UNIVERSIDAD PONTIFICIA COMILLAS

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

OFFICIAL MASTER'S DEGREE IN THE ELECTRIC POWER INDUSTRY

Master's Thesis

ADAPTATION OF DOMINA TOOL TO COMPLETE THE AUTOMATION OF CALCULATION OF INVOICES

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Supervisor: **Cristina Martínez Pérez-Beato**

Madrid, July 2016

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Abstract

After the commissioning of the renewable power plants, its management has become a major issue. The tools used to operate them must guarantee the quality and reliability of the data flows.

The target of this job is to integrate in the metering and billing department a reliable method that secures and automatizes the calculation of invoices of the mini hydro power plants. To achieve it, these plants have been integrated in DOMINA tool, which is the operational and management tool that Iberdrola uses for the administration of the renewable technologies.

Reagarding the information of the plants (basically the lectures of the meters and the actual situation of the power plants), this is gathered in CORE, which is the Renewable Energies Opearion Center of Iberdrola. DOMINA takes that information and allows to any user with internet connection to perform the validation of the measurements and the billing of the power plants. The tool has also the legal and technical information of them.

DOMINA works properly with windfarms and the objective has been to adapt it in order to use it for the mini hydro power plants. For that purpose, firstly a classification of the power plants has been done, attending to the configuration. Depending on how the energy is measured and billed, the configuration can be principal, principal of phase and formula. Eah one has its own characteristics. This is checked revewing the single line scheme of the mini hydro and the data that the System Operator disposes.

Once the classification of the plants is finished the metering equipment is introduced in the application. The System Operator requires a supervision of this equipment every determined time length, and if the verification is not up to date, the measures could be pointed out as invalid. DOMINA alerts before this situation occurs, and permits to bill the electricity sold as fast as possible. The metering equipment also contains the access code to CORE for storaging the data of the gross energy produced.

The coefficients for calculating the net values are determined and introduced in the tool. Once you have the net value, the valid measure must be validated. This value is calculated by DOMINA, but you have to indicate which are those right numbers. Most of the times the net values are the ones that are going to be billed, but others a formula is

required. When this sistuation occurs, the application must be programmed in order to know that the valid measure will be the one calculated this way.

In the end, what is pretended is to automatize as much as possible the flux of information from the power plants to the billing department. With DOMINA you collect the information, validate it (check that everything is correct), and bill the energy, avoiding possible mistakes.

The main objective, which is to solve the weaknesses of the power plants management, is finally solved, and a flexible solution has been put into place, allowing to make quick changes if necessary in a future.

Resumen

Después de la construcción de las instalaciones de energías renovables en España, se debe prestar especial atención a su gestión, que se convierte en un asunto prioritario. Las herramientas utilizadas deben garantizar la fiabilidad de los flujos de información.

El objetivo de esta tesina consiste en integrar en el departamento de medidas y liquidaciones un proceso fiable que asegure y automatice el cálculo de las liquidaciones de las centrales mini hidráulicas. Para lograrlo, éstas se han integrado en DOMINA, que es la herramienta que Iberdrola utiliza para la gestión de sus centrales renovables.

Respecto a la información que generan las plantas (básicamente la lectura de contadores-registradores y el estado de las centrales), ésta se almacena en CORE, que es el Centro de Operación de Renovables en España de Iberdrola. DOMINA toma la información de ahí y permite validar las mediciones y liquidar a cualquier usuario con acceso a internet. La herramienta contiene también la información técnica y legal de los generadores.

DOMINA funciona correctamente con parques eólicos y el objetivo es adaptarla para el uso de las mini hidráulicas. Para ello primero se clasifican las plantas, cada una con una configuración única (principal, principal de alineación o fórmula), revisando los esquemas unifilares de las mismas y los datos proporcionados por el Operador del Sistema.

Después, se introduce en la aplicación la información de los aparatos de medida. El Operador del Sistema exige la supervisión de estos aparatos cada cierto tiempo, y las medidas pueden ser consideradas como inválidas si las verificaciones no se llevan a cabo. DOMINA emite una alerta antes de que ocurra esta situación, y permite generar ingresos de la manera más rápida posible. El equipamiento de medida igualmente contiene el código de acceso a CORE para la descarga de medidas (valor bruto de medida).

Para obtener la medida neta, se deben introducir los valores de los coeficientes de pérdidas. Una vez conseguido este valor, la medida válida (futura liquidable) debe ser validada. Para ello hay que indicarle a DOMINA cuáles son los números a validar. La mayoría de las veces es la medida neta, pero a veces se requiere una fórmula de cálculo, que debe ser desarrollada en la aplicación.

Al final lo que se pretende es automatizar en la medida de lo posible el flujo de información, desde las plantas generadoras hasta el departamento de liquidación. Con DOMINA se recoge la información, se valida (asegurándose de que es correcta), y se liquida la energía, evitando posibles errores.

El principal objetivo, que es solventar en los puntos débiles en la gestión de las mini hidráulicas, se ha resuelto proponiendo una solución flexible que permita futuros cambios si fueran necesarios.

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Chapter 1 INTRODUCTION

1.1 MOTIVATION OF THE MASTER'S THESIS

The purpose of this Master's Thesis is to adapt the DOMINA tool developed by Iberdrola in order to use it for the calculation of the invoices in an automatic and reliable approach.

The brand has been historically pioneering in hydro technology in Spain, and now it is crucial to establish safe methods that ensure the O&M of the power plants using the resources in a cost-effective manner.

For assuring the profitability of projects there must be a control over the operational expenses. Due to this, it is necessary a control of the data flows and its quality.

It is crucial to dominate the technology and the key management factors, so the main objective is to maximise the economic yield during the power plant lifecycle.

1.2 KEY ELEMENTS

This section describes the main elements that provide support to the operation and management department. They are:

- **DOMINA:** It is the operation management system. It includes: master of facilities, inventory, maintenance management, control of non-produced energy, return on experience, incident management, billing, change management design ...
- **CORE:** System that allows to the Operational Centre the control and remote operation of the total renewable energy plants. These include hydro, solar (thermal and photovoltaic), wind farms (onshore and offshore), cogeneration and biomass.

- **SIMEL[1]:** Is the main hub of the Information System of Electrical Measures. It is a key element for the performing of the opened market. When the closure of the exchanged energy between different subjects is done, then the economic settlement is finished

  The system receives, directly or through secondary hubs of other electrical companies, the hourly data of the energy registered in all the counters installed in Spain (more than 27 million), situated in the frontier point between activities (generation and distribution, for instance).

1.3 OBJECTIVE

Due to the necessity of the company of developing tools that guarantee the quality and reliability of the data flows, the target of this Master's Thesis is to integrate in the metering and billing department a reliable method that secures and automatizes the calculation of invoices of the mini hydro power plants.

