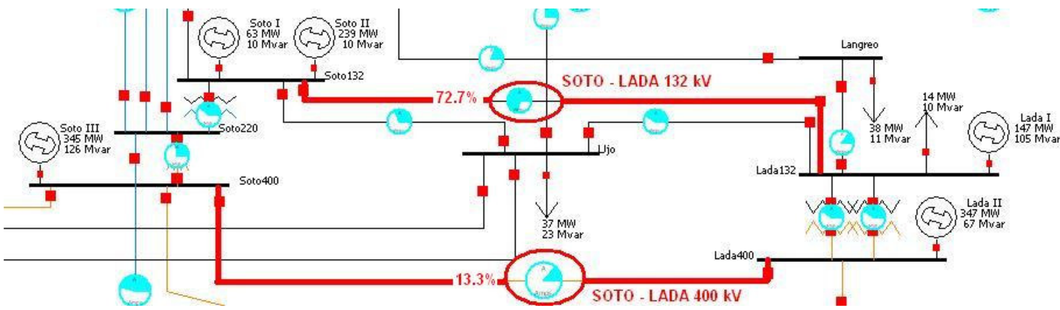


Figure 23. Lada – Soto load level

- Miranda – Corredoria. The main duty of this line is to conduct the energy from a hydro power plant and a couple of wind farms located in the south-west area to the central substation of Corredoria which delivers it to the rest of the central area. The west is an area with future projects for wind farms so this route could require upgrading the line Miranda-Corredoria, currently showing a 66.2% overload, or even planning a new one depending on the number of wind farms to be installed in the following years.

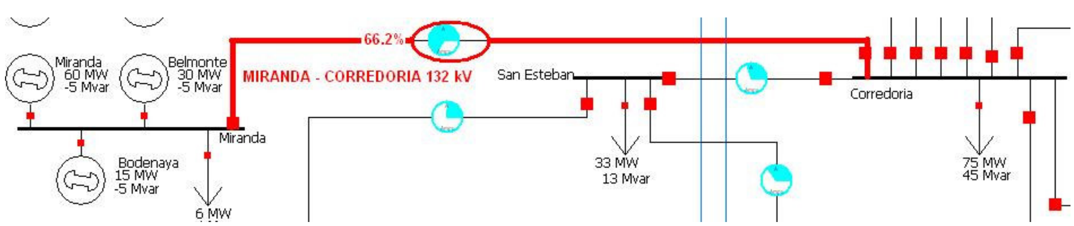


Figure 24. Miranda – Corredoria load level

- Corredoria – Siero. The power line Corredoria-Siero (65% overload) is one of the three routes used to export energy from Asturias through East of the region along with Ujo - Siero (24,7%) and Soto – Siero (72,7%). As the generation of energy is expected to increase much more than the consumption in the following years it could be interesting to increase the capacity of this line.

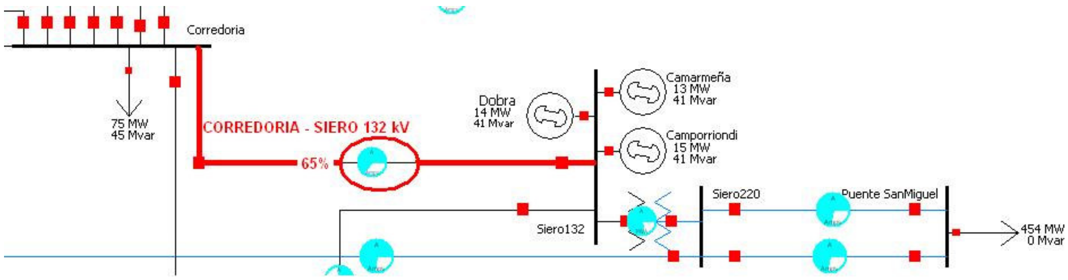


Figure 25. Corredoria – Siero load level

5.4.1.2. 220 kV power lines running under a standard situation

220 kV Lines charge level						
From	To	MW (from)	Mvar (from)	MVA (from)	MVA Limit	% of MVA Limit
Tabiella	Carrio	-136,9	-16,2	137,9	636	21,8
Tabiella	Carrio	-136,9	-16,2	137,9	636	21,8
Tabiella	Soto	111	-5,7	111,2	470	23,8
Carrio	Uninsa	92	10,9	92,7	366	25,3
La Pereda	Soto	-71,8	68,6	99,3	220	45,2
Aboño	Carrio	350,3	28,6	351,5	640	54,9
Aboño	Carrio	350,3	28,6	351,5	640	54,9
Carrio	Soto	353,4	-10,2	353,5	636	55,6
La Pereda	Villablino	121,8	0,5	121,8	200	**60,9**
Siero	Puente SanM	237,9	29,8	239,8	340	**71,5**
Siero	Puente SanM	237,9	29,8	239,8	340	**71,5**
Siero	Soto	-363,3	-42,4	365,8	510	**72,7**

Table 28. Simulation results for 220 kV power lines

According to the results from simulations shown in the previous table, the 220 kV power lines that could bring up future problems were:

- Siero – Soto. As explained before, in the 132kV study, this is one of the three exportation routes that drain away the energy from Asturias through the East.

- Siero – Puente San Miguel. It is the connection between Siero substation, which collects energy to export from Asturias through the east, and Puente San Miguel, the first substation after crossing the Eastern border of Asturias. Despite it is a double circuit power line to fulfill exportation of energy, the overload is still high (71,5%) so it could be interesting upgrading this route to a 400 kV line. That would mean doubling current exporting capacity.

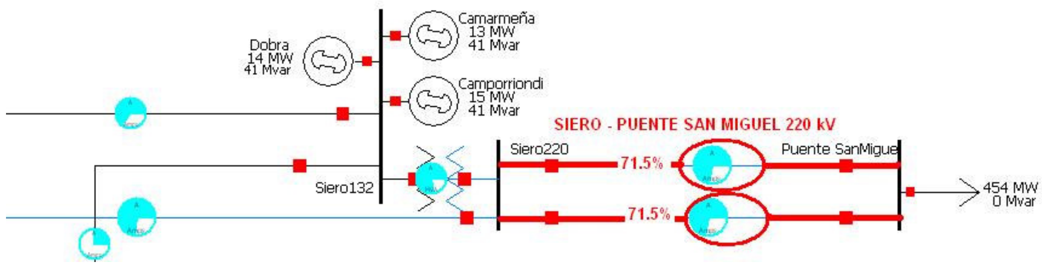
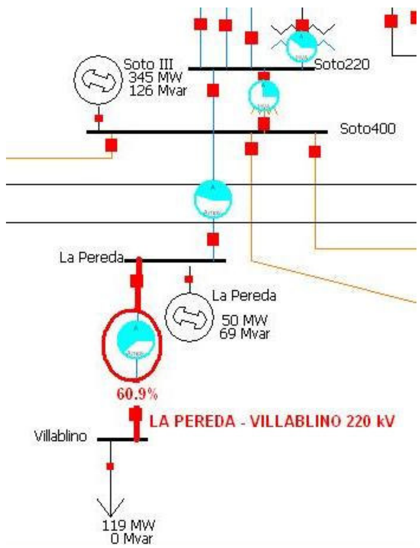


Figure 26. Siero – Puente San Miguel load level



- La Pereda – Villablino.

This line represents again an exportation route for the surplus energy. Overload obtained from simulation was 61%. So it could be necessary upgrading the capacity for future increases of surplus energy.

Figure 27. La Pereda – San Miguel load level

5.4.1.3. 400 kV power lines running under a standard situation

400 kV Lines charge level						
From	To	MW (from)	Mvar (from)	MVA (from)	MVA Limit	% of MVA Limit
Soto	Lada	159	-21,1	160,4	1210	13,3
Narcea	Soto	535,6	-50,9	538	1210	44,5
Soto	La Robla	875,1	67,8	877,7	1540	57
La Robla	Lada	-734,7	2	734,7	1030	72,5

Table 29. Simulation results for 400 kV power lines

Finally, for the case of 400 kV transmission lines, problems seemed to be point again to the exportation of energy:

- Soto – La Robla and Lada – La Robla: Showing overload levels of 57% and 72% respectively, these lines export a 70% of the total generation energy surplus from Asturias. That is because this route is the main way to evacuate energy from Asturias to the rest of Spain. In that case, an upgrade of the lines could be a short term solution. However a definitive solution must undergo planning of another 400kV corridor.

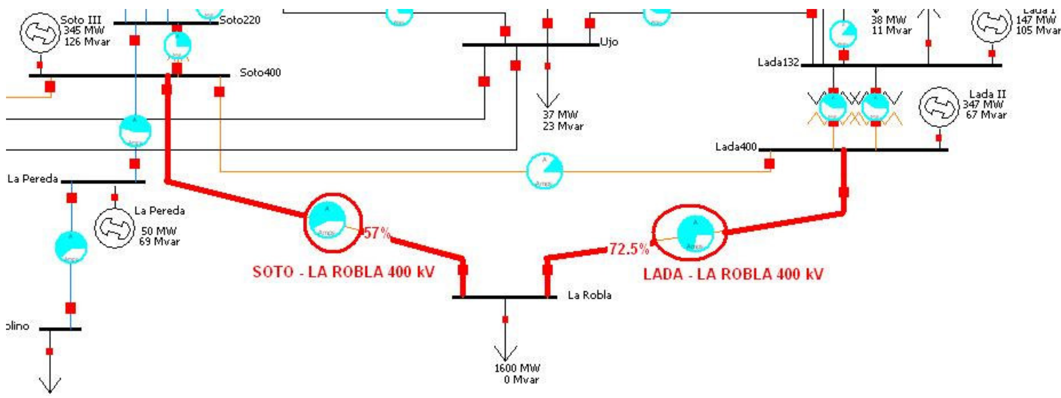


Figure 28. Soto – La Robla and Lada – La Robla load levels

Once the main weak points of the power system were determined, the next step consisted of the study of possible contingencies.

5.4.2. Contingencies

Contingencies to analyze were selected taking into account the weakest points in the power system. These points matched up most of the times with highest voltage levels power lines for the exportation of energy.

Contingencies were the following:

Contingency	Voltage level	Description
#1 Soto – La Robla	400 kV	Main exportation line
#2 Lada – La Robla	400 kV	Main exportation line
#3 Siero – Puente San Miguel	220 kV	Exportation line

Table 30. Contingencies under study

5.4.2.1. Contingency # 1: Soto – La Robla

Soto – La Robla (1540 MVA of maximum capacity) is one of the main lines for the exportation of surplus energy from Asturias. It shapes a 400 kV "triangle" form by Soto, Lada and La Robla Substations. The main objective of this triangle is to sustain a reliable evacuation of energy from Asturias to the rest of Spain.

The following picture shows how the disconnection of the line Soto – La Robla affected the surrounding power lines and how the flow of energy is redistributed.

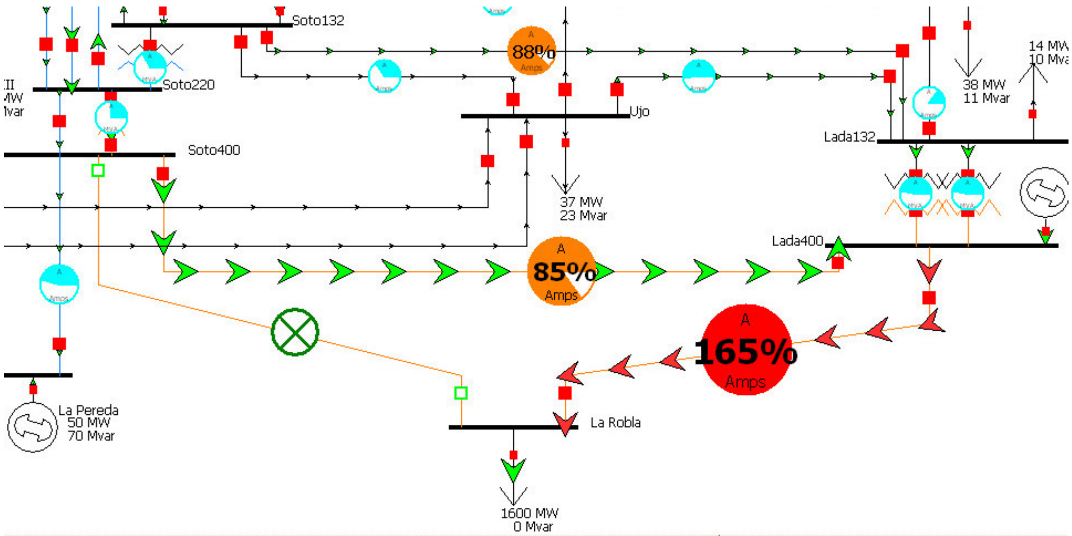


Figure 29. Contingency 1

The main problem that comes up just after the contingency simulation is the overload on the other exportation line Lada – La Robla (400 kV). It rises from a previous 72.5% to a new enormous 165% overload. The margins established by the directions were set around a 15% overload when facing a simple failure. This new overload is by far out of the margins so this line could not resist the requirements. So the system would automatically move to an emergency state.

Apart from that outcome, the increase in the flow of energy from Soto to Lada is also shown in the previous figure. First, directly on the lines that interconnect both substations and secondly, indirectly on the lines that pass by Ujo substation.

The evolution (before and after contingency) in the load level for those lines is shown in the following table 31:

From	To	kV	Load levels %	
			Before contingency	After contingency
Lada	Soto	132	72,7	88
Soto	Lada	400	13,3	85
Soto	La Robla	400	57	0
La Robla	**Lada**	**400**	**72,5**	**165**

Table 31. Contingency 1 load levels

Nodes which suffer voltage variations are represented in the following table 32:

Node	Nom kV	pu	kV
Puente SanMiguel	**220**	**0,927**	**204,026**
La Robla	**400**	**0,941**	**376,273**
Maruca	132	0,975	128,659
Villablino	220	0,977	214,877
Castiello	132	0,980	129,418
Pumarin	132	0,981	129,464
Tabiella132	132	0,985	130,030
Siero220	220	0,986	216,926
DuPont	132	0,986	130,161
Trasona	132	0,986	130,169
Corredoria	132	0,990	130,670
Carrio132	132	0,993	131,091
Soto220	220	0,995	218,811
San Esteban	132	0,996	131,406
Tabiella220	220	0,996	219,042

Table 32. Contingency 1 voltage levels

220 kV node Puente San Miguel showed voltage values out the of the safety margins: 204.026 (must be in between 205 – 245 kV). In the same way 400 kV node La Robla showed voltage values out the of the safety margins: 376.273 (must be in between 380 – 435 kV).

5.4.2.2. Contingency #2: Lada – La Robla

Lada – La Robla line is a very similar case to the previous one analyzed. Apart from following a similar route it is the other major power line (1030 MVA maximum capacity) responsible of the evacuation of surplus energy from Asturias.