To assure that those are calculated correctly, the metering and billing of the mini hydro power plants is integrated in DOMINA tool. Once the measures are set as valid, the closeout of the energy sold can be performed.

1.4 METHODOLOGY

Firstly, a review of the current legislation is shown. It is important to know the current legal framework where the job is being developed, the changes that affect the power plants and how are they managed.

Then, it is described the situation of the power plants inside this legal framework and how this influence over the mini-hydro.

[1] SIMEL stands for *Sistema de Información de Medidas Eléctricas* in Spanish.

An overview of the O&M department of the Iberdrola Renewables is performed considering that the adaptation of DOMINA tool is going to be inside a bigger structure of the company.

In addition, a description of DOMINA tool is given. Some key aspects are how it works, and what kind of information it manages. The adaptation of the tool involves also the integration of the necessary information for the plants management. Some examples are given in order to clarify the challenges faced.

Finally, both old and new situations are compared and presented to the reader as a way to examine the improvement in the management.

1.5 RESOURCES USED

The resources used for the development of the Master's Thesis are:

- DOMINA tool.
- Information from the Spanish official bulletin (BOE, in Spanish): Regulation that affects the operation of the mini hydro.
- Internal documentation of the company: single line diagrams.
- SIMEL: From this online platform all the metering data is extracted. Not only the measures of the power plants, but also the single line diagrams that the SO has and the configuration of the mini hydro power plants.
- Documentation from SIMEL: All the legal documents that explain how the O&M departments must behave in relation with the metering and billing.

Chapter 2 STATE OF THE ART

2.1 LEGAL FRAMEWORK

The Royal Decree Law 9/2013 published on July 12th pursued the guarantee of the financial stability of the electric sector. It entered into force the 14th of July of 2013.

JUSTIFICATION

The text seeks to justify the measures taken in the fight against the deficit. The use of the figure of the royal decree law constitutionally (reserved for cases of extraordinary and urgent necessity) is to rely on the contraction of electricity demand during the first semester of 2013.

MEASURES ADOPTED IN RELATIONSHIP WITH THE SPECIAL REGIME: NEW REMUNERATION MECHANISM

The Royal Decree quits the special regime and substitutes it for a new economic regime. This one changes the retribution mechanisms, which is subject to:

a) There is stablished a specific retribution, additionally to the energy sold, which is integrated for:
   - One part due to the unit of power installed. It should cover when possible the investment costs that cannot be recovered by the energy sales.
   - Another for the operation costs that cover the difference between the O&M costs and the profits made by the power plant in the market.

b) Reasonable profitability: The Royal Decree-Law foresees that the remuneration system does not exceed the minimum threshold necessary to obtain a reasonable

return. This reasonable return will be expected to be before taxes on the average yield in the secondary market Obligations ten-year government applying a differential. This differential is three hundred basis points for installations in operation.

c) Methodology for calculation:
   - The methodology will consider (for a standard installation, through its regulatory life, and referred to an efficient and well-run company):
     1. Revenues from the sale of energy valued at the market price of production.
     2. Average operating costs necessary for the activity.
     3. The value for the initial investment-type installation.
   - The methodology does not consider the costs coming from the investments determined by administrative acts that do not apply to the Spanish territory (e.g. regional charges) nor disconnected from the power production of electricity.
   - Retributions will be reviewed each six years.

d) The inscription of the power plants in the Administrative Register of Specific Remuneration Regime is mandatory for the application of this new retributive regime.

SITUATION OF FACILITIES CURRENTLY ENJOYING THE RIGHT TO THE SPECIAL REGIME

From now on the efficiency complement is eliminated for installations that perceived it in accordance to the article 28 of the Royal Decree 661/2007, so as the reactive power bonus provided in the article 29 of such Royal Decree.

For the purposes of the methodology for calculating the remuneration of such facilities is approved a reasonable return determined before taxes. It will focus on the average performance of the last ten years of Obligations of the State to ten years in the secondary market, increased by 300 basis points. This profitability may be reviewed at six years.

- Urgent measures are taken in relation to the remuneration regime distribution and transmission activities.
- Measures are adopted in relation to the Fund Deficit Securitisation of the Electric system.
- Certain aspects of capacity payments are modified.
- The regime of assumption of the cost of social bond is modified.
- The revision of access tariffs is expected. Proceeds to the creation of a log for self-consumption (transitory) assumption by the National Commission of Markets and Competence.
- Taxes related to carbon are modified.

2.2 SITUATION OF THE MINI-HYDRO POWER PLANTS: WHY THE ACTUAL REGULATION IS IMPORTANT?

Before the legal change of 2013 mini-hydro power plants were divided in two main groups, as described before: special regime and ordinary regime.

After the legal change, there is no special regime anymore for the mini hydro power plants (even though some of the plants still receive some extra premium).

Because different methods were used for calculating the energy produced (and therefore the billing) it is necessary a method that bring together all the mini hydro power plants.

From now on, the calculation of the measures and the billing will be done from a single place, in the most reliable manner.

Chapter 3 DOMINA TOOL

3.1 MANAGEMENT OF THE RENEWABLE POWER PLANTS

The flux of information and the data bases management are two factors that characterize the operation of the renewable power plants.

This management can be easily understandable when placing three different levels of organization, and classifying it with a layer scheme:

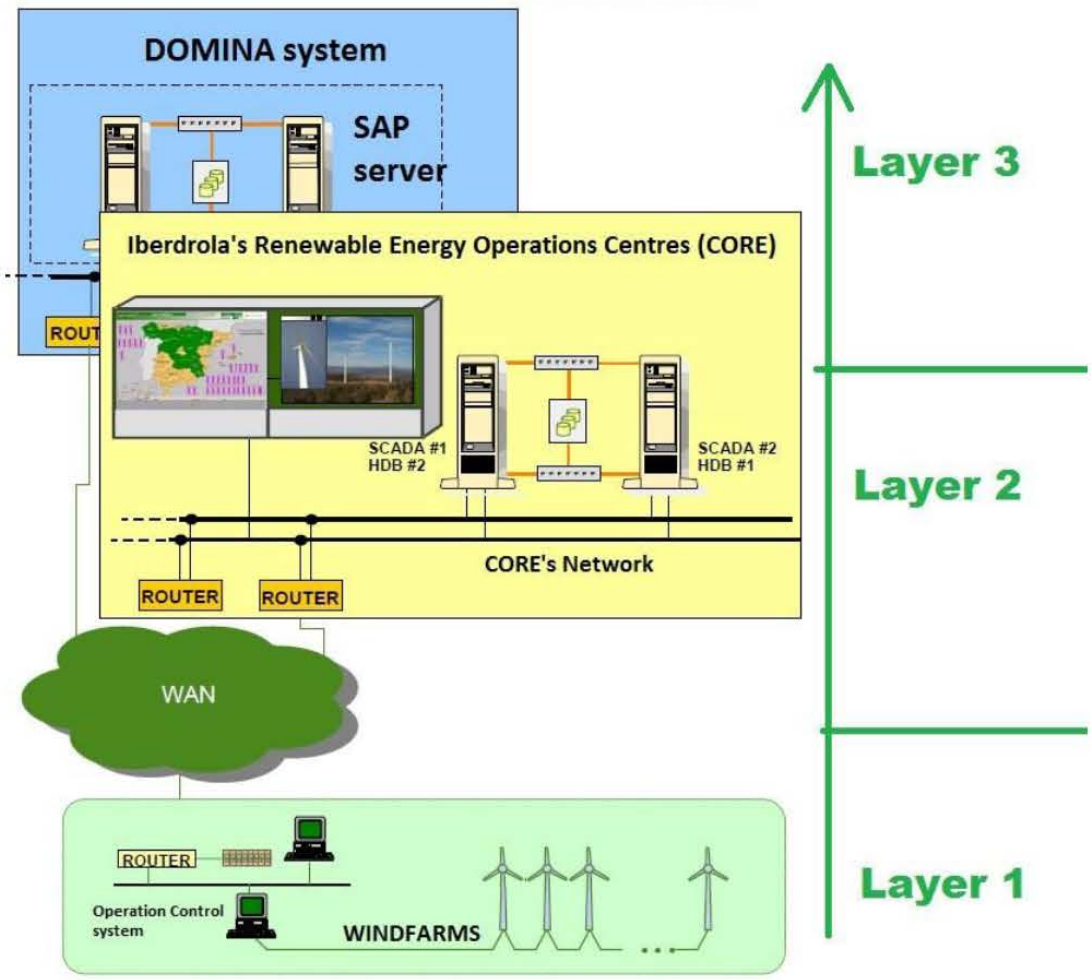


Figure 3-1.System Flux of Information

The flux of information goes from the power plants (layer 1) to the superior levels. Each layer has its own characteristics:

- Layer 1: This is related with the assets belonging to the power plants. The control and the local metering system gather all the metering information about the generation of the mini-hydro. With a secured internet connection, the information is sent to CORE.

  The O&M of this layer is characterized by:

  - **Physical metering equipment**.
  - First level supervision.
  - Physical control of the assets.
  - Detailed asset maintenance.
  - Local Operation.
  - Operative experience.

- Layer 2: This is the CORE[2]. From this centre situated in Toledo, there is a real time remote control, management and maintenance centre for all electric power facilities using renewable energy sources.

  It is designed to optimise the technical management of the company's facilities as well as their economic performance, thereby enhancing the quality of the renewable energy supplied to the grid. It provides service to wind farms and mini-hydro power stations of the Iberdrola Renewable Energy Business, 24 hours a day, and 365 days a year.

  CORE makes a call every night to all the metering equipment of the total power plants and clusters them in a Data Base, where DOMINA gets the information.

  Some of the main characteristics are:

  - **Metering database.**
  - Second level supervision.
  - Remote monitoring of all the assets.

[2] CORE means Renewable Energies Operation Centre for its initials in Spanish.

- Centralised and remote operation.
- Communication with SO.
- Service 24x7.
- CORE system management.

- Layer 3: DOMINA tool. It comprises all the information of the power plants, and is accessible from any web browser. The main users are the ones belonging to the operational services of the renewable power plants. Some of its aspects are:
  - Third level supervision.
  - Results analysis.
  - Control of the aggregated production and billing.
  - Operational management tools (environmental, maintenance and prediction management).

3.2 DESCRIPTION OF DOMINA TOOL

DOMINA is a tool developed by Iberdrola which gathers all the information about the plants that Iberdrola Renewables owns. It not only has the legal data, position and technical information, but thanks to it the metering and billing is done from a single place.

Figure 3-2.Screenshot of DOMINA webpage

The metering tab contains information such as the metering equipment, and when it has to be checked by the System Operator. As it can be seen in the *Figure 3-3*, the information of the metering equipment comprises interesting modules like the one that links the information of the metering equipment with the code of CORE (and can be observed in the same picture).