The following figure 30 shows how the disconnection of this line affects surrounding:

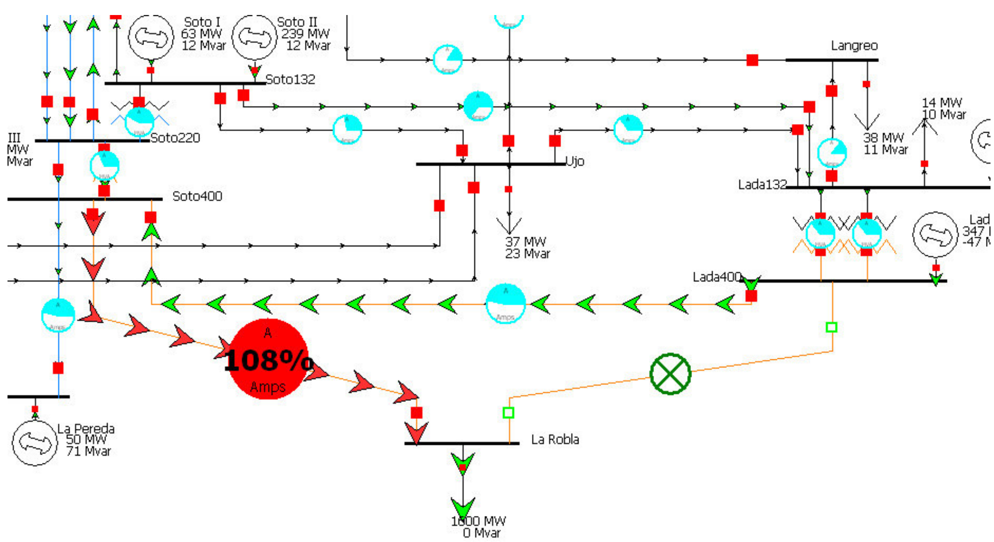


Figure 30. Contingency 2

The situation is pretty much the same as in the previous case but now the flow is on the other side. Now it flows from Lada to Soto substation and once there the energy is sent away through La Robla.

As expected, the main increase of load level turns up now in the line Soto – La Robla which moves from a previous 57 % to a current 108%. According to the reliability guidelines from REE, an overload up to 115% could be stood during 20 minutes. If the overload is not resolved within this time the line would fall down leading to an emergency situation.

In the following table 33 the main significant charge levels before and after contingency are detailed:

From	To	kV	Load level %	
			Before contingency	After contingency
Soto	Lada	400	13,3	46,4
Soto	**La Robla**	**400**	**57**	**108**
La Robla	Lada	400	72,5	0
Siero	Siero	132/220	76,9	81

Table 33. Contingency 2 load levels

Substations that suffer voltage variations are represented in the next table:

Node	Nom kV	pu	kV
Puente SanMiguel	**220**	**0,92742**	**204,032**
La Robla	400	0,95597	382,387
Maruca	132	0,97505	128,707
Villablino	220	0,97672	214,877
Castiello	132	0,98043	129,417
Pumarin	132	0,98078	129,463
Tabiella132	132	0,98544	130,078
Siero220	220	0,98605	216,93
DuPont	132	0,98651	130,219
Trasona	132	0,98657	130,228
Corredoria	132	0,98991	130,669
Carrio132	132	0,99313	131,093
Soto220	220	0,9945	218,791
San Esteban	132	0,99549	131,405
Tabiella220	220	0,99576	219,066
Langreo	132	0,99651	131,54
Ujo	132	0,99654	131,543
Uninsa	220	0,99824	219,613
Carrio220	220	0,99892	219,761

Table 34. Contingency 2 voltage levels

As in the previous contingency, Puente San Miguel does not meet the acceptable operation margins. So the system moves from an Alarm State to an Emergency State.

5.4.2.3. Contingency #3: Siero – Puente San Miguel (1 line)

Siero - Puente San Miguel is the second most important route (after La Robla) for the exportation of energy from Asturias to the rest of Spain. It is a double circuit long (90 miles) power line frequently close to overloads (72%) so when facing situations like the one presented in this contingency, the disconnection of one of the circuits, major overloads immediately emerge.

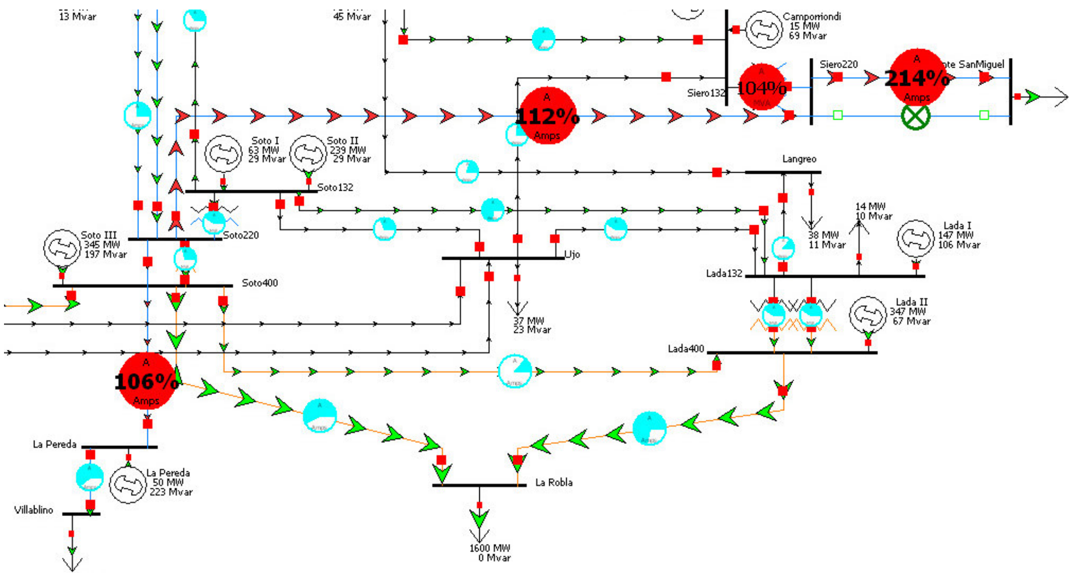


Figure 31. Contingency 3

The most serious problem shows up in the second circuit that remains in operation between Siero and Puente San Miguel overloading close to 214%, a level of charge completely out of the reliability margins. Some other minor also overloads show up in surrounding lines and transformer.

Next table 35 shows how all the remain affected lines are under 115% overload so the situation could be maintained up to 20 minutes before finding a solution.

From	To	kV	Charge level %	
			Before contingency	After contingency
La Pereda	Soto	220	45,2	106
Siero	Puente SanMiguel	220	71,5	0
Siero	Puente SanMiguel	220	71,5	214
Siero	Soto	220	72,7	112
Siero	Siero	132 / 220	76,9	104

Table 35. Contingency 3 load levels

Having a look to voltage variations, the always under the limit node Puente San Miguel drops down in that case to very worrying values that move the system again to an emergency state.

Node	Nom kV	pu	kV
Puente SanMiguel	**220**	**0,54794**	**120,547**
Siero220	220	0,93836	206,439
Maruca	132	0,97414	128,587
Villablino	220	0,97672	214,877
Soto220	220	0,97809	215,179
Castiello	132	0,98034	129,405
Pumarin	132	0,9807	129,452
La Robla	400	0,98421	393,684
Tabiella132	132	0,98454	129,959
DuPont	132	0,98564	130,105
Trasona	132	0,98571	130,113
Corredoria	132	0,98981	130,655
Carrio132	132	0,99269	131,035
Tabiella220	220	0,9938	218,637
San Esteban	132	0,99546	131,401
Langreo	132	0,99649	131,536
Ujo	132	0,99663	131,556
Uninsa	220	0,99747	219,444
Carrio220	220	0,99815	219,593

Table 36. Contingency 3 voltage levels

5.5. Final results for the study of the current situation (2008)

Simulations and analysis of the Asturian power system current situation left the following final results inferred from those power lines showing overloads above 50%.

5.5.1. 132 kV power lines

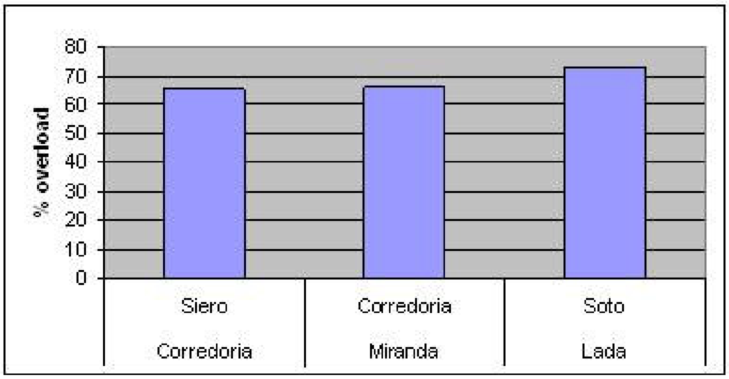


Figure 32. Overload comparison in 132 kV power lines

132 kV voltage level is closer to distribution than to transmission stages, therefore overload problems could be more related to increasing demands in industries or large cities. However, results obtained from the simulations showed overload tendencies in 132 kV lines that could have a decisive role in future situations but not because they had to increase the supply of energy to increasing demand consumers.

It was the case of Corredoria – Miranda (66.2%), in charge of the transport of wind farm generation from the west of Asturias, where the best wind conditions are found, to the centre of Asturias, where energy is delivered to consumers or to other substations for exportation at higher voltage levels. Increase wind generation in Asturias is one of the targets for the next years so the upgrade of lines like Corredoria – Miranda or the commissioning of similar ones from the west to the centre is a essential requirement.

5.5.2. 220 kV power lines

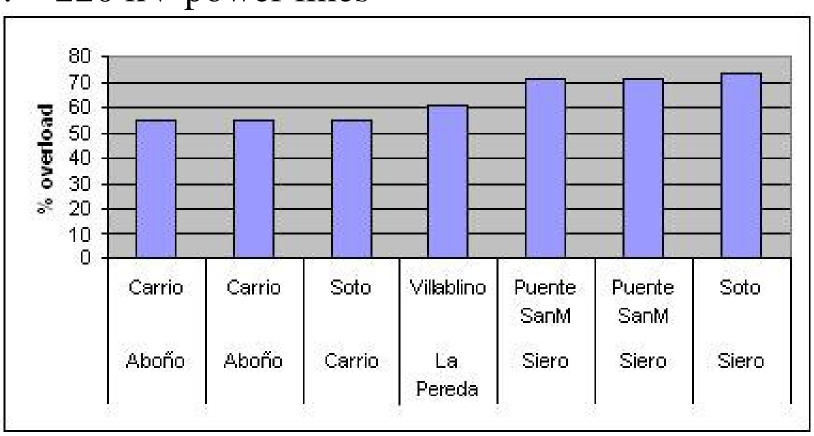


Figure 33. Overload comparison in 220 kV power lines

When analysing the results from the simulation of 220 kV power lines, the highest overloads were found on those lines in charge of the exportation of energy to vicinity regions:

- Villablino – La Pereda (61%) exports energy from Asturias to Castilla (South)
- Siero – Puente SanMiguel (71.5%) exports energy from Asturias to Cantabria (East)

As well as in the line Soto – Siero (72.7%), this indirectly transports energy for later exportation through the east of the region.

Therefore, even not considering future increases in the total generation of the Asturian power plants, it would be interesting for the reliability of the system designing new power lines through the east and the south of the region for the exportation of energy.

5.5.3. 400 kV power lines.

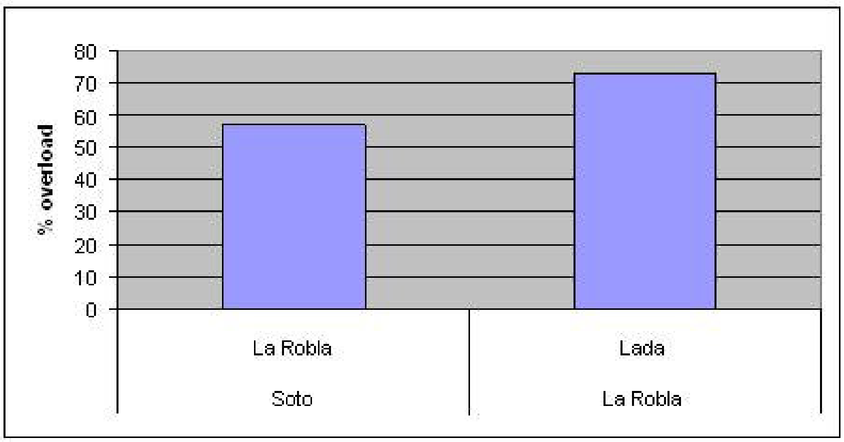


Figure 34. Overload comparison in 400 kV power lines

Finally, both 400 kV power lines in charge of the exportation of most of the surplus energy from Asturias show notable overloads:

- Soto – La Robla: 57%
- Lada – La Robla: 73%

As this route of exportation already has two power lines and therefore seems to be overcrowded, the only possible solution for those lines would be an upgrade in their capacity.

To sum up, the current situation of the Asturian power system is acceptable, no defects were found under a standard operation simulation and all the surplus energy can be dispatched to the rest of Spain.

However, according to the future plans for the Asturian power system directing to the increase of generation in current and new power plants it is of the utmost importance improve the situation of:

- The interconnections between western and central areas of the region
- The exportation routes to through the East and South.

6. ASTURIAN FUTURE ELECTRICAL NETWORK

According to the main strategy lines from the regional government of Asturias, the future plans (2008 – 2015) for the electrical network of the region will be based in two working areas:

Firstly, the energy plans of Asturias are mainly focused on the increase of the generation units. In a short term Asturias will undergo a steady incorporation of up to twenty three new wind farms to the electrical network. In a long term, a much greater amount of MW is expected to be in operation by installing up to seven combined cycle generation units. Those units will be installed in power plants already in operation (replacing the oldest generation units) as well as in new proposed power plants. However the current supply of natural gas to the region could not withstand so many projects. Thus, the creation of new combined cycle power plants relies on the conclusion of the works of a new regasification plant expected to be finished by the end of 2012. [12]

Secondly, in order to manage this dramatic increase of the generation adapting the high voltage transmission and distribution grid will be a priority of the utmost importance. This will be the most complicated step for the future plans of the region as the upgrade of the grid will need to go through the erection of the always controversial 400 kV power lines close to urban areas and natural reserves.

6.1. Generation

6.1.1. Coal fire / Combined cycle power stations

Coal will continue being the main source of energy at least until 2012, just before the implementation of the new combined cycle power plants. Most of the coal fire power plants will undergo upgrades consisting on decommission of the oldest generation units while installing new ones.

6.1.1.1. Soto power station

Soto will be the first power station in Asturias to begin working with combined cycle generation units. In that way, Soto IV (400 MW) is expected to be already replacing the old Soto I (from 1967) in 2009. Short after and also with a power out of 400 MW Soto V is expected to begin working.

6.1.1.2. Aboño power station

Aboño coal fire power station will undergo anytime over the following seven years the decommissioning of it first generation unit (1974) with a max power output 380 MW while expect to implement upgrade works for the construction of an 800 MW combined cycle unit around 2015. [14]

6.1.1.3. La Pereda power station

The limited generation from La Pereda power plant (50 MW) will see how its power output significantly increases with the installation of a combined cycle unit of 400 MW by the year 2012. [13]

6.1.1.4. Lada power station
As in the previous case of Aboño power plant, Lada will also change its old Lada I generation unit (1967) for a new combined cycle unit with a power output of 800 MW. The expected date for the operation of the new unit is 2012. [10]

6.1.1.5. Narcea power station
Narcea power station is so far the only one in Asturias which has not planned yet any upgrade in its generation units.

6.1.1.6. Nalon Power station
This new combined cycle power station to be located in the central area of Asturias is expected to begging operating around 2012. The power output of the only group planned so far will be 400 MW. [11]

6.1.1.7. Musel power station
Musel power station will be a new combined cycle power plant to be built in Musel harbour, next to the future regasification plant. This power plant will be the biggest in Asturias with an 860 MW generation unit. It is expected to be built around 2014.

6.1.2. Hydro power stations
Hydro power is a type of energy already highly implemented in Asturias. Most of the locations suitable for hydro power plants were already studied years ago so this section needs little expansion.

The only increase that this energy can experience would be possible by upgrading the already existing plants or by the installation of mini hydro power generation units. First option has not been considered; just the second one seems to be feasible. However the new generation implemented in this sector will not be considered in the future models and simulations of this study due to the small amount of energy those generators generate in comparison with the global generation.

6.1.2.1. Biomass and photovoltaic power plants
As in the current situation, other renewal energies such as biomass and photovoltaic energy have no great expansion plans in the region. So they will continue unconsidered for future models and simulations.

6.1.3. Wind farms
The field of wind energy will be the one to play a very important role in Asturian generation over the right coming years. The main reason is a moratorium that has just been removed at the beginning of 2008.

Seven years ago, when the first wind farms began to operate in Asturias, the applications for new wind farm construction were so many that the government was forced to impose a moratorium against the massive stream of wind farm projects. The main reasons were due to the fact that most of the projects turn out to be the same for different locations and many of them had no into consideration natural reserves and environmental impact.

Since last March 2008 the moratorium that slowed down the spread of wind farms was removed. So after reconsidering the projects to go ahead it has been estimated that wind energy will triple current values of generation over the following three years.

The wind farms already approved by the local government and some of them currently under construction are shown in the following table:

NAME	Company	Towers	kW (generator)	Maximum Capacity (MW)	Area (County)
Carondio - Muriellos	North eolic	51	750	42.7	North west (Allande - Villayon)
El segredal	Cantaber generacion eolica	59	750	44.2	North west (villayon - valdes)
Vidural	Energias renovables del principado de Asturias	17	1500	25.5	North west (Navia y Villayon)
San Roque	Gamesa Energia	16	1500	24	North West (Villayon - Allande)
Mancebon	Energias renovables del principado de asturias	24	1500	36	North west (tineo - Allande)
Pico Quemado	Terranova Energy Corp SA	37	850	31.5	North West (Allande - Tineo)
Ouroso	Terranova	55	660	36.3	North west (Taramundi)
Panondres	Energias renovables del principado de asturias	29	690	43.5	North west
El candal	Producciones energeticas de Asturias SL	66	750	49.5	North West (Castropol - Vegadeo)
Bobia Las cruces	Totalfina eolica	45	800	36	North west (Castropol - Boal)
Pico Jarrio	Terranova Energy Corp SA	21	850	17.8	North West (El Franco - Coaña)
Monte Pereira	Terranova Energy Corp SA	31	850	26.3	North West (Taramundi)
Monte buño	North Eolic	15	1300	19.5	North west (Tineo)
Buseco II	Asturwind	28	1500	42	North west (villayon - tineo)
Sierra Tineo	North eolic	28	1750	49	North west (Tineo)
Palancas	Asturwind	11	1500	16.5	North west (valdes)
Las Cruces	Energias renovables del pricipado de asturias	28	1500	43.5	North west (tineo -valdes)
Busceo I	Asturwind	19	1500	28.5	North west (valdes - tineo)
Begaga	Barbao	68	660	47.3	Sout West (Belmonte)
El Cordel	Energias renovables del pricipado de asturias	29	1500	43.5	North west (Valdes - Navia)
Estoupo	Terranova Energy Corp SA	31	850	26.35	North West (Valdes - Tineo)
Pico de Liebres	Terranova Energy Corp SA	23	850	19.6	North West (Tineo)
Carrocedo	Energia Hidroelectrica de Navarra SA	58	850	49.3	South (Lena - Aller)

Table 37. Future Asturian wind farms [4] [8]

The twenty three wind farms listed above will make a total of new 1090 MW power output installed in the west of the region.

However, before the full operation of all those future wind farms the western transmission grid must undergo important transformations.

6.2. Power lines and substations

The main problem arising from all the future plans of generation is the transmission of energy. The electrical network currently existing in Asturias is unable to bear the dramatic increase of MW to be running over its power lines once new wind farms and combined cycle power plants were ready to operate.

So the solutions proposed are summarized as follows:

- 400 kV route "ASGA"
- 400 kV connection Nancea – Tineo
- 400 kV central ring
- Upgrade 400 kV power lines Soto – La Robla and Lada – La Robla
- 400 kV power line Soto – Penagos
- 400 kV power line Lada – Velilla [5]

In the following figure all the previous proposed power lines are represented in red dotted line over the map of Asturias:

Figure 35. Asturian future power lines and substations [3]

6.2.1. 400 kV route "ASGA"

All the lines currently transporting the energy from wind farms located in the west of Asturias to the centre are 132 kV power lines. Those lines are enough for the current wind farms in operation but they will not be able to deal with the future wind generation plans. New 400 kV power lines need to be erected along the same route in order to satisfy wind generation requirements. So the main purposes of the route ASGA are:

- On the one hand, transport the energy generated by the wind farms to the central area of Asturias.
- On the other hand, as it is connected to Galicia, it will improve the evacuation on energy route to the west.

The capitals ASGA stand for Asturias-Galicia. The 400 kV route ASGA plans to interconnect the western border county, Galicia, with the centre area of Asturias by erecting several 400 kV power lines which will also interconnect the new 400 kV substations planned for the coming wind farms.

The following 400 kV substations were planned for the accomplishment of this route:

- Boimonte. Located in Galicia, Boimonte is considered as the starting point of the route
- Pesoz. It will collect all the energy generated by the northwestern wind farms.
- Palo. Former 132 kV Cuesta - Palo substation will be upgraded to a new 400 kV one named Palo.
- Tineo. It will collect all the energy generated by the most southwestern wind farms.
- Santa Maria. Located in the centre area of Asturias it is considered the other end of the route. Here the ASGA route will be connect with the Central ring. [5]

In the same way, the consequent 400 kV power lines designated for the connection of the previous substations will be:

- Boimonte – Pesoz
- Pesoz – Palo
- Palo- Tineo
- Tineo – Santa Maria

The 400 kV route ASGA in between the western region of Galicia (light brown background) and Asturias (light pink background) is represented by a dotted red line in the following figure:

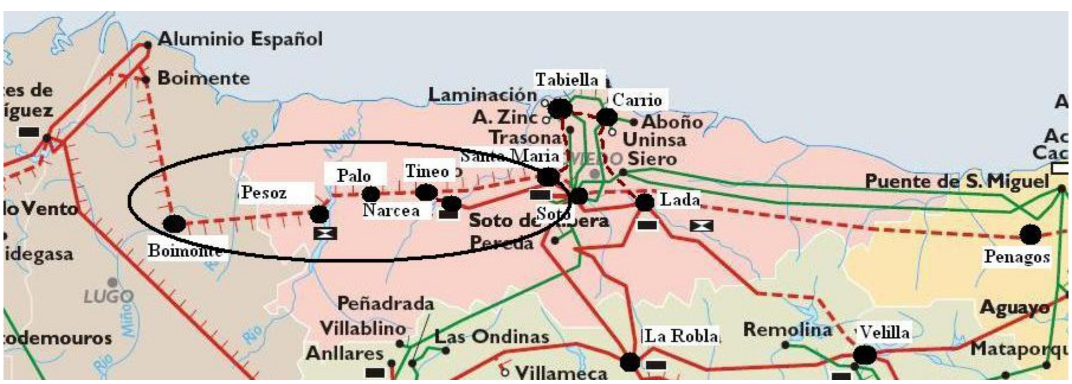


Figure 36. ASGA route [3]

6.2.2. 400 kV connection Narcea – Tineo

A short 400 kV power line of just 5 miles will be erected in between Narcea substation and the new substation of Tineo. The main object of this line is interconnection ASGA route and the already existing South West – South line Narcea – Soto and therefore give more reliability to the 400 kV network. [5]

6.2.3. 400 kV central ring

400 kV central ring will interconnect the northern, central and southern areas of Asturias. It will consist on the following 400 kV substations:

- Santa Maria. Already projected for the ASGA route it will be located in the central Area.
- Tabiella. The former 132 / 220 Tabiella substation located in the North (Aviles) area will be upgraded to a new 400 kV one.
- Carrio. As in the previous case, the former 132 / 220 kV Carrio substation located in the North (Gijon) area will be upgraded to a new 400 kV one.
- Lada. The already existing 400 kV substation will not need any major modification.
- Soto. The already existing 400 kV substation will not need any major modification. [5]

The consequent 400 kV power lines needed for the interconnection of the previous substations will be:

- Santa Maria – Tabiella
- Tabiella – Carrio
- Carrio – Lada
- Lada – Soto (already existing)
- Soto – Santa Maria

The central ring and its substations are represented in the following figure over the map of the Asturian 400 kV electrical network

Figure 37. Central ring [3]

In a short term, the central ring would necessary for the evacuation of energy from the new wind farms. However, from 2012 on it will be essential in order to distribute the enormous amounts of energy generated by the proposed combined cycle power plants.

6.2.4. Upgrade 400 kV power lines Soto – La Robla and Lada – La Robla

A first solution to the upcoming problems related to the exportation of the approximately new 1000 MW generated by the proposed wind farms from Asturias will be the upgrade of the Southern lines Soto – La Robla and Lada – La Robla. The increase of capacity considered has been set around a 20% of new load in their lines.

However, this will not be a definitive solution. The real solution for the evacuation of new energy is no other than the planning of new 400 kV power lines from Asturias to the southern and eastern border regions. [5]

6.2.5. 400 kV power line Soto – Penagos

Soto - Penagos is the first of the two projected power lines to be ready for the exportation of electrical energy from Asturias. It will run from Soto substation (south of Asturias), towards the east to Penagos substation which is located in the border region of Santander. Once finished, along with the ASGA route, it will make possible a 400 kV connection between all the northernmost regions of Spain.

Despite the fact most of the pylons for the construction of this line had already been erected in 2000, the works were held up due to many formal complaints from resident associations of the nearby villages that moved the High Court to officially stop the works. It forced the execution company (REE) to the planning of alternative routes where the line runs close to opposing villages and natural reserves.

Nowadays the final layout of the line has already obtained the legal permissions from the High Court, so the line is expected to be ready by the end of 2009. [5]

Figure 38. Soto – Penagos power line [3]

6.2.6. 400 kV power line Lada – Velilla

This is the second of the projected lines for the exportation of energy from Asturias. In this case the line runs from Lada substation through the south of Asturias until it reaches Velilla, located in the border region of Castilla.

The project of this line first came up more than twenty years ago, in 1986. Since the beginning it was a controversial project, as part of the route ran across “Picos de Europa” natural resource. Even though half of the line was erected it could not be completed due to the constant disputes held between the contractors and the city councils of Castilla. [5]

Furthermore, over the course of the years more and more complaint associations were established. Because of the persistent struggles the execution company was forced to propose an alternative route, whose environmental impact study is currently under approval process. The estimated date for the conclusion of this line has been set in 2011. In the following figure the power line is represented half with a red dotted line (unfinished) and the other half with a continuous line (finished).

Figure 39. Lada – Velilla power line [3]

6.3. Demand

In reference to the demands of energy and taking into account trends registered over the last years, the situation showed up that an increase of the 7% in the internal demand of energy could be considered each 3 years over the following time of the study. [15]

Regarding the external demand, surplus will be shared out among the new external demand points:

- Villablino
- Doiras
- Puente San Miguel
- Robla
- Penagos
- Velilla

The percentages of energy absorbed by those external demand points will vary depending on the power lines in operation and the power plants installed, so more precise values will be detailed in the simulation and analysis chapter.

7. STUDY OF THE FUTURE SITUATIONS

Study of future situations were carried out by simulating several possibilities of generation and exportation of surplus energy.

As the future situation showed in the previous chapter was developed as far as year 2015 and considering the gap of seven years too long for the study. It was decided to split up future situation in two horizons of analysis:

- 2011 horizon: On the one hand, in reference to upcoming generation, all the new proposed wind farms (800 MW aprox) are expected to be gradually operating during the three years gap between 2008 - 2011. Also two new combined cycle generation units (400 + 400 MW) will be operating in Soto power plant. On the other hand, in reference to power line works, the three mayor 400 kV exportation of energy projects (Velilla, Penagos, ASGA) are expected to be finished by the end of 2011.

- 2015 horizon: Over the last years of the future study, the new combined cycle power plants of Nalon, La Pereda, Lada III, Musel and Aboño (up to 3310 MW) were analyzed independently. In order to get ready the last two generation projects (Musel and Aboño) it was essential having ready the 400 kV central ring which will transport all the new energy from the north to the south of the region for later exportation.

Thereby, previous Asturian network model used during 2008 simulations was updated in two new models designed for each horizon.

In relation to the acquisition of new data for the future models, as the infrastructure is not yet in operation it was not be possible getting the data like previously done from REE. Hence, most of the new information related to max power capacity of the new installations and project deadlines were obtained from:

- BOPA: Boletín oficial del principado de Asturias (Asturian goverment publication) [5]
- BOE: Boletin oficial del estado (Spanish government publication)
- University journals
- News and articles

Other more technical data, such as generation in the moment of the simulations and reactance parameters of the power lines, was assumed taking into account previous model trends.

7.1. 2011 Horizon

7.1.1. Modelling the network

Over the following sections it is detailed the new necessary data as well as modifications and additions to the previous 2008 model in order to get it ready for the new simulations.

No specifications are given about how to introduce data in Power World simulator, as it has already being explained for the current 2008 situation.

7.1.1.1. New bus data

The new buses added to the 2011 model are mainly a consequence either of the new wind farms projects or because of the layout from the new power lines.

Node Name	Voltage (kV)	Area	Duty
Velilla	400	South	Exportation of energy coming from Lada to the south
Penagos	400	East	Exportation of energy coming from Soto to the east
Santa Maria	400	Centre	Part of ASGA route
Tineo	400	South West	Part of ASGA route
Palo	400	North West	Part of ASGA route
Pesoz	400	North West	Part of ASGA route
Boimonte	400	North West	Part of ASGA route
Villalana	132	South	Collect energy from wind farm
Tineo	132	South West	Collect energy from wind farms
Pesoz	132	North West	Collect energy from wind farms
Salas	132	South West	Collect energy from wind farms

Table 38. New Power World model nodes

New Asturian power system model is represented in the following figure slightly modified due to the insertion of the new nodes.