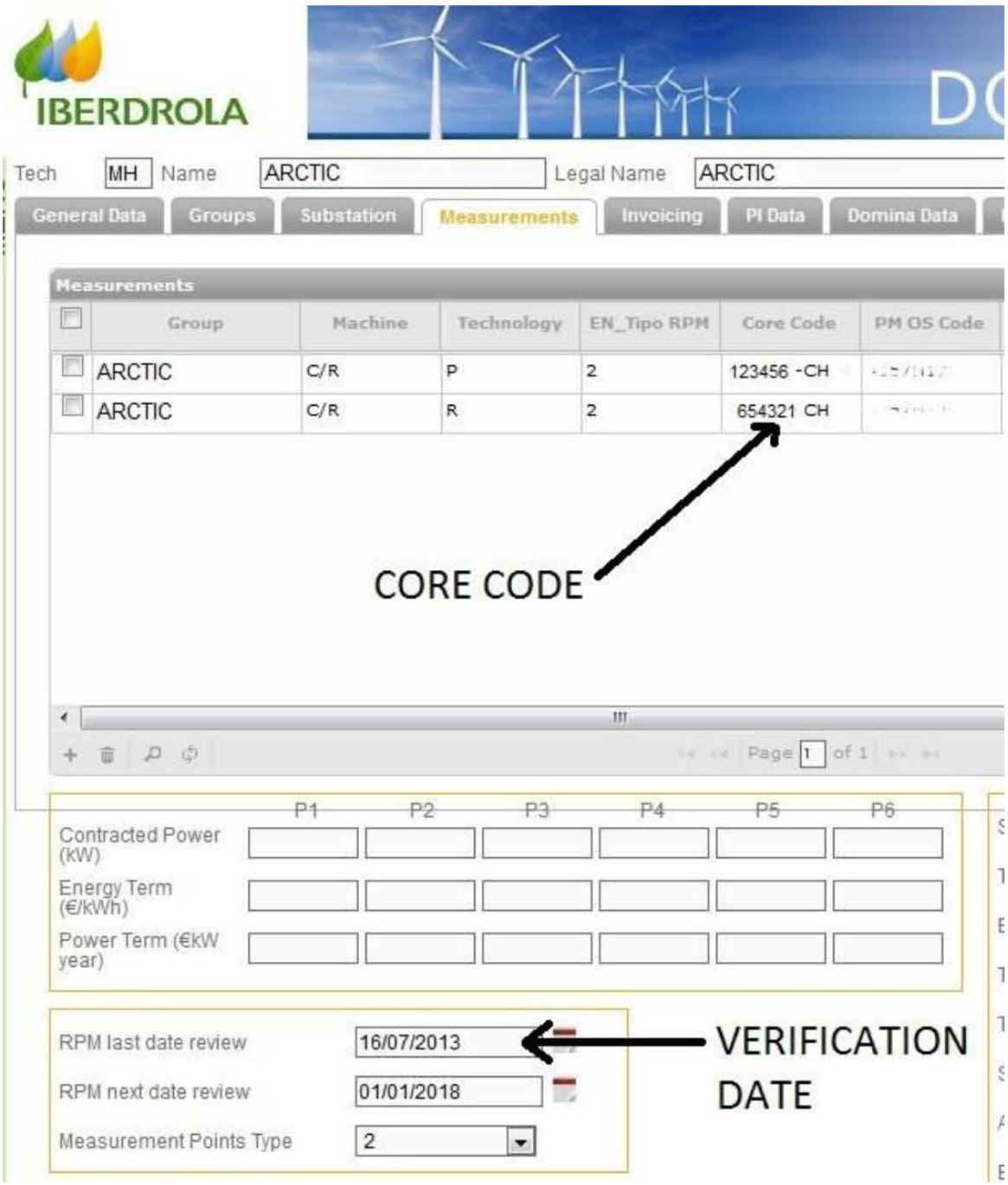


Figure 3-3.DOMINA measurements tab

It is significant to highlight the verification date associated to the equipment. If the equipment is out of date in relation with the verification, the measurements can be pointed out as invalid by the System Operator, and therefore the invoicing cannot be done. In conclusion, it is a great way to get the profits as fast as possible.

DOMINA also generates a notification when the power plants must be verified, assuring that everything complaints with the SO requirements.

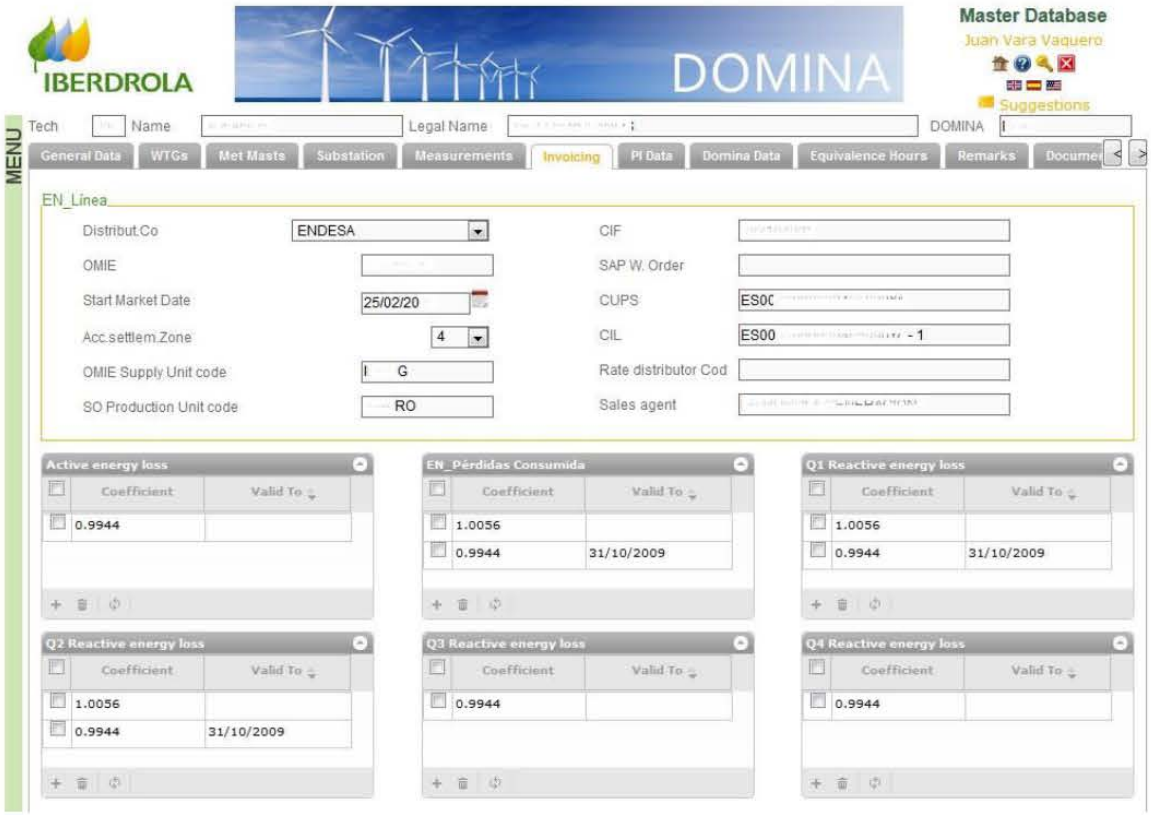


Figure 3-4.Screenshot of DOMINA invoicing tab

The invoicing tab contains some legal information about the power plants, the distribution company and the losses coefficients. The latter will be explained in the next section, as an attribute of the metering information.

3.3 ADAPTATION OF DOMINA

The tool properly works with windfarms and the main objective is to adapt it in order to use it for the mini-hydro power plants.

The main information that must be included is:

- The metering equipment: REE[3] requires a control over the equipment. It is necessary a supervision of the metering equipment in order to assure the correct performance of the Power Plants (to see more about the rules of the metering equipment see *Annex 1*: *Rules of verification of the metering* equipment).

Figure 3-5.Figure of the metering equipment of a mini-hydro

After the revision of the metering equipment, REE provides the company with a verification protocol that is binding for all the power plants. Without it the metering could be pointed out as invalid, and therefore, that plant would not bill the energy sold. Billing is crucial for receiving the revenues, so the back office

[3] REE: Spanish Transmission System Operator (TSO).

here uses DOMINA for controlling that everything complies with the System Operator regulation.

- Metering information: The configuration of the power plants affects the lectures of the metering devices. It is important to know what the configuration is like and how to calculate the right measure. A more detailed explanation of the configuration of the power plants will be given in *Chapter 4*.