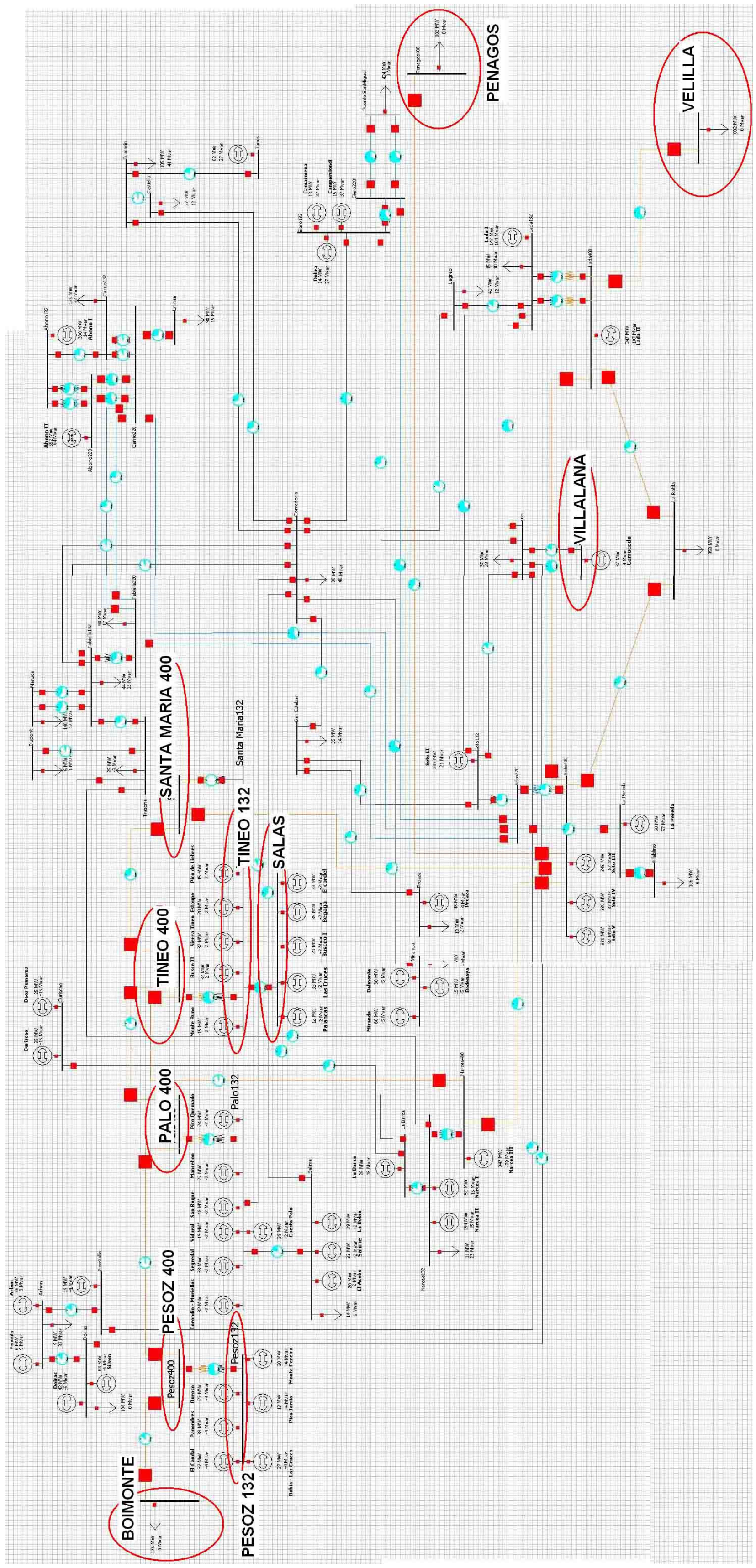


Figure 40. New Power World model

7.1.1.2. New load data

In the future horizons no new internal demand points were considered. However, these energy demands have been assumed to increase a 7% over the following three years. The final demands for the year 2011 were:

Load / Node Name	Voltage (kV)	Area	Type	Load (MW)
Corredoria	132	Centre (Oviedo)	Internal	80.25
San Esteban	132	Centre (Oviedo)	Internal	35.31
Maruca	132	North (Aviles)	Internal	140.38
Tabiella	132	North (Aviles)	Internal	43.65
Dupont	132	North (Aviles)	Internal	6.42
Trasona	132	North (Aviles)	Internal	24.73
Tabiella	220	North (Aviles)	Internal	98.31
Pumarin	132	North (Gijon)	Internal	104.69
Castiello	132	North (Gijon)	Internal	36.70
Carrio	132	North (Gijon)	Internal	135.03
T uninsa	220	North (Gijon)	Internal	98.44
Salime	132	North West	Internal	13.91
Arbon	132	North West	Internal	8.56
Langreo	132	South	Internal	40.66
Lada	132	South	Internal	14.98
Ujo	132	South	Internal	39.12
Narcea	132	South West	Internal	11.02
Miranda	132	South West	Internal	6.85
Proaza	132	South West	Internal	12.84
Puente San Miguel	220	East	External	423.49 (variable)
Penagos	400	East	External	882.27 (variable)
Doiras	132	North West	External	105.87 (variable)
Boimonte(ASGA)	400	North West	External	176.45 (variable)
Villablino	220	South	External	105.87 (variable)
La Robla	400	South	External	952.85 (variable)
Velilla	400	South	External	882.27 (variable)

Table 39. New Power World model loads

The last seven values of external demands are not definitive as they varied during the simulations depending on whether all the evacuation lines or just some of them were in operation. Nevertheless for the case of having all the exportation lines working the values of the table are the appropriate.

External demands are represented in the following figure 41. New demand points are shown in red while the old demand points are in blue:

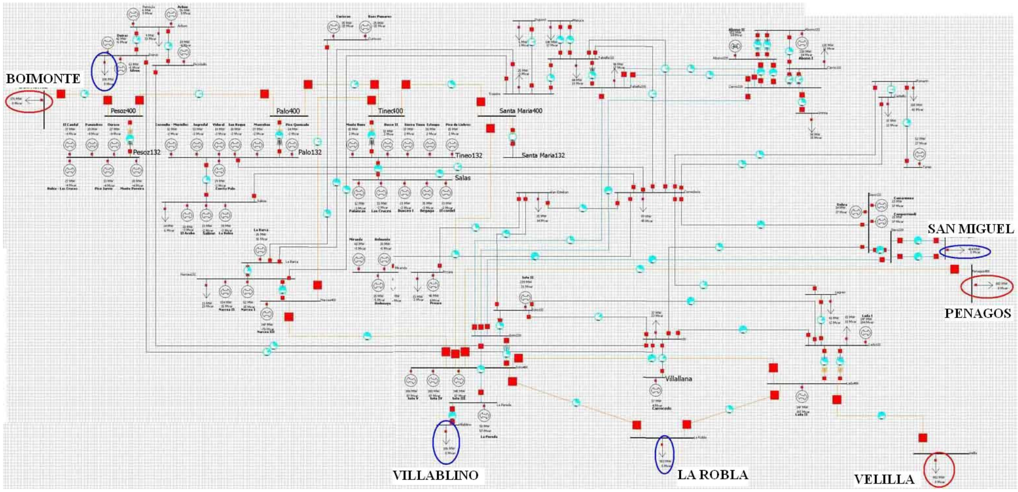


Figure 41. New Power World model loads

7.1.1.3. New generator data

As already said before, new generation (to model until 2011) consisted on the commission of wind farms and combined cycle units. New wind farm generation and essential data for Power World model is shown in the following table:

Wind farm	Node name	Voltage (kV)	Max. Power Output (MW)	Power output (MW)*	Area
Carondio y muriellos	PALO	132	42.7	32.03	North West
El segredal	PALO	132	44.2	33.15	North West
Vidural	PALO	132	25.5	19.13	North West
San Roque	PALO	132	24	18.00	North West
Mancebon	PALO	132	36	27.00	North West
Pico Quemado	PALO	132	31.5	23.63	North West
Ouroso	PESOZ	132	36.3	27.23	North West
Panondres	PESOZ	132	43.5	32.63	North West
El candal	PESOZ	132	49.5	37.13	North West
Bobia Las cruces	PESOZ	132	36	27.00	North West
Pico Jarrio	PESOZ	132	17.8	13.35	North West
Monte Pereira	PESOZ	132	26.3	19.73	North West
Monte buño	TINEO	132	19.5	14.63	South West
Buseco II	TINEO	132	42	31.50	South West
Sierra Tineo	TINEO	132	49	36.75	South West
Palancas	SALAS	132	16.5	12.38	South West
Las Cruces	SALAS	132	43.5	32.63	South West
Busceo I	SALAS	132	28.5	21.38	South West
Begaga	SALAS	132	47.3	35.48	South West
El Cordel	SALAS	132	43.5	32.63	South West
Estoupo	TINEO	132	26.35	19.76	South West
Pico de Liebres	TINEO	132	19.6	14.70	South West
Carrocedo	VILLALANA	132	49.3	36.98	South
TOTAL			1090.07	826.7625	

Table 40. New Power World model generators (wind farm)

*As the power output for the simulations was unknown, it was supposed to be a 75% of the maximum power output from each wind farm.

All those wind farms were located in the west (excluding Carrocedo which was on the south) and thus connected to the 400 kV route ASGA which interconnects the western areas of Asturias with the centre.

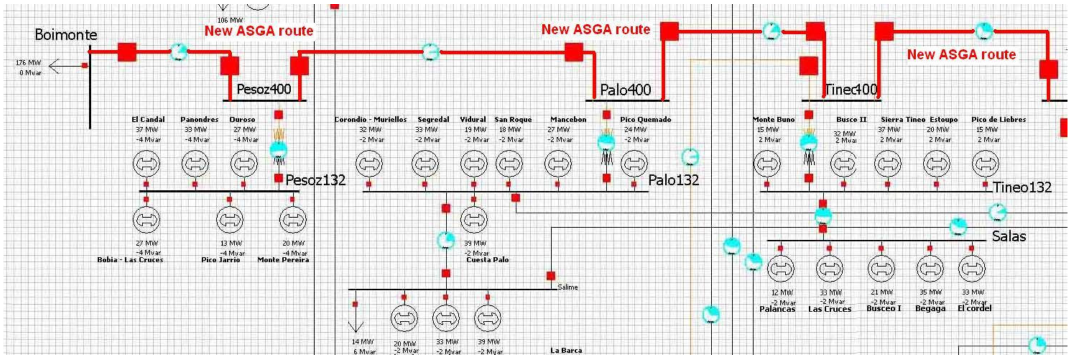


Figure 42. New Power World model generators (wind farm)

Another power plant that will suffer modifications in this period of time was Soto power station, in which two new combined cycle turbines were added to the model (Soto IV and Soto V) while the oldest coal fire unit (Soto I) was deleted.

THERMAL POWER PLANT GENERATION						
Power Station	Unit name	Node name	Voltage (kV)	Max. Power Output (MW)	Power output (MW)*	Area
	Soto I (decommission)	Soto	132	70	62.8	
	Soto II	Soto	132	255	239	
SOTO	Soto III	Soto	400	350	346	South
	Soto IV (new)	Soto	400	400	380	
	Soto V (new)	Soto	400	400	380	

Table 41. New Power World model generators (CCGT)

*As in the case of the wind farms the power output necessary for the simulations was an unknown value, so it was supposed to be a 95% of the maximum power output.

Hydro and rest of coal fire power stations did not experiment any upgrade in this first future period of study of time (2008 – 2011).

7.1.1.4. New branch data

New power lines added to the model for the future situation with horizon 2011along with their necessary characteristics for the model were:

From	To	Voltage (kV)	Capacity (MVA)	Length (miles)
Boimonte	Pesoz	400	1300	43.75
Pesoz	Palo	400	1300	12.5
Palo	Tineo	400	1300	15
Tineo	Santa Maria	400	1300	21.87
Santa Maria	Soto	400	1300	13.75
Soto	Penagos	400	2415	112.5
Lada	Velilla	400	1600	62.5
Narcea	Tineo	400	1300	3.75
Salas	Tineo	132	280	11.25
Villalana	Ujo	132	280	7.5
Soto	Robla	400	1848	52.82
Lada	Robla	400	1236	52.2

Table 42. New Power World model power lines

Despite Soto – Robla and Lada – Robla already existed in the current situation they were included in the list of new power lines since an upgrade of their capacity was carried out with the object of improve the overloaded route of La Robla.

Per unit impedance parameters R, X and B were unknown values for these future lines, however they were dispensable as power world has an option that calculates those parameters for the simulations.

7.1.1.5. New transformer data

Te new transformers added to the model with their capacity and voltage levels are listed in the following table:

Bus	Voltage step	Capacity
Santa Maria	400 / 132	300
Palo	400 / 132	450
Tineo	400 / 132	450
Pesoz	400 / 132	300

Table 43. New Power World model transformers

7.1.2. Simulation and analysis of the 2011 horizon

The situation to be studied over the following three years (2008 / 2011) was organized as follows:

- All the old power plants (except for those to be decommissioned), new wind farm and new combined cycle units are in operation during the whole horizon.
- The simulations were carried out in a series of steps taking into account the several different proposed upgrades in the time for the 400 kV transport network.

In that way the simulations were split up in four scenarios:

1. Scenario I: All the generation and addition of the new ASGA route
2. Scenario II: Addition to the previous scenario La Robla route upgrades
3. Scenario III: Addition to the previous scenario the 400 kV evacuation line Soto – Penagos
4. Scenario IV: Addition to the previous scenario the 400 kV evacuation line Lada – Velilla

Like in the past analysis for the 2008 situation the analysis of the future situation was also based on a comparison between the load levels showed by the power lines and transformers.

7.1.2.1. Scenario I: ASGA Route

During the first scenario of study it was studied how the power system responded to the increase of generation due to:

- The new 23 wind farms in operation: 826.76 MW
- The new 2 combined cycle units from Soto: 760 MW.

With the only modification of the 400 kV ASGA route in the transport system.

Because of the new exportation route energy demand for this case was split up as follows:

General energy balance	
Total Generation	4480.96 MW
Internal demand	951.88 MW
External demand	3529.08 MW
External energy balance	
Villablino (3%)	105.87 MW
Dorias (3%)	105.87 MW
P.SanM (12%)	423.49 MW
Robla (77%)	2717.39 MW
asga (5%)	176.45 MW

Table 44. Energy balance (scenario I)

The reason why the new 400 kV ASGA route was not evacuating greater values of energy is due to the fact that the vicinity region of Galicia, like Asturias, also presents surplus of energy. So the route ASGA can not be used as a main exporting route like happens with Robla.

From	To	kV	MVA Limit	% of MVA Limit
Tineo132	Salas	132	280	48.2
Santa Maria400	Tineo400	400	1300	32.9
Soto400	Santa Maria400	400	1300	32.8
Palo400	Tineo400	400	1300	14.5
Boimonte	Pesoz400	400	1300	13.8
Ujo	Villallana	132	280	13.3
Tineo400	Narcea400	400	1300	3
Palo400	Pesoz400	400	1300	1.9

Table 45. Simulation results for new power lines (scenario I)

As shown in the previous table 45, none of the new power lines exceed the 50% of their level of charge.

However in the following table 46, which shows the old lines whose overload exceeds 50% load level, gave some negative results for the evacuation lines (Lada – La Robla and Soto – La Robla).

From	To	kV	MVA Limit	% of MVA Limit
Lada400	La Robla	400	1030	**121.4**
Soto400	La Robla	400	1540	**101.8**
Siero220	Soto220	220	510	70.3
Miranda	Corredoria	132	150	65.9
Siero220	Puente SanMiguel	220	340	65.4
Puente SanMiguel	Siero220	220	340	65.4
Lada132	Soto132	132	122	64.1
Abono220	Carrio220	220	640	57.8
Abono220	Carrio220	220	640	57.8
Soto220	Carrio220	220	636	55.6
Lada132	Ujo	132	110	55.5
Soto400	Lada400	400	1210	54.4
Villablino	La Pereda	220	200	54.1
Corredoria	Siero132	132	150	50.1

Table 46. Simulation results for old power lines (scenario I)

Old power lines with charge levels over 50%

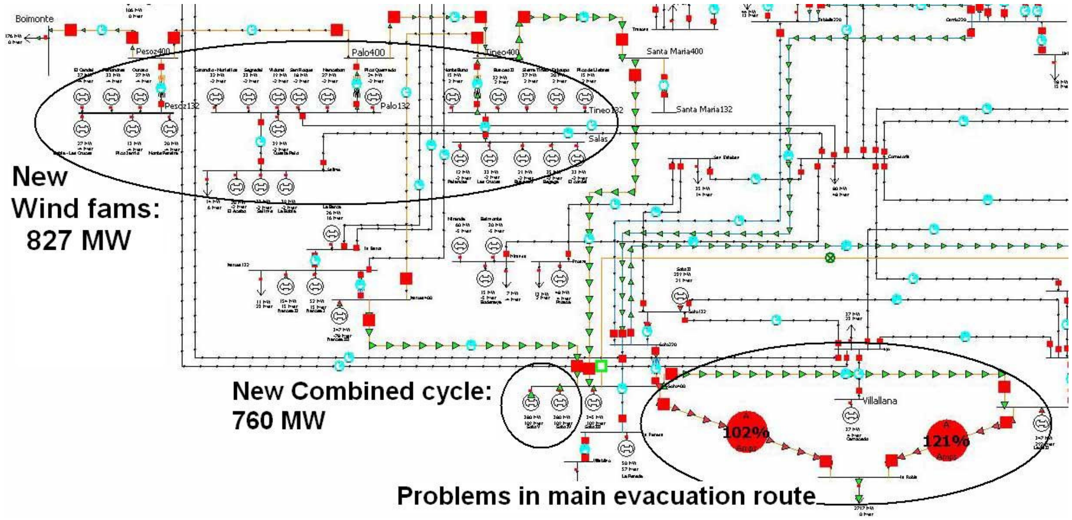


Figure 43. Simulation results (scenario I)

On the one hand, the 102 % overload in the power line Lada – La Robla was not acceptable for the operation of the system. But it is below the 115% limit set in the REE standards so the power system operators would have up to 20 minutes to solve the problem.

On the other hand, the 121.4 % level of charge in the power line Lada – La Robla was completely unacceptable. The system could not stand this overload situation provoking the fall of the line.

As for the case of transformers load level both the new ones and the old ones showed acceptable levels below or slightly above 50% overload.

From	To	kV	MVA limit	% of MVA Limit
Tineo400	Tineo132	132 / 400	450	55.9
Pesoz400	Pesoz132	132 / 400	300	53
Palo400	Palo132	132 / 400	450	46.3

Table 47. Simulation results for new transformers (scenario I)

From	To	kV	MVA limit	% of MVA Limit
Siero220	Siero132	132 / 220	150	60.2
Narcea400	Narcea132	132 / 400	350	49.8
Lada400	Lada132	132 / 400	300	38.8
Lada132	Lada400	132 / 400	300	38.8
Abono132	Abono220	132 / 220	225	40.1
Abono132	Abono220	132 / 220	225	40.1
Tabiella132	Tabiella220	132 / 220	270	35.3
Soto220	Soto132	132 / 220	350	26.9
Soto220	Soto400	220 / 400	600	23.1
Carrio220	Carrio132	132 / 220	270	5.5
Carrio220	Carrio132	132 / 220	270	5.5

Table 48. Simulation results for old transformers (scenario I)

7.1.2.2. Scenario II: Soto – La Robla and Lada – La Robla upgrade

For the second scenario of study, as a short term solution to the previous scenario overload problems, it was carried out the upgrade of the 400 kV power lines that send out the energy through La Robla.

Both evacuation lines (Soto – La Robla and Lada – La Robla) experienced a 20 % increase in their power capacity: Soto – La Robla, moved from a previous 1540 MVA to a new 1848 MW. While Lada – La Robla moved from a previous 1030 MW to a new 1236 MW.

Referring to demand, as no new evacuation lines were proposed in this scenario, the external demand remained the same as during the previous scenario:

External energy balance	
Villablino (3%)	105.87 MW
Dorias (3%)	105.87 MW
P.SanM (12%)	423.49 MW
Robla (77%)	2717.39 MW
asga (5%)	176.45 MW

Table 49. Energy balance (scenario II)

The following table shows once again how new power lines kept under the 50% overload.

From	To	kV	MVA Limit	% of MVA Limit
Tineo132	Salas	132	280	48.2
Santa Maria400	Tineo400	400	1300	32.9
Soto400	Santa Maria400	400	1300	32.8
Boimonte	Pesoz400	400	1300	13.8
Palo400	Tineo400	400	1300	14.5
ujo	Villallana	132	280	13.3
Palo400	Pesoz400	400	1300	1.9
Soto400	Penagos400	400	2415	3.6
Tineo400	Narcea400	400	1300	3

Table 50. Simulation results for new power lines (scenario II)

However, improvements carried out in the evacuation route through la Robla did not seem to be enough, overload problems arose again:

From	To	kV	MVA Limit	% of MVA Limit
Lada400	La Robla	400	1236	101.2
Soto400	La Robla	400	1848	84.8
Miranda	Corredoria	132	150	65.9
Siero220	Soto220	220	510	70.3
Siero220	Puente SanMiguel	220	340	65.4
Puente SanMiguel	Siero220	220	340	65.4
Lada132	Soto132	132	122	64.1
Abono220	Carrio220	220	640	57.8
Abono220	Carrio220	220	640	57.8
Soto220	Carrio220	220	636	55.6
Lada132	ujo	132	110	55.5
Soto400	Lada400	400	1210	54.4
Villablino	La Pereda	220	200	54.1
Corredoria	Siero132	132	150	50.1

Table 51. Simulation results for old power lines (scenario II)

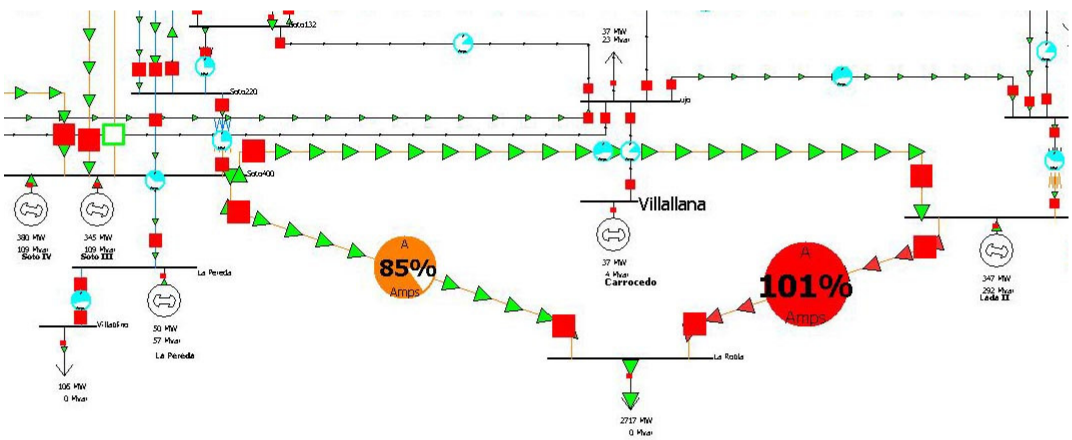


Figure 44. Simulation results (scenario II)

In that case Soto – La Robla load level went down from a previous 102 % to a new 85 %, which is a worrying value but acceptable. The other line Lada – La Robla went down from a previous 121 % to a new 101 %, and kept as an unacceptable situation.

Having a look to the transformers results, both new and old ones, load levels remain under tolerable values.

From	To	kV	MVA Limit	% of MVA Limit
Tineo400	Tineo132	132 / 400	450	55.9
Pesoz400	Pesoz132	132 / 400	300	53
Palo400	Palo132	132 / 400	450	46.3

Table 52. Simulation results for new transformers (scenario II)

From	To	kV	MVA Limit	% of MVA Limit
Siero220	Siero132	132 / 220	150	60.2
Narcea400	Narcea132	132 / 400	350	49.8
Lada400	Lada132	132 / 400	300	38.8
Lada132	Lada400	132 / 400	300	38.8
Abono132	Abono220	132 / 220	225	40.1
Abono132	Abono220	132 / 220	225	40.1
Tabiella132	Tabiella220	132 / 220	270	35.3
Soto220	Soto132	132 / 220	350	26.9
Soto220	Soto400	220 / 400	600	23.1
Carrio220	Carrio132	132 / 220	270	5.5
Carrio220	Carrio132	132 / 220	270	5.5

Table 53. Simulation results for old transformers (scenario II)

7.1.2.3. Scenario III: 400 kV line Soto – Penagos

A solution to the constant evacuation problems showed in previous scenarios was the addition of the new 400 kV exportation power line Soto – Penagos.

As a consequence, the external demands varied in the following way:

External energy balance	
Villablino (3%)	105.87 MW
Dorias (3%)	105.87 MW
P.SanM (12%)	423.49 MW
Robla (39%)	1376.34 MW
asga (5%)	176.45 MW
Penagos (38%)	1341.05 MW

Table 54. Energy balance (scenario III)

All the external demand previously managed by Robla is in this case split between Robla and Penagos.

Simulation results from the new and old lines are shown in the following tables:

From	To	kV	MVA Limit	% of MVA Limit
Soto400	Penagos400	400	2415	73
Tineo132	Salas	132	280	48.2
Santa Maria400	Tineo400	400	1300	33.5
Soto400	Santa Maria400	400	1300	33.4
Palo400	Tineo400	400	1300	14.9
Boimonte	Pesoz400	400	1300	13.8
ujo	Villallana	132	280	13.3
Tineo400	Narcea400	400	1300	2.9
Palo400	Pesoz400	400	1300	1.9

Table 55. Simulation results for new power lines (scenario III)

From	To	kV	MVA Limit	% of MVA Limit
Siero220	Soto220	220	510	69.9
Miranda	Corredoria	132	150	65.9
Siero220	Puente SanMiguel	220	340	65.4
Puente SanMiguel	Siero220	220	340	65.4
Abono220	Carrio220	220	640	62.6
Abono220	Carrio220	220	640	62.6
Soto220	Carrio220	220	636	61.5
Lada132	Soto132	132	122	60.3
Villablino	La Pereda	220	200	54.1
Lada132	ujo	132	110	52.8
Lada400	La Robla	400	1236	52.3

Table 56. Simulation results for old power lines (scenario II)

By commissioning this new evacuation route through the east of the region, a lighten in the previously overloaded power lines (Soto - La Robla and Lada – La Robla) was obtained. Both lines decreased their values from 85% to 40.4% and from 101% to 52.3% respectively.

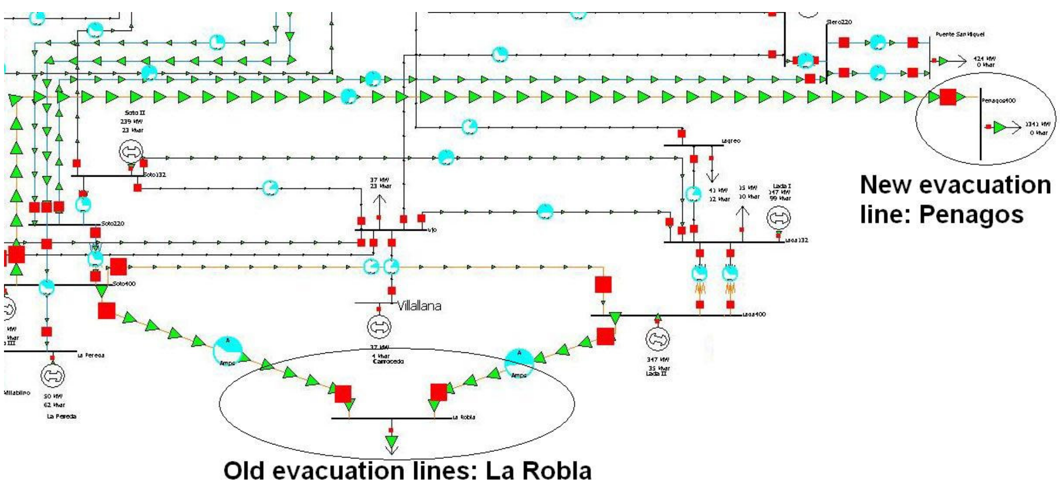


Figure 45. Simulation results (scenario III)

Once again transformers did not experiment anomalous values in their load level:

From	To	kV	MVA Limit	% of MVA Limit
Tineo400	Tineo132	132 / 400	450	55.9
Palo400	Palo132	132 / 400	450	47.7
Pesoz400	Pesoz132	132 / 400	300	53

Table 57. Simulation results for new transformers (scenario III)

From	To	kV	MVA Limit	% of MVA Limit
Siero220	Siero132	132 / 220	150	61.6
Narcea400	Narcea132	132 / 400	350	53.1
Lada132	Lada400	132 / 400	300	36.9
Lada400	Lada132	132 / 400	300	36.9
Tabiella132	Tabiella220	132 / 220	270	39.4
Abono132	Abono220	132 / 220	225	40
Abono132	Abono220	132 / 220	225	40
Soto220	Soto400	220 / 400	600	32.4
Soto220	Soto132	132 / 220	350	28.1
Carrio220	Carrio132	132 / 220	270	5.5
Carrio220	Carrio132	132 / 220	270	5.5

Table 58. Simulation results for old transformers (scenario III)

7.1.2.4. Scenario IV: 400 kV line Lada - Velilla

The last scenario of study for the 2011 horizon future situation was the addition of the second large project for the exportation of energy through the south of the region: The 400 kV power line Lada – Velilla, which is expected to be in operation by the end of 2011.

The introduction of the new external demand on Velilla makes necessary a recalculation of the energy surplus to be sent away to other regions.

External energy balance	
Villablino (3%)	105.87 MW
Dorias (3%)	105.87 MW
P.SanM (12%)	423.49 MW
Robla (27%)	952.85 MW
asga (5%)	176.45 MW
Penagos (25%)	882.27 MW
Velilla (25%)	882.27 MW

Table 59. Energy balance (scenario IV)

Results from the simulations for the new power lines and old power lines (above 50% overload) are shown in the following tables:

From	To	kV	MVA Limit	% of MVA Limit
Lada400	Velilla	400	1600	56.5
Tineo132	Salas	132	280	48.2
Soto400	Penagos400	400	2415	38.9
Santa Maria400	Tineo400	400	1300	32.9
Soto400	Santa Maria400	400	1300	32.7
Palo400	Tineo400	400	1300	14.4
Boimonte	Pesoz400	400	1300	13.8
ujo	Villallana	132	280	13.3
Tineo400	Narcea400	400	1300	3
Palo400	Pesoz400	400	1300	1.9

Table 60. Simulation results for new power lines (scenario IV)

From	To	kV	MVA Limit	% of MVA Limit
Siero220	Soto220	220	510	70.3
Miranda	Corredoria	132	150	65.9
Siero220	Puente SanMiguel	220	340	65.4
Puente SanMiguel	Siero220	220	340	65.4
Lada132	Soto132	132	122	64.1
Abono220	Carrio220	220	640	57.4
Abono220	Carrio220	220	640	57.4
Soto400	Lada400	400	1210	57.2
Lada132	ujo	132	110	55.5
Soto220	Carrio220	220	636	55
Villablino	La Pereda	220	200	54.1
Corredoria	Siero132	132	150	50.1

Table 61. Simulation results for old power lines (scenario IV)

The main 400 kV exportation power lines experimented a even greater lightening in their overloads:

- Soto – Penagos moved from 73 % to 38.9 %
- Lada – La Robla moved from 52.3 % to 29.9 %
- Soto – La Robla moved from 40.4% to 32 %

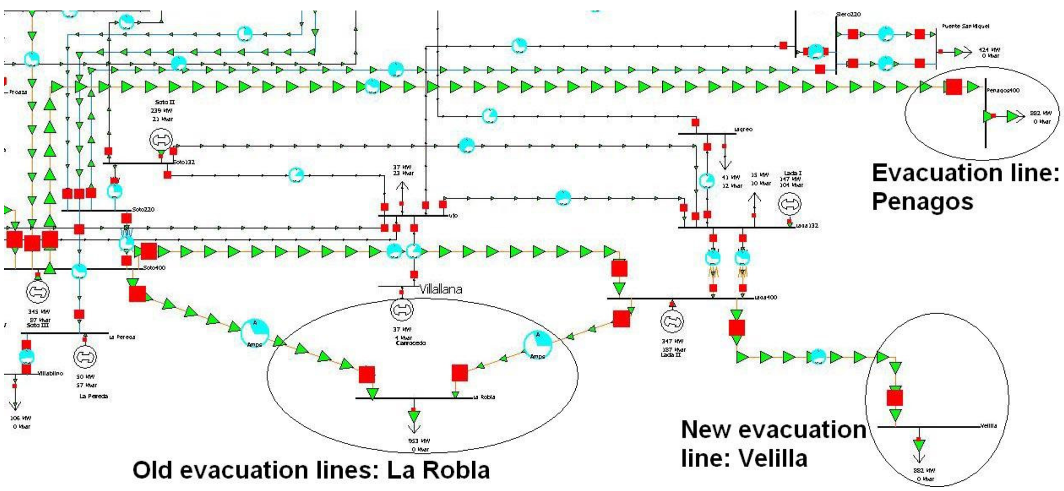


Figure 46. Simulation results (scenario IV)

Transformers did not experiment major changes

From	To	kV	MVA Limit	% of MVA Limit
Tineo400	Tineo132	132 / 400	450	55.9
Pesoz400	Pesoz132	132 / 400	300	53
Palo400	Palo132	132 / 400	450	46.3

Table 62. Simulation results for new transformers (scenario IV)

From	To	kV	MVA rating	Percent
Siero220	Siero132	132 / 220	150	60.1
Narcea400	Narcea132	132 / 400	350	49.6
Abono132	Abono220	132 / 220	225	40.1
Abono132	Abono220	132 / 220	225	40.1
Lada132	Lada400	132 / 400	300	38.8
Lada400	Lada132	132 / 400	300	38.8
Tabiella132	Tabiella220	132 / 220	270	34.9
Soto220	Soto132	132 / 220	350	26.9
Soto220	Soto400	220 / 400	600	22.4
Carrio220	Carrio132	132 / 220	270	5.5
Carrio220	Carrio132	132 / 220	270	5.5

Table 63. Simulation results for old transformers (scenario IV)

7.2. 2015 Horizon

7.2.1. Modelling the network

The new model for the 2015 horizon will be obtained by adding to the previous 2011 model new expected generation and the buses, lines and transformer related. No new evacuation lines were considered in this period of time.