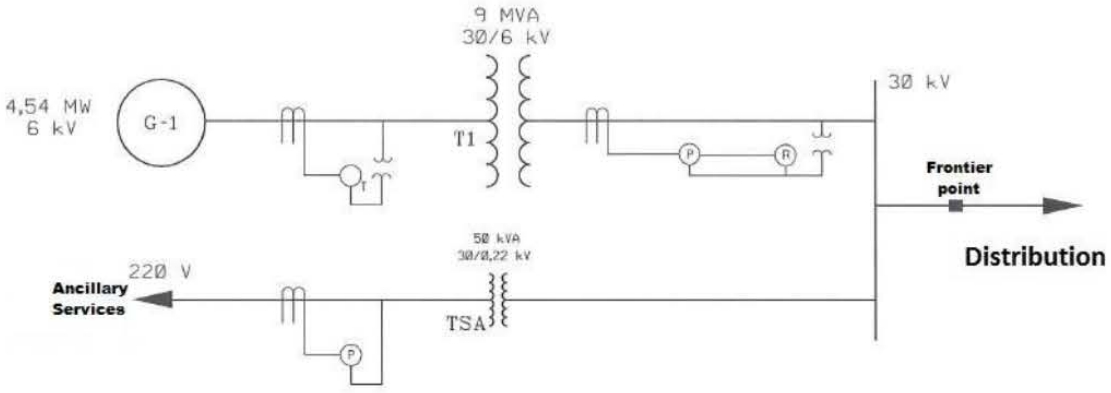


Figure 3-6.Example of metering that should be multiplied by a coefficient

Working jointly with Iberdrola distribution, the losses coefficient can be known. According to regulation, the lecture given to the SO must be the one belonging to the high voltage line. In consequence, if the metering equipment is after the transformer, or is far from the high voltage node, the losses coefficient would be different to 1.

The *Figure 3-6* is an example of metering that should be multiplied by a coefficient, and illustrates this situation. It can be observed that the measure of the equipment belonging to the ancillary services would have to be multiplied by some coefficient.

- Billing information: Some coefficients are applied in order to calculate the right amount of energy that is finally going to be billed. The inclusion of these coefficients in DOMINA can be seen in *Figure 3-4*.

The metering equipment just described is able to measure the flow in both directions:

- If the measure is outgoing, the coefficient is lower to one (net energy in the node is lower than the energy produced).
- If the measure is incoming, the coefficient is superior to one (the energy required is lower than the energy that arrives at the node).

More information about the difficulties of characterising a power plant will be given in the *Practical cases study.*

One of the advantages of DOMINA is that it always preserves all the information collected, so it can be reviewed in any of the stages: the gross values, the net ones, or those that are going to be validated.

It allows the user to have a register of what REE as SO is going to validate, independently of what has been the measure.

In the end all this process of adapting DOMINA is for selecting the measure that is finally going to be invoiced. Not all power plants are the same, and the valid measure varies from one mini hydro to another. Next chapter will explain the different validated measures, depending of the mini hydro plants configuration.

Chapter 4 PRACTICAL CASES STUDY

4.1 INTRODUCTION

This section will provide with an insight of how has been the process like when adapting DOMINA and examples of three power plants. In order to assure the confidentiality of the information, the names and some aspects will be modified on purpose, but the academic view will remain intact.

In the end, there have been implemented more than 50 mini-hydro power plants, each of them with its own characteristics.

DEFINITIONS

For the easier tracking of the vocabulary used in the next sections some brief definitions are given:

- Frontier point: Exact point of the network where the connection of the power plants to distribution or transmission networks is produced. This is an "imaginary" point stablished by the System Operator.
- Measuring point: Exact place of the network where the metering equipment is installed. The energy registered corresponds to the energy circulated for that point. According to the regulation, it can be found three configurations:
    - Principal configuration: The measuring equipment is used as the only valid measure according to the regulation.
    - Redundant configuration: The measuring equipment is installed in the same point as the principal configuration. Therefore, the measures should be practically the same. It is used in case of a failure of the principal equipment.

- Check configuration: Device installed on the other side of one element (transformer, line, etc.) respect to the main counter. The measure is usually compared with the main counter with a simple calculation, which eliminates the real effect existing between them.

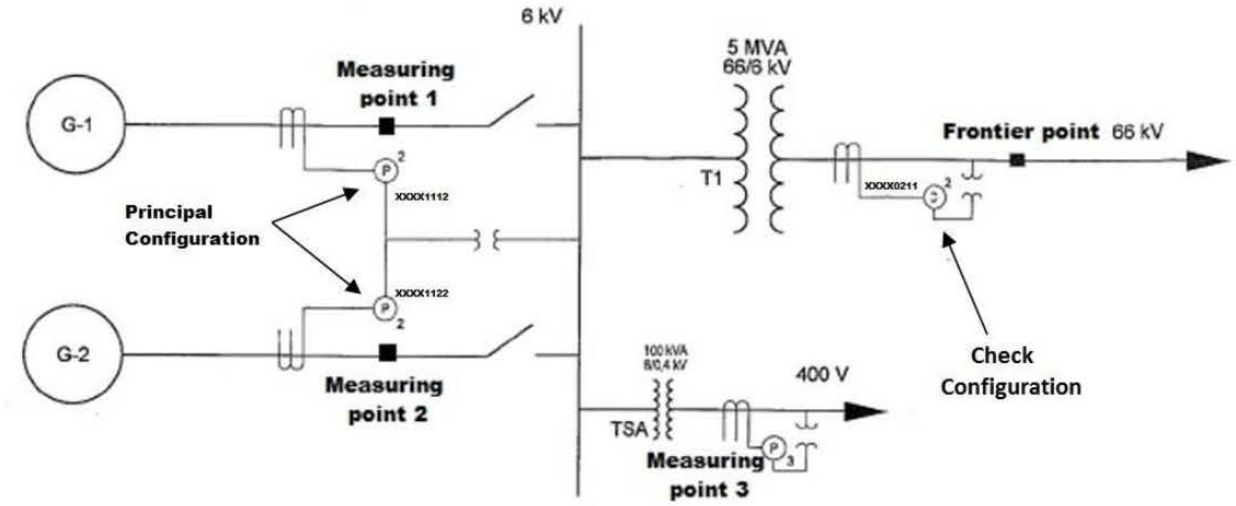


Figure 4-1.Example of points and configurations of a power plant

DIFFERENT KINDS OF POWER PLANTS

According to the law, each generator must have its own metering device, but the billing is finally done per frontier point. This situation leads us to three different situations when calculating the "valid" measure, which will be the one that must be the same as the one that the System Operator has. These three kinds are:

1. Principal: All the energy is measured through a unique device. This kind of configuration is the most popular when there is only one single line that goes to distribution.