7.2.1.1. New bus data

The new nodes considered for 2015 horizon were a consequence of the new combined cycle power plants (Musel and Santa Maria) and the conclusion of the central ring (Tabiella and Carrio).

Node Name	Voltage (kV)	Area	Duty
Musel	220	North (Gijon)	Connection of a new combined cycle unit to the grid
Carrio	400	North (Gijon)	Part of the central ring.
Tabiella	400	North (Aviles)	Part of the central ring.
Santa Maria	132	Centre (Oviedo)	Connection of a new combined cycle unit to the grid

Table 64. New Power World model nodes

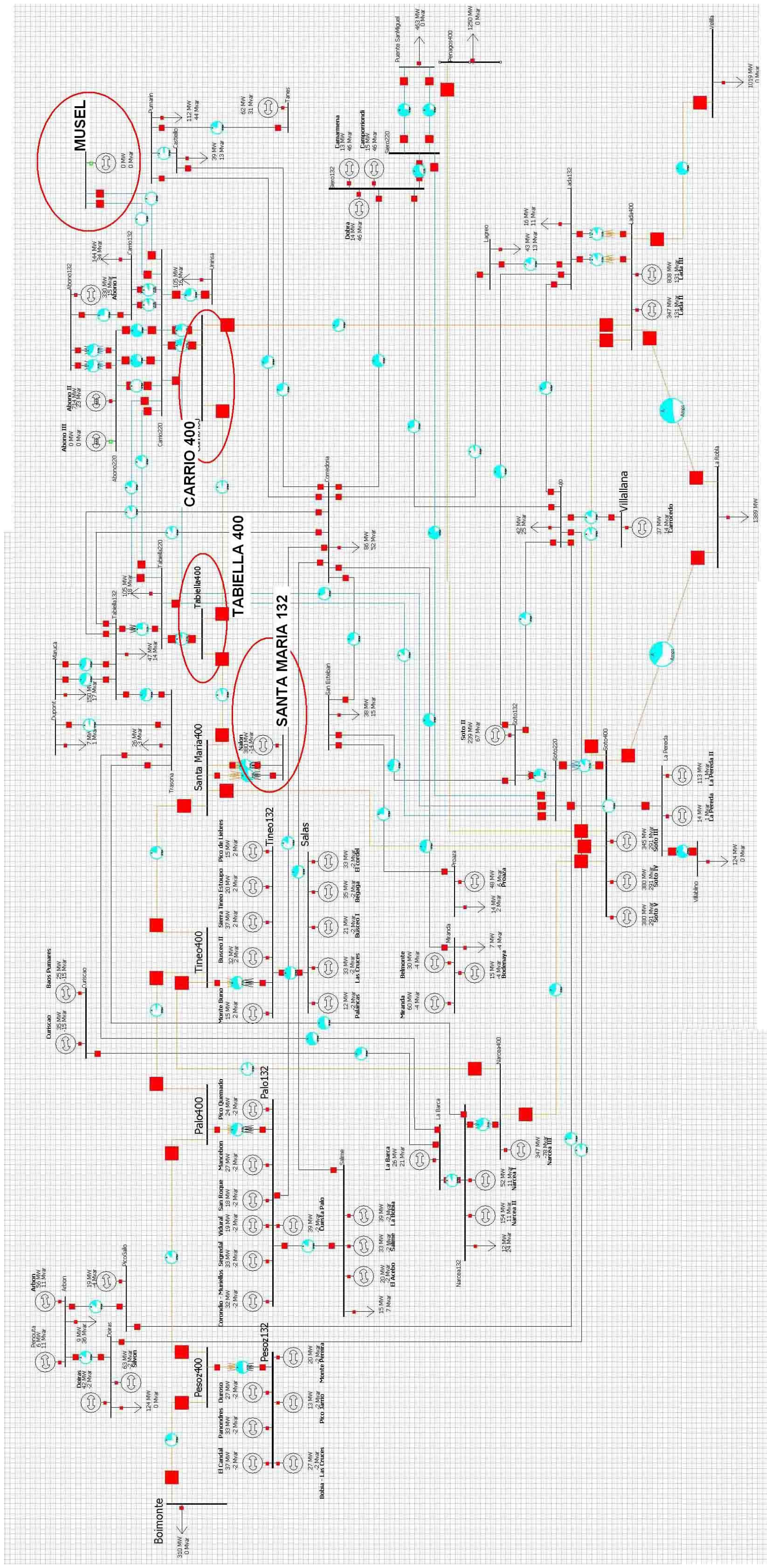


Figure 47. New Power World model

7.2.1.2. New load data

As in the previous 2011 horizon, internal energy demand remains the same according to the number of demanding points but once again an increase of another 7% was assumed. So final demands for the year 2015 were:

Load / Node Name	Voltage (kV)	Area	Type	Load (MW)
Salime	132	North West	**Internal**	**14.82**
Arbon	132	North West	**Internal**	**9.12**
Narcea	132	South West	**Internal**	**11.74**
Maruca	132	North (Aviles)	**Internal**	149.56
Tabiella	132	North (Aviles)	**Internal**	46.51
Dupont	132	North (Aviles)	**Internal**	**6.84**
Pumarin	132	North (Gijon)	**Internal**	**111.55**
Castiello	132	North (Gijon)	**Internal**	**39.10**
Corredoria	132	Centre (Oviedo)	**Internal**	**85.50**
Carrio	132	North (Gijon)	**Internal**	143.87
Trasona	132	North (Aviles)	**Internal**	**26.357**
Miranda	132	South West	**Internal**	**7.29**
Proaza	132	South West	**Internal**	**13.68**
San Esteban	132	Centre (Oviedo)	**Internal**	**37.62**
Langreo	132	South	**Internal**	**43.32**
Lada	132	South	**Internal**	**15.96**
Ujo	132	South	**Internal**	**41.678**
Tabiella	220	North (Aviles)	**Internal**	**104.743**
T uninsa	220	North (Gijon)	**Internal**	**104.88**
Villablino	220	South	External	124.19 (variable)
Doiras	132	North West	External	124.19 (variable)
Puente San Miguel	220	East	External	496.74 (variable)
La Robla	400	South	External	2483.72 (variable)
Boimonte(ASGA)	400	North West	External	310.47 (variable)
Penagos	400	East	External	1366.05 (variable)
Velilla	400	South	External	1303.95 (variable)

Table 65. New Power World model loads

The seven last values of external demands are not definitive as they varied during the simulations depending on the number of new generation units in operation. Nevertheless for the case of having all the new generators in operation the values of the showed in the table were the appropriates.

7.2.1.3. New generator data.

As in the previous case hydro power plants were not expected to experiment any upgrade. Neither did wind farms. So the only modifications on the generation took place in the coal fire power plants, as several new combined cycle units are expected to begin operating by the end of 2015.

In the following table shows (for the 2011 – 2015 period of time):

- The old coal fire units to be decommissioned (Aboño I, Lada I)
- The new combined cycle units to be built in already existing power plants (Lada III, Aboño III, La Pereda II)
- The new power plants expected to be operating by the end of 2015 (Musel, Nalon)

THERMAL POWER PLANT GENERATION						
Power Station	Unit name	Node name	Voltage (kV)	Max. Power Output (MW)	Power output (MW)*	Area
SOTO	Soto II	Soto	132	255	239	South
	Soto III	Soto	400	350	346	
	Soto IV	Soto	400	400	380	
	Soto V	Soto	400	400	380	
ABOÑO	**Abono I (decommission)**	Abono	132	380	330	North (Gijon)
	Abono II	Abono	220	543	525	
	Aboño III (new)	Aboño	220	800	760	
LA PEREDA	La Pereda	La Pereda	220	50	50	South
	La Pereda II (new)	La Pereda	220	400	380	
LADA	**Lada I (decommision)**	Lada	132	155	147	South
	Lada II	Lada	400	350	347	
	Lada III (new)	Lada	400	850	807.5	
NARCEA	Narcea I	Narcea	132	65	52	South West
	Narcea II	Narcea	132	166	154.2	
	Narcea III	Narcea	400	364	347	
Nalon	**Nalon (new)**	Santa Maria	132	400	380	Centre (Oviedo)
Musel	**Musel (new)**	Musel	220	860	817	North (Gijon)

Table 66. New Power World model generators (CCGT)

*Like in the previous model, the power output necessary for the simulations is an unknown value, so it was assumed to be a 95% of the maximum power output.

The new added generation units are represented in the two following Power World figures:

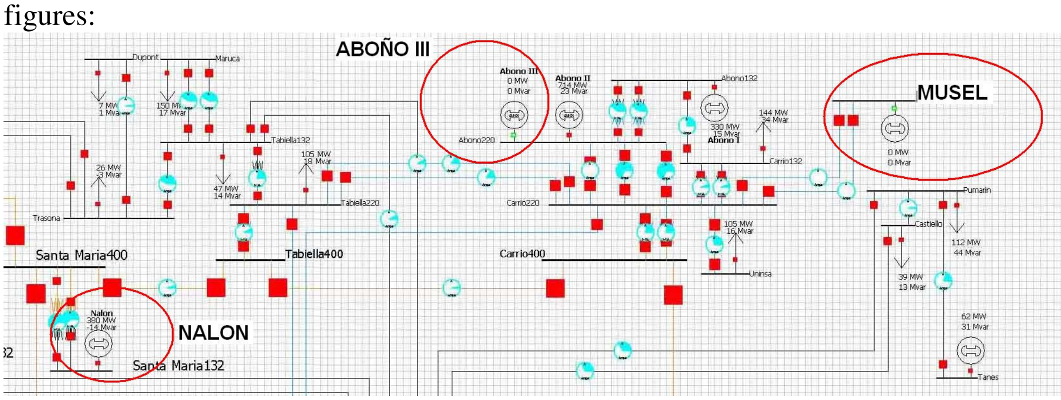


Figure 48. New Power World model generators (North)

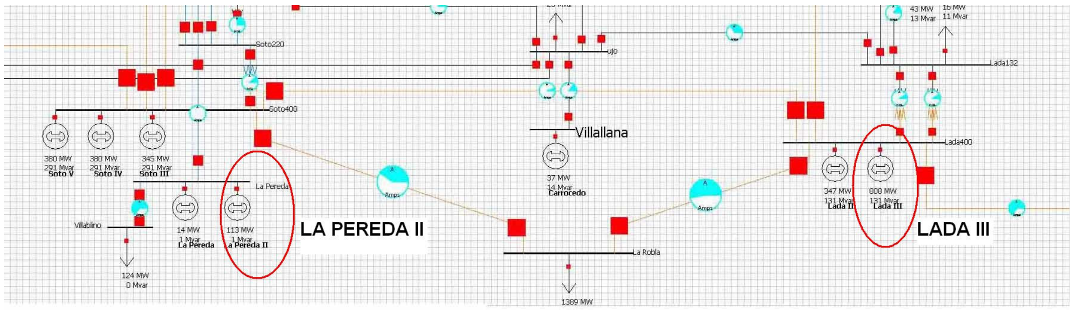


Figure 49. New Power World model generators (South)

7.2.1.4. New branch data

The new power lines added for the future situation with horizon 2015 were:

From	To	Voltage (kV)	Capacity (MVA)	Length (miles)
Carrio	Musel	220	640	0.63
Carrio	Musel	220	640	0.63
Santa Maria	Tabiella	400	1300	16.88
Tabiella	Carrio	400	1300	6.88
Carrio	Lada	400	1300	17.50
La Pereda	Soto	220	640	4.97

Table 67. New Power World model power lines

In this case the aim of the lines was just the interconnection between power plants substations and other distribution and transmission substation. No new exportation routes were added for 2015 horizon.

7.2.1.5. New transformer data

The transformers added to complete the model are shown in the following table:

Bus	Voltage step	Capacity
Tabiella	400 / 220	600
Carrio	400 / 220	600
Carrio	400 / 220	600
Carrio	400 / 220	600
Santa Maria	400 / 132	300
Santa Maria	400 / 132	300

Table 68. New Power World model transformers

7.2.2. Simulation and analysis of the 2015 horizon

In order to begin simulation and analysis of this new future horizon (2015) it is remembered over the following lines the starting point and the process to follow with the simulations.

Continuing the previous situation the system presented the following features:

- In reference to power lines, all the evacuation lines proposed in the previous horizon were already in operation and no more evacuation routes were added during 2015 horizon. The only modification in the transmission system was the conclusion of the central ring.

- In reference to the generation, all the new wind farms were already in operation but seven new combined cycle units were added as they are expected to be in operation by the end of 2015.

Therefore, 2015 horizon was split up in the following three simulation scenarios:

1. Scenario I: Nalon, La Pereda and Lada III combined cycle units
2. Scenario II: Musel combined cycle unit
3. Scenario III: Aboño III combined cycle unit.

7.2.2.1. Scenario I: Nalon, La Pereda and Lada III combined cycle units

During the first scenario of the 2015 horizon, three new combined cycle units were in operation. Two of then (Nalon and La Pereda) in new power stations while the third one, Lada III, replacing the old unit Lada I.

The internal demand of energy was constant for the whole horizon and thus it did not suffer any modification. However, the distribution of external demand varied because of the increase of generation.

General energy balance	
Total Generation	5646.46 MW
Internal demand	1014.16 MW
External demand	4632.31 MW
External energy balance	
Villablino (3%)	138.97 MW
Dorias (3%)	138.97 MW
P.SanM (10%)	463.23 MW
Robla (30%)	1389.69 MW
asga (5%)	231.62 MW
Penagos (27%)	1250.72 MW
Velilla (22%)	1019.11 MW

Table 69. Energy balance (scenario I)

Overload results from new (all) and old (those above 50% overload) lines are shown in the following tables:

From	To	kV	MVA Limit	% of MVA Limit
Carrio400	Lada400	400	1300	26.3
Tabiella400	Carrio400	400	1300	11.4
Santa Maria400	Tabiella400	400	1300	10.6

Table 70. Simulation results for new power lines (scenario I)

From	To	kV	MVA Limit	% of MVA Limit
La Pereda	Soto220	220	220	**130.6**
Siero220	Soto220	220	510	82.6
Siero220	Puente SanMiguel	220	340	72.1
Puente SanMiguel	Siero220	220	340	72.1
Villablino	La Pereda	220	200	71.5
Lada400	Velilla	400	1600	65.8
Miranda	Corredoria	132	150	65.4
Lada132	Soto132	132	122	63.8
Soto400	Penagos400	400	2415	62.4
La Barca	Trasona	132	132	58.9
Corredoria	Siero132	132	150	57.7
Narcea132	Trasona	132	132	54.2
Lada400	La Robla	400	1236	52.3

Table 71. Simulation results for old power lines (scenario I)

The previous tables show how the increase in the generation did not provoke any anomalous overload in the 400 kV evacuation power lines:

- Soto – La Robla: 41.1 %
- Lada – La Robla: 52.3 %
- Soto – Penagos: 62.4 %
- Lada – Velilla: 65.8 %

But the main problem arose in the 220 kV power line which connects La Pereda substation, where a new 400 MW combined cycle unit was installed, with Soto substation:

- La Pereda – Soto: 130.6 %

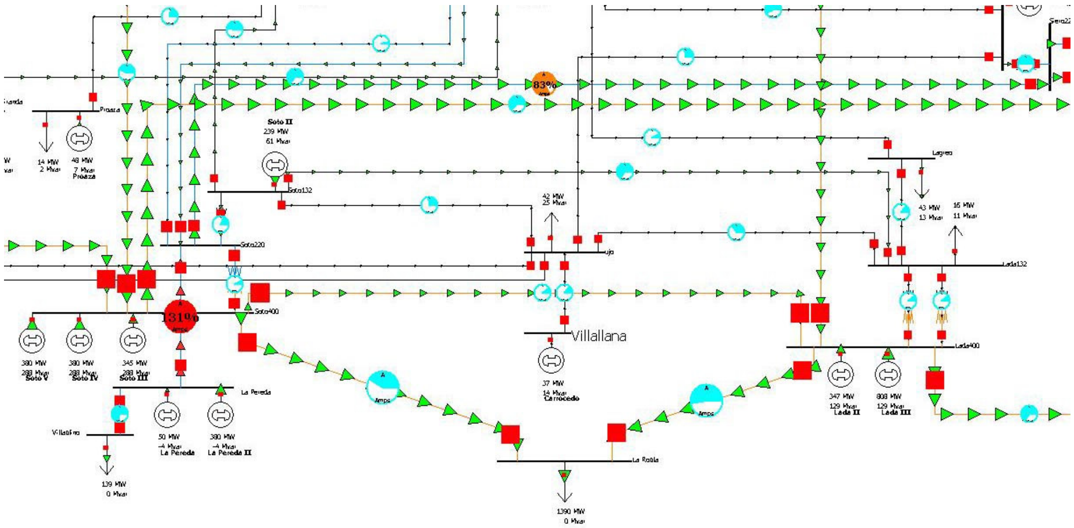


Figure 50. Simulation results (scenario I)

The solution to this problem was no other but upgrade the capacity of this 220 kV power line from the limited 200 MVA to a new power line with 600 MVA.

Another line that showed worrying values was 220 kV Soto – Siero, with an 82.6 % overload. The most effective solution to that increase in the load level was the diversion of the energy through a power line like Soto – Penagos which runs along a similar route.

Transformer levels of charge remained acceptable.

From	To	kV	MVA Limit	% of MVA Limit
Santa Maria400	Santa Maria132	132 / 400	300	63.4
Santa Maria400	Santa Maria132	132 / 400	300	63.4
Carrio220	Carrio400	220 / 400	600	32.6
Tabiella220	Tabiella400	220 / 400	600	6.3

Table 72. Simulation results for new transformers (scenario I)

From	To	kV	MVA Limit	% of MVA Limit
Tineo400	Tineo132	132 / 400	450	55.9
Pesoz400	Pesoz132	132 / 400	300	52.8
Siero220	Siero132	132 / 220	150	50.4
Palo400	Palo132	132 / 400	450	42.5
Abono132	Abono220	132 / 220	225	40
Abono132	Abono220	132 / 220	225	40
Narcea400	Narcea132	132 / 400	350	37.4
Soto220	Soto132	132 / 220	350	18.8
Tabiella132	Tabiella220	132 / 220	270	18.6
Lada132	Lada400	132 / 400	300	11.2
Lada400	Lada132	132 / 400	300	11.2
Soto220	Soto400	220 / 400	600	7.4
Carrio220	Carrio132	132 / 220	270	5.3
Carrio220	Carrio132	132 / 220	270	5.3

Table 73. Simulation results for old transformers (scenario I)

7.2.2.2. Scenario II: Musel combined cycle unit

During the second scenario of study a new combined cycle turbine, Musel, were added to the Asturian Power system.

Because of this new increase in the generation of energy, the external demand of energy also increased and needed to be redistributed among the several external demand points.

General energy balance	
Total Generation	6463.46 MW
Internal demand	1014.16 MW
External demand	5449.31 MW
External energy balance	
Villablino (2%)	108.99 MW
Dorias (2%)	108.99 MW
P.SanM (8%)	435.94 MW
Robla (40%)	2179.72 MW
asga (5%)	272.47 MW
Penagos (22%)	1198.85 MW
Velilla (21%)	1144.35 MW

Table 74. Energy balance (scenario II)

Load levels after the simulation for the new and old power lines are shown in the following tables:

From	To	kV	MVA Limit	% of MVA Limit
Carrio220	Musel	220	640	63.9
Carrio220	Musel	220	640	63.9
Carrio400	Lada400	400	1300	60.4
Santa Maria400	Tabiella400	400	1300	10.6
Tabiella400	Carrio400	400	1300	9.5

Table 75. Simulation results for new power lines (scenario II)

From	To	kV	MVA Limit	% of MVA Limit
Lada400	La Robla	400	1236	83.7
Lada132	Soto132	132	122	80.5
Siero220	Soto220	220	510	79
Lada400	Velilla	400	1600	74.5
Siero220	Puente SanMiguel	220	340	67.5
Puente SanMiguel	Siero220	220	340	67.5
Miranda	Corredoria	132	150	65.4
Soto400	La Robla	400	1848	64.9
Soto400	Santa Maria400	400	1300	59.6
Soto400	Penagos400	400	2415	58.2
Lada132	ujo	132	110	57.3
Villablino	La Pereda	220	200	55.7
Corredoria	Siero132	132	150	55.6
La Barca	Trasona	132	132	52.6

Table 76. Simulation results for old power lines (scenario II)

The charge levels in the 400 kV power lines remained within an acceptable situation:
Soto – Penagos: 58.2 %
Soto – La Robla: 64.9 %
Lada – Velilla: 74.5 %
Lada – La Robla: 83.7 %

Despite all the values remained under 100 % overload limit, lines like Lada – La Robla showed values that should be considered as problematic when facing future increases in the surplus energy.

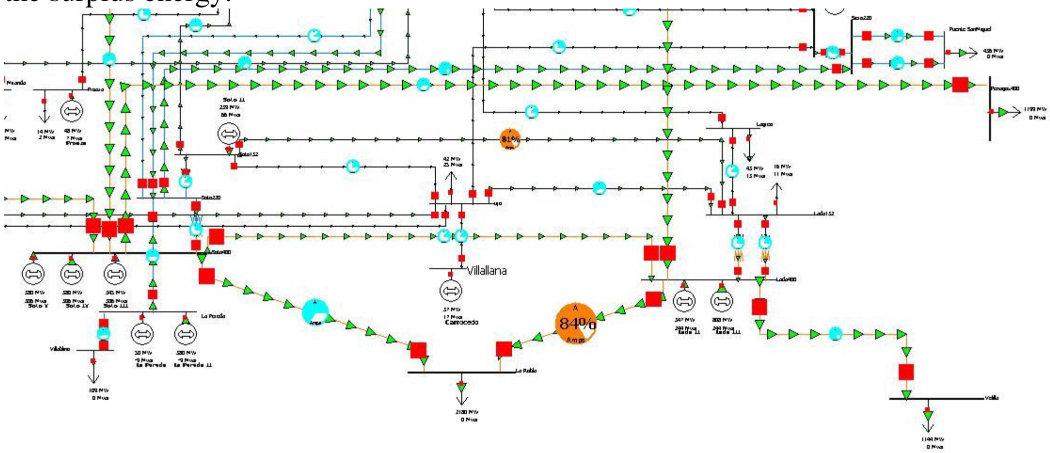


Figure 51. Simulation results (scenario II)

Results from the transformers overload are shown in the following tables:

From	To	kV	MVA Limit	% of MVA Limit
Carrio220	Carrio400	220 / 400	600	110.5
Santa Maria400	Santa Maria132	132 /400	300	63.4
Santa Maria400	Santa Maria132	132 / 400	300	63.4
Tabiella220	Tabiella400	220 / 400	600	43.3

Table 77. Simulation results for new transformers (scenario II)

From	To	kV	MVA Limit	% of MVA Limit
Tineo400	Tineo132	132 / 400	450	55.9
Pesoz400	Pesoz132	132 / 400	300	52.6
Palo400	Palo132	132 / 400	450	44.5
Narcea400	Narcea132	132 / 400	350	42.6
Siero220	Siero132	132 / 200	150	41.9
Abono132	Abono220	132 / 220	225	39.9
Abono132	Abono220	132 / 220	225	39.9
Soto220	Soto400	220 / 400	600	27.9
Tabiella132	Tabiella220	132 / 220	270	25.7
Lada132	Lada400	132 / 400	300	20.7
Lada400	Lada132	132 / 400	300	20.7
Soto220	Soto132	132 / 220	350	14.1
Carrio220	Carrio132	132 / 220	270	5.5
Carrio220	Carrio132	132 / 220	270	5.5

Table 78. Simulation results for old transformers (scenario II)

And unusual load level increment showed up in the transformer interconnecting Carrio 220 – Carrio 400. This was due to the start operation of the 860 MW unit installed in Musel, which drain all this energy directly to Carrio 220.

The most efficient solution was no other that the installation of a second transformer identical to the already existing.

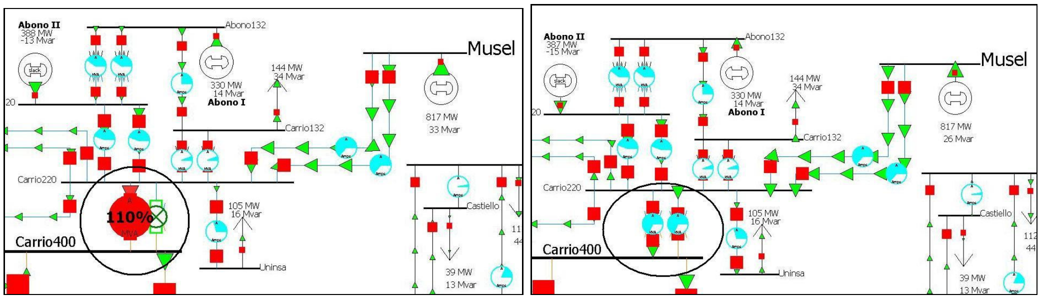


Figure 52. Simulations results after and before adding a second transformer

7.2.2.3. Scenario III: Aboño III combined cycle unit

During the third scenario of study the new combined cycle turbine Aboño III was added to the Asturian Power system.

Surplus energy increased and therefore external demand points needed to be recalculated.

General energy balance	
Total Generation	7223.46 MW
Internal demand	1014.16 MW
External demand	6209.31 MW
External energy balance	
Villablino (2%)	124.19 MW
Dorias (2%)	124.19 MW
P.SanM (8%)	496.74 MW
Robla (40%)	2483.72 MW
asga (5%)	310.47 MW
Penagos (22%)	1366.05 MW
Velilla (21%)	1303.95 MW

Table 79. Energy balance (scenario III)

Load levels results for power lines are shown in the following tables:

From	To	kV	MVA Limit	% of MVA Limit
Carrio400	Lada400	400	1300	96.6
Carrio220	Musel	220	640	64.1
Carrio220	Musel	220	640	64.1
Santa Maria400	Tabiella400	400	1300	31.6
Tabiella400	Carrio400	400	1300	16.1

Table 80. Simulation results for new power lines (scenario III)

From	To	kV	MVA Limit	% of MVA Limit
Abono220	Carrio220	220	640	111.2
Abono220	Carrio220	220	640	111.2
Lada400	La Robla	400	1236	97.4
Siero220	Soto220	220	510	91.8
Lada400	Velilla	400	1600	86
Soto400	Penagos400	400	2415	80.6
Lada132	Soto132	132	122	80.1
Siero220	Puente SanMiguel	220	340	78.1
Puente SanMiguel	Siero220	220	340	78.1
Soto400	Santa Maria400	400	1300	75.2
Soto400	La Robla	400	1848	73.5
Miranda	Corredoria	132	150	65.4
Villablino	La Pereda	220	200	63.6
Corredoria	Siero132	132	150	56.2
La Barca	Trasona	132	132	50.9
Lada132	ujo	132	110	50.6
Narcea400	Soto400	400	1210	50.4

Table 81. Simulation results for old power lines (scenario III)

In this situation many overload problems arouse due to the new generation from Aboño III. The problems can be summarized as:

- Problems for the transmission of energy from the power plant to the central ring
- Problems for the exportation of the new surplus energy.

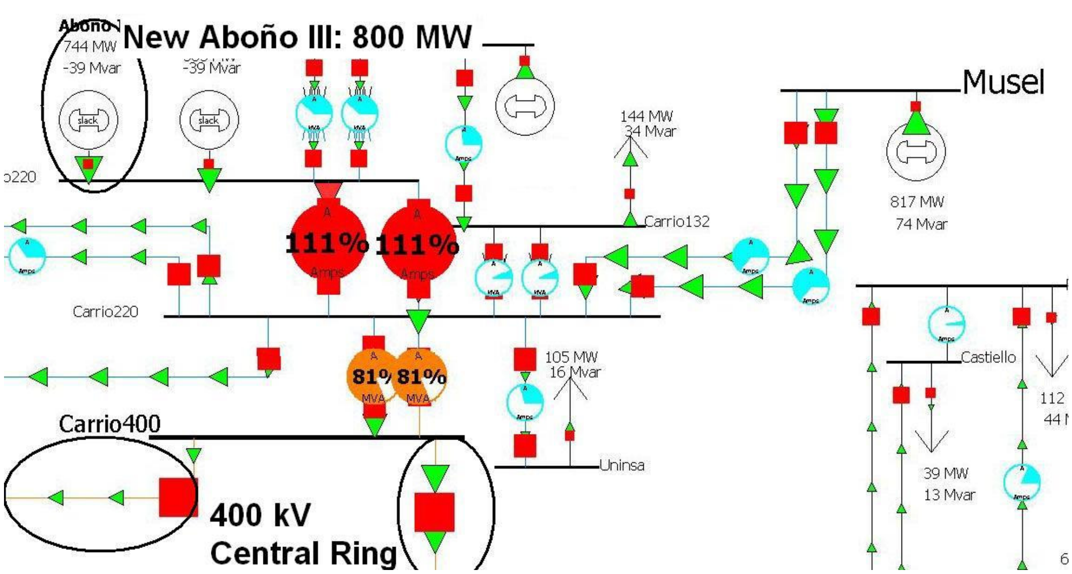


Figure 53. Simulation results (scenario III)

The first and most worrying problem arose from the transmission of the new energy to the central ring. The power two 220 kV power lines interconnecting Aboño substation and Carrio shower 111% overload levels. The only solution to move the new amount of energy to the central ring would be the addition of a third 220 kV power line between both substations.