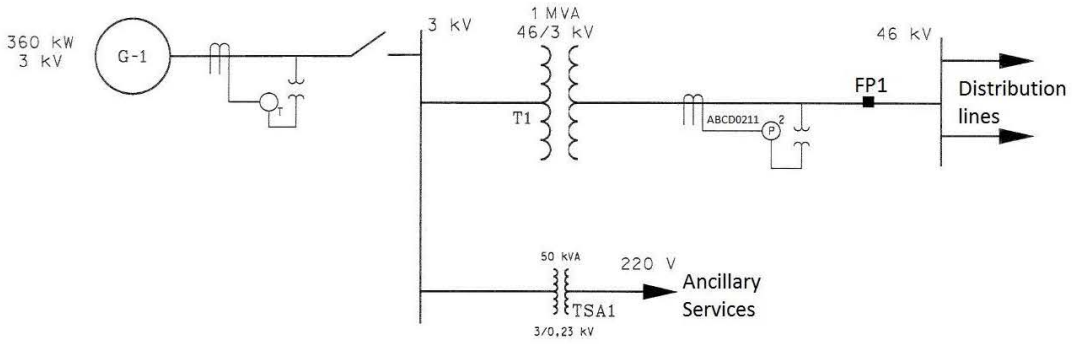


Figure 4-2.Example of a power plant with "Principal" configuration

2. Principal of phase: When there is more than one generator per power plant and each one has its own metering device (each line is called a phase). The final billing is the sum of each generator or phase.

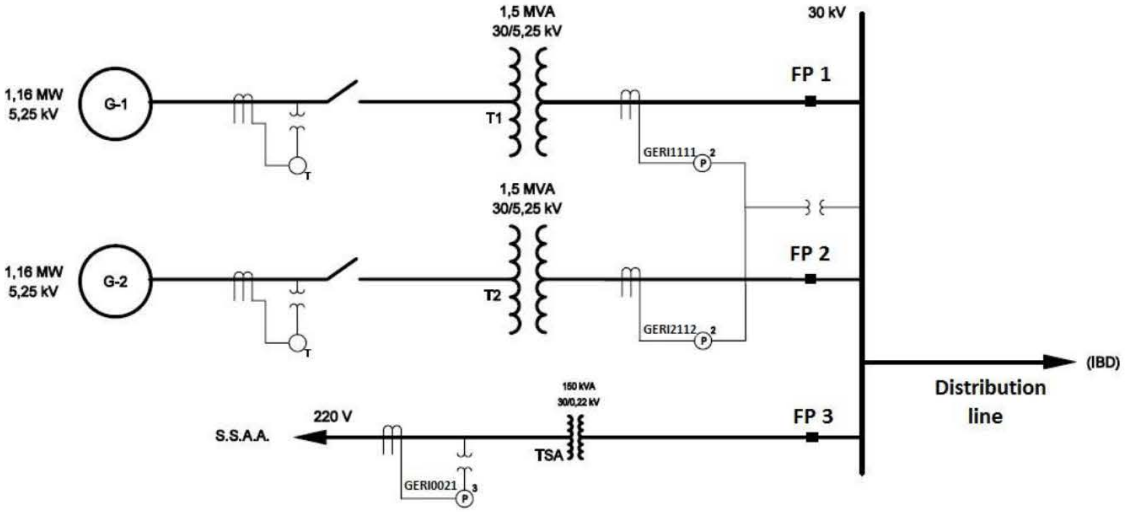


Figure 4-3.Example of a power plant with "Principal of Phase" configuration

3. Formula: This is the most difficult option. Very similar to the previous case, in the end the billing is done through a simple formula.

   The reasons for using a formula are diverse, but the most important ones are, first, that each phase has its own coefficient factor. In this case the formula will be the sum of each phase multiplied by its losses factor.

The other reason is the one shown in the *Royal* study case, where each generator belongs to a different entity. So the formula used is the one seen in the section *4.2 Case Study 1: Royal.*

STEPS TAKEN IN ORDER TO REGULARIZE THE POWER PLANTS

Firstly, we have to see how many power plants there are in order to estimate the amount of work that the department is going to face.

Mini hydro power plants are classified according to the configuration: principal, principal of phase or formula. It is checked how many measuring points has each one and the associated frontier points. This is essential, because the valid measure will be associated to the frontier point.

Then, an identification of the frontier point is done with SIMEL (the Information hub from the System Operator).

It is obvious that the analysed characteristics of each power plant are unique, but they all have always something in common. In the end, we can follow some steps, which have been the same for everyone:

1) Review how the measure of energy in the frontier point is calculated from REE.

   If we take a look at the example of the *Figure 4-1*, the formula that we would find for the measuring of the second generator (simplified) will be:

$$Energy\ G2\ (kWh) = Energy\ Check\ \times \frac{Energy\ G2}{Energy\ G2 + Energy\ G1}$$

2) Observe if the most updated single line scheme complies with the formula that the SO has. If not, it is necessary to review the single line scheme that REE has of the installation and see if it must be updated.

   When the latter situation occurs, it is necessary to begin a process that involves other departments. When there must be implemented a new formula, Iberdrola distribution must agree with it, and then the new single line scheme, together with the formula and other documents must be sent to the SO.

In the meetings with other departments there are discussions about the configuration of the power plant, the coefficients applied and which the most efficient solution is for regularizing the mini hydro.

3) The metering equipment is then updated in DOMINA, so does the other information related to the metering and billing department.

   At this point, a close work with the IT department is performed. The formulas (if any) must be included in the tool.

4) The correct functioning of the tool must be checked. To do this, the measuring of the power plant is downloaded from SIMEL[4] and also the measuring of DOMINA. Then, a comparison is done with Excel.

Note: data in MWh

Month	jan-16			feb-16			mar-16		
	DOMINA	REE		DOMINA	REE		DOMINA	REE	
	-20.4	-20.4	0.0	250.4	250.3	0.1	4402.5	4402.0	0.5
ROYAL	879.4	879.4	0.0	780.6	780.6	0.0	947.5	947.5	0.0
	618.2	619.4	-1.2	1091.6	1092.0	-0.5	1770.8	1773.3	-2.4
	499.7	499.7	0.0	498.5	498.5	0.0	630.1	173.4	456.7
	335.5	335.5	0.0	288.4	288.4	0.0	769.5	770.7	-1.2
	446.3	446.3	0.0	340.6	340.6	0.0	108.3	108.3	0.0
	9.9	9.9	0.0	70.9	70.9	0.0	55.7	56.0	-0.3
	289.4	289.4	0.0	266.0	266.0	0.0	342.2	342.6	-0.4
	986.4	986.4	0.0	877.8	877.8	0.0	848.0	849.1	-1.1
HUME	329.0	329.7	-0.7	352.5	353.4	-0.9	275.1	275.8	-0.7
	605.2	605.2	0.0	633.1	633.1	0.0	966.2	967.5	-1.3
	631.0	631.0	0.0	590.4	590.4	0.0	459.7	460.2	-0.5
	227.3	227.3	0.0	472.8	472.8	0.0	663.2	664.3	-1.2
	1817.5	1817.5	0.0	2240.0	2240.0	0.0	2417.9	2422.4	-4.5
	1141.9	1148.0	-6.1	1246.1	1246.8	-0.7	1790.9	1793.5	-2.6
	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.9	0.0
	752.6	752.6	0.0	526.7	526.7	0.0	1338.8	1338.8	0.0
ARCTIC	1112.1	1112.1	0.0	989.8	990.7	-0.9	973.5	976.7	-3.2
	492.4	492.4	0.0	600.3	600.3	0.0	694.8	696.2	-1.4
	294.1	295.8	-1.6	517.8	518.7	-0.9	1197.7	1199.5	-1.8
	69.3	69.3	0.0	146.6	146.6	0.0	137.8	138.1	-0.4

Figure 4-4.Comparison of measures in Excel

[4] SIMEL is the REE system of metering and billing. In fact, it means System of Metering and Billing for its initials in Spanish.

5) If there is any difference, there must be checked where is the error and correct it.

Note: data in MWh

Month	jan-16			feb-16			mar-16		
	DOMINA	REE		DOMINA	REE		DOMINA	REE	
	-20.4	-20.4	0.0	250.4	250.3	0.1	4402.5	4402.0	0.5
ROYAL	879.4	879.4	0.0	780.6	780.6	0.0	947.5	947.5	0.0
	618.2	619.4	-1.2	1091.6	1092.0	-0.5	1770.8	1773.3	-2.4
	499.7	499.7	0.0	498.5	498.5	0.0	630.1	173.4	456.7
	335.5	335.5	0.0	288.4	288.4	0.0	769.5	770.7	-1.2
	446.3	446.3	0.0	340.6	340.6	0.0	108.3	108.3	0.0
	9.9	9.9	0.0	70.9	70.9	0.0	55.7	56.0	-0.3
	289.4	289.4	0.0	266.0	266.0	0.0	342.2	342.6	-0.4
	986.4	986.4	0.0	877.8	877.8	0.0	848.0	849.1	-1.1
HUME	329.0	329.7	-0.7	352.5	353.4	-0.9	275.1	275.8	-0.7
	605.2	605.2	0.0	633.1	633.1	0.0	966.2	967.5	-1.3
	631.0	631.0	0.0	590.4	590.4	0.0	459.7	460.2	-0.5
	227.3	227.3	0.0	472.8	472.8	0.0	663.2	664.3	-1.2
	1817.5	1817.5	0.0	2240.0	2240.0	0.0	2417.9	2422.4	-4.5
	1141.9	1148.0	-6.1	1246.1	1246.8	-0.7	1790.9	1793.5	-2.6
	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.9	0.0
	752.6	752.6	0.0	526.7	526.7	0.0	1338.8	1338.8	0.0
ARCTIC	1112.1	1112.1	0.0	989.8	990.7	-0.9	973.5	976.7	-3.2
	492.4	492.4	0.0	600.3	600.3	0.0	694.8	696.2	-1.4
	294.1	295.8	-1.6	517.8	518.7	-0.9	1197.7	1199.5	-1.8
	69.3	69.3	0.0	146.6	146.6	0.0	137.8	138.1	-0.4

Figure 4-5.Errors that must be reviewed

6) In case a correction must be done, the System Operator must know about it, and finally the change is done with mutual agreement.

4.2 CASE STUDY 1: ROYAL[5]

INTRODUCTION

The problem with this power plant was that the two generators did not belong to Iberdrola Renewables, but only the second one (G2).

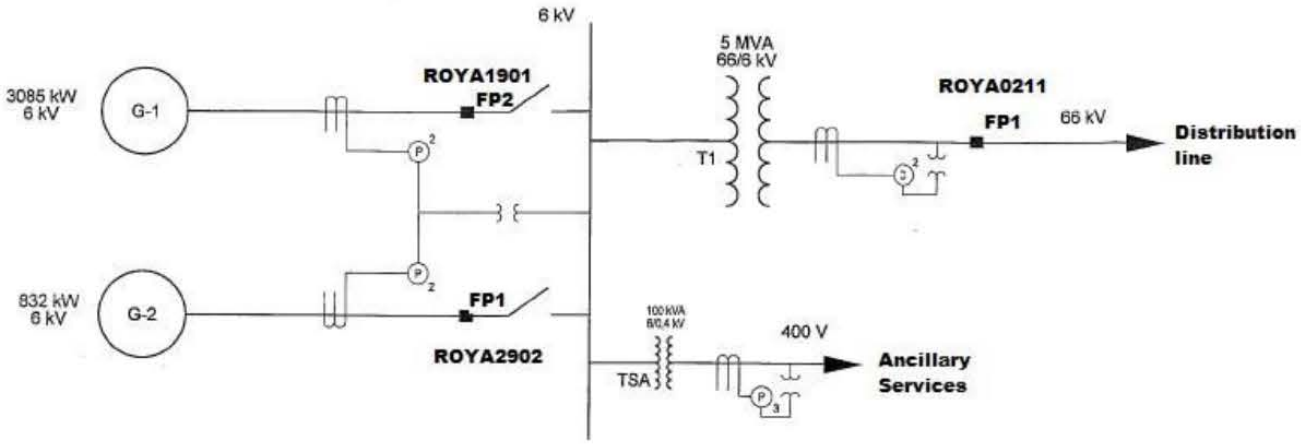


Figure 4-6.Single line scheme of Royal

It was hence necessary a reliable method for calculating the right metering at FP1 (frontier point 1), taking into account that both G1 and G2 could be producing at the same time.

PROBLEM DESCRIPTION AND SOLUTION PROPOSED

It was needed a formula to define accurately the energy sold by the generator (G2) and the energy bought.

After some research done, the formula proposed for the Active Energy Ingoing was:

[5] Unreal name

$$GDROYA0211\ (AI) = ROYA0211\ (AI) * \frac{ROYA2902(AI)}{ROYA1901(AI) - ROYA1901(AO) + ROYA2902(AI) - ROYA2902(AO)}$$

Where:

- AI stands for Active (energy) ingoing.
- AO stands for Active (energy) outgoing.
- "GD" before the measuring point ROYA0211 means Generation-Distribution, which all together constitutes the frontier point between generation and distribution of the measure.

As it can be extracted from the formula, it weights the overall energy measured at the check point (ROYA0211) with the energy produced by the second generator (G2), ROYA2902.