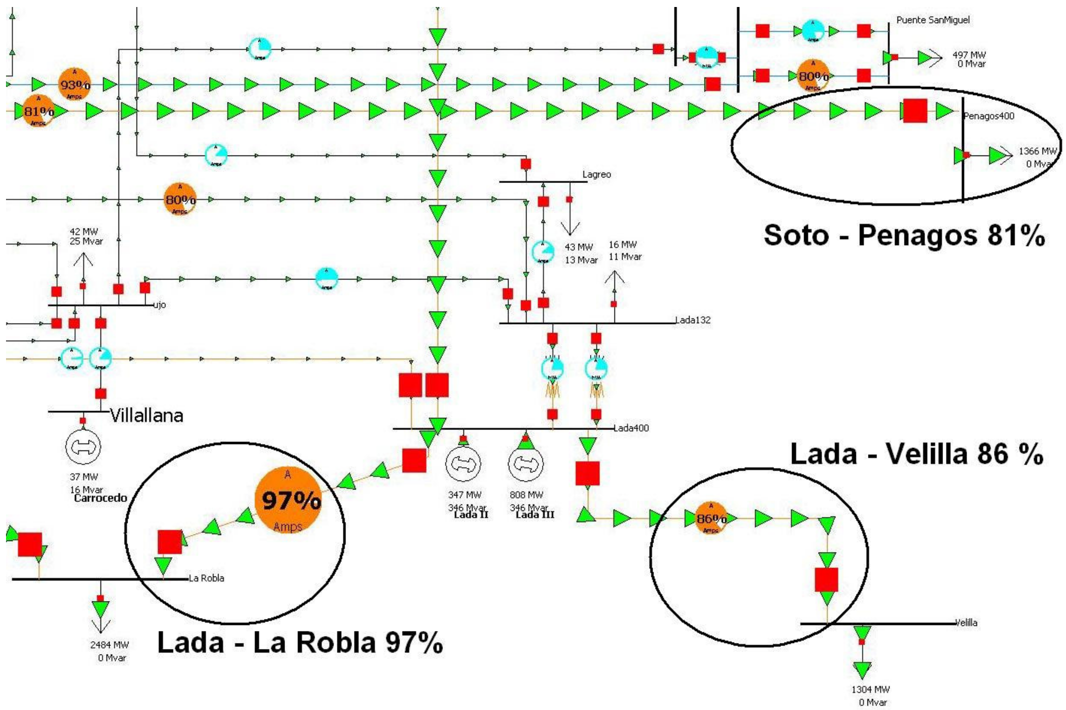


Figure 54. Simulation results (scenario III)

The other problem was related to the exportation of the new amount of surplus energy. Three main power lines that send away energy to the vicinity regions are under acceptable but very worrying overload values.

- Lada – La Robla 97%
- Lada – Velilla 86 %
- Soto – Penagos 81%

Therefore, with those high overloads close to the contingency the operation of the combined cycle unit Aboño III is inadmissible for the reliability of the electric grid. proposed for the 2015 horizon

7.3. Final results for the study of the future situations (2008 - 2015)

7.3.1. First part of the future study (horizon 2011)

The study of the first future situation (2008 – 2011) was characterized by the addition of new power lines:

- Scenario I: No new power lines
- Scenario II: La Robla route upgrade
- Scenario III: New 400 kV Soto – Penagos
- Scenario IV: New 400 kV Lada - Velilla

that eased the surplus energy exportation from an increased of generation situation (addition of 1000MW of new wind farms and around 800 MW of CCGT). The following figure shows load level trends in the exportation power lines:

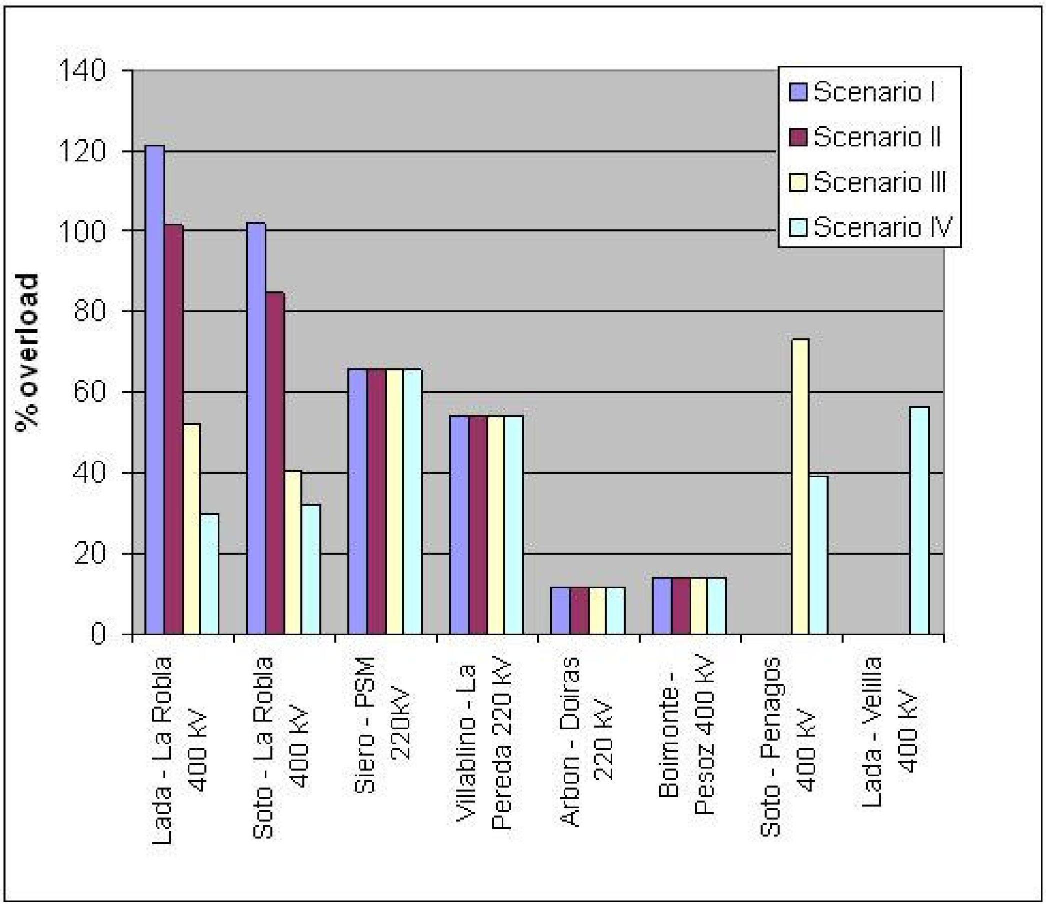


Figure 55. Overload trends in exportation power lines (2011 Horizon)

400 kV power lines across La Robla route (Lada – La Robla and Soto – La Robla), showed unacceptable overloads during the first scenario. Therefore, a quick short term solution was upgrading the capacity of the power lines in a 20% during the second scenario, reducing the overloads but not enough to get a safe power system. The effective alleviation in those lines took place when adding new 400 kV power lines for the exportation of surplus energy during the third and fourth scenarios.

220 kV power lines Siero –Puente SanMiguel, Villablino – La Pereda, and Arbon – Doiras had a very limited margin for the evacuation of energy. That is why the four of them does not experience any reduction when adding new 400 kV power lines in the last two scenarios. The 400 kV power line Boimonte Pesoz did have capacity for the transmission of large amounts of energy but it connected Asturias with Galicia, another surplus region.

So, according to the study of the first future horizon, Asturian power system showed a very convenient and reliable network from the third scenario on.

7.3.2. Second part of the future study (horizon 2015)

The study of the second part of the future situation (2011 – 2015) was characterized by the increase of the total generation along several scenarios:

- Scenario I: Nalon, La Pereda and Lada III CCGT.
- Scenario II: Musel CCGT
- Scenario III: Aboño CCGT

While keeping the power lines already added in the previous situation.

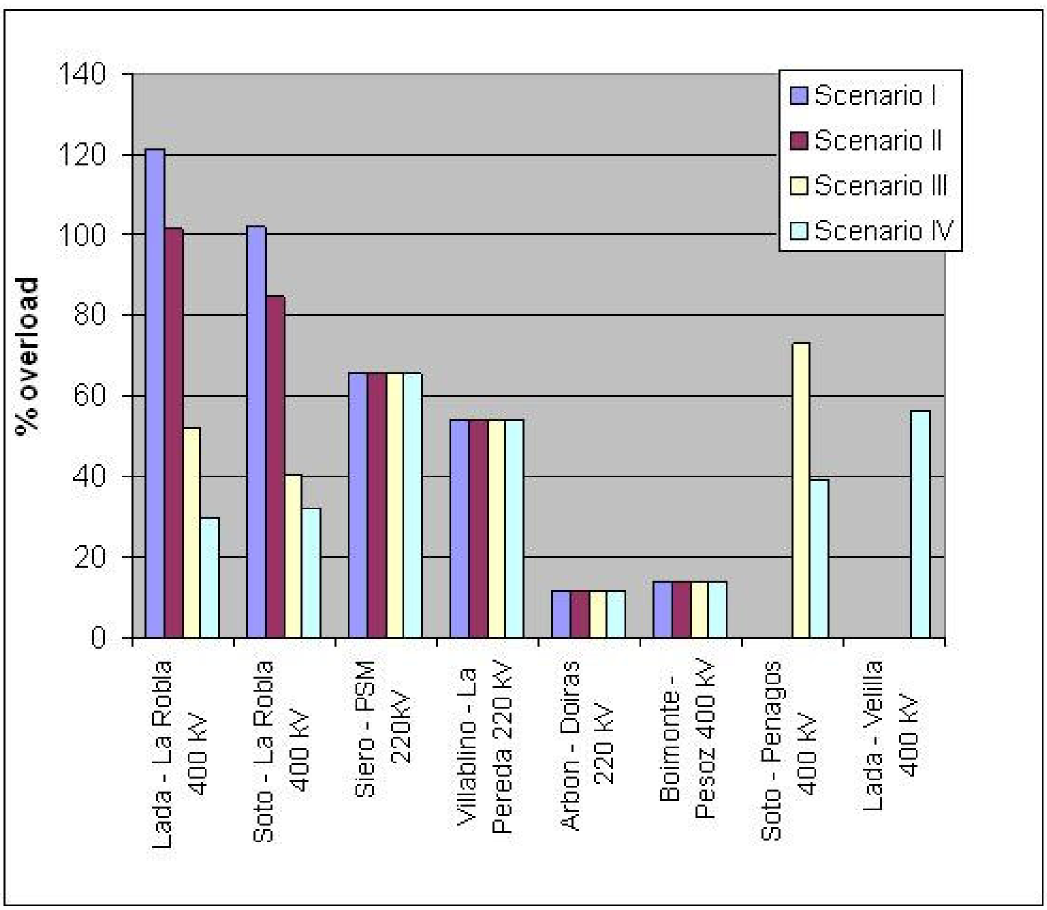


Figure 56. Overload trends in exportation power lines (2015 Horizon)

220 kV power lines have a limited exportation capacity so no major increases of overload are allowed through them. They are not a good sign to draw conclusions.

The lines that better reflect the increase of surplus generation are those with higher capacities, in which is possible to distinguish a step by step increase in the overload of the line, cases of 400 kV power lines Lada – La Robla; Soto – La Robla; Soto – Penagos and Lada – Velilla.

So, until the second scenario all the lines keep operating within acceptable overloads. However the addition of the last generation unit could bring high instability to the system as 3 out of the 4 exportation lines show overloads above 80 %.

8. CONCLUSIONS

The region of Asturias stands out from the rest of Spanish ones due to its potential for the implementation of generation technologies, either renewable or conventional.

On the one hand, referring to the renewable energy, western areas of Asturias are affected by favorable winds conditions already harnessed by several wind farms. In addition, many more are expected to be in operation over the following years.

On the other hand, referring to conventional energies, previously thriving coal fields in the southern areas of Asturias made the implementation of many coal fire power plants in their surrounding areas possible. Currently coal mines are undergoing a closure process, however, the future of thermal power plants will move on from coal to natural gas. The future regasification plant in the main harbour of Asturias (currently under construction) will trigger the commission of several combined cycle gas turbines in the already operating power plants as well as in new projected ones.

An increase in electricity generation is the main objective for the next years according to the region energy strategies. The reasons of the increase tendency, focused in the addition of new wind farms and combined cycle power plants, respond to the following energy requests

- As Asturias is an exporting region and Spain an importing country in terms of energy. New generation plants in the region will send out most of their generation in order to try to mitigate Spanish dependence on French energy.

- Asturias, currently not meeting Kyoto protocol, is a region with an important presence of sectors (iron, steel and electricity production) with intensive emissions of CO2, the chief greenhouse gas. Therefore, Asturias will undergo a slow but steady process for the replacement of the highly contaminating oldest coal fire generation units for new CCTG units, fueled by the cleanest of the fossil fuels: natural gas.

- According to the European energy policy the directive aims to establish a national renewal energy target consisting on a 20% share of renewal in EU by 2020. Thus, the Asturian government has already removed a moratorium that prevented over the last years the construction of new wind farms and has already approved new wind farm projects for the triplication of wind energy generation over the following years.

However, all those projects for the increase of generation in Asturias are not compatible with the current transmission grid operating in the region.

Analysis of the Asturian electrical grid showed acceptable levels of reliability and security for the current situation. But when analyzing future situations characterized by increases of generation without an adequate upgrade of the electrical grid, overloads arose in some of the main transmission lines. Those overloads took place most of the times in the lines which duty is to send away surplus energy from Asturias.

Therefore, the main solution to the drainage of electricity from Asturias to the rest of Spain is no other than the construction of new 400 kV transmission power lines. According to the analysis, the essential 400 kV power lines to fulfill the generation plans of the region were:

- Firstly, the so called ASGA route necessary for transport of all the new wind energy from remote western areas of the region to the central areas where the energy can be distributed to internal or external consumption.
- Secondly, in order to send away the new amounts of surplus energy, a new route for the evacuation of energy through the east of the region, currently covered by a 220 kV double circuit line.
- Thirdly, a central ring indispensable for the transmission of the coming large amounts of energy generated by the programmed combined cycle power plants.
- Finally, at the same time as the central ring, a new route for the exportation of energy through the south of the region is necessary to send away the surplus energy from the forecasted combined cycle power plants.

Apart from the technical problems analyzed in the project for the exportation of energy there are other important constraints that should not be overlooked as in Asturias they were most of the times the real obstacle when projecting power lines:

1. Environmental impact. Some of the projects proposed for the exportation of energy did not have environmental impact studies and considered the erection of 400 kV power lines through nature reserves.

2. Neighbour or affected villages. People are reluctant to the implementation of new power lines in their vicinities mainly because of the fear to the controversial magnetic fields emitted by the power lines.

Despite Asturias having a surplus energy and no need for extra energy to meet its internal demands, increases of energy generation would bring together an increase in the economy of region and even less dependency on international imports of energy for the country. But those purposes only can be achieved when new power lines were ready. So the first priority of the region is to look for a sustainable solution for the construction of new 400 kV exportation power lines in Asturias, uniting people complaints and industrial requirements.

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