At the same time, the energy proposed for the Active Energy Outgoing was:

$$GDROYA0211\ (AO) = ROYA0211\ (AO) * \frac{ROYA2902(AO)}{ROYA1901(AO) - ROYA1901(AI) + ROYA2902(AO) - ROYA2902(AI)}$$

IMPLEMENTATION AND TESTING

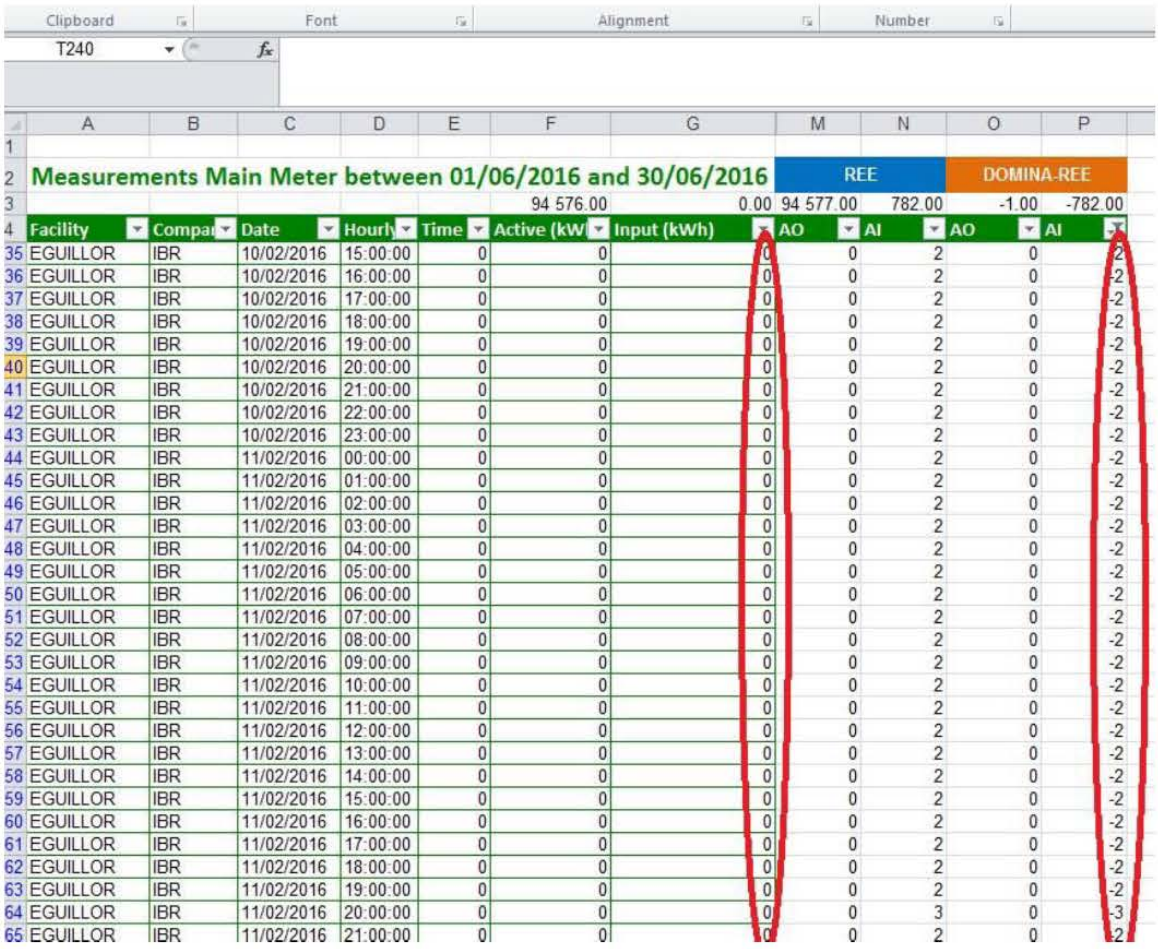
At first, all the metering devices are implemented and all the information related to them, such as brand name, when they must be reviewed or year of manufacturing.

Figure 4-7.Screenshot of Royal implementation in DOMINA

The most important box to complete is the link to CORE. This link will provide with the measure for each of the hours of the power plant from its construction to its decommissioning.

Once the formula of the hydro power plant is implemented in the tool, the metering must be checked. The measure that must be checked is the one that REE has, which must be the same as the validated in DOMINA tool.

DOMINA allows to "calling" for old records. For controlling the measures of the Power Plant, the measures given by the System Operator are compared with the ones given by our tool. We check the last year of measures and we discover that the Active Energy Outgoing (the one sold to the market) is calculated all right, but the Active Energy Ingoing (the one that you buy from the market) is not correct.



	A	B	C	D	E	F	G	M	N	O	P
1											
2	Measurements Main Meter between 01/06/2016 and 30/06/2016							REE		DOMINA-REE	
3						94 576.00	0.00	94 577.00	782.00	-1.00	-782.00
4	Facility	Compar	Date	Hourly	Time	Active (kW	Input (kWh)	AO	AI	AO	AI
35	EGUILLOR	IBR	10/02/2016	15:00:00	0	0	0	0	2	0	-2
36	EGUILLOR	IBR	10/02/2016	16:00:00	0	0	0	0	2	0	-2
37	EGUILLOR	IBR	10/02/2016	17:00:00	0	0	0	0	2	0	-2
38	EGUILLOR	IBR	10/02/2016	18:00:00	0	0	0	0	2	0	-2
39	EGUILLOR	IBR	10/02/2016	19:00:00	0	0	0	0	2	0	-2
40	EGUILLOR	IBR	10/02/2016	20:00:00	0	0	0	0	2	0	-2
41	EGUILLOR	IBR	10/02/2016	21:00:00	0	0	0	0	2	0	-2
42	EGUILLOR	IBR	10/02/2016	22:00:00	0	0	0	0	2	0	-2
43	EGUILLOR	IBR	10/02/2016	23:00:00	0	0	0	0	2	0	-2
44	EGUILLOR	IBR	11/02/2016	00:00:00	0	0	0	0	2	0	-2
45	EGUILLOR	IBR	11/02/2016	01:00:00	0	0	0	0	2	0	-2
46	EGUILLOR	IBR	11/02/2016	02:00:00	0	0	0	0	2	0	-2
47	EGUILLOR	IBR	11/02/2016	03:00:00	0	0	0	0	2	0	-2
48	EGUILLOR	IBR	11/02/2016	04:00:00	0	0	0	0	2	0	-2
49	EGUILLOR	IBR	11/02/2016	05:00:00	0	0	0	0	2	0	-2
50	EGUILLOR	IBR	11/02/2016	06:00:00	0	0	0	0	2	0	-2
51	EGUILLOR	IBR	11/02/2016	07:00:00	0	0	0	0	2	0	-2
52	EGUILLOR	IBR	11/02/2016	08:00:00	0	0	0	0	2	0	-2
53	EGUILLOR	IBR	11/02/2016	09:00:00	0	0	0	0	2	0	-2
54	EGUILLOR	IBR	11/02/2016	10:00:00	0	0	0	0	2	0	-2
55	EGUILLOR	IBR	11/02/2016	11:00:00	0	0	0	0	2	0	-2
56	EGUILLOR	IBR	11/02/2016	12:00:00	0	0	0	0	2	0	-2
57	EGUILLOR	IBR	11/02/2016	13:00:00	0	0	0	0	2	0	-2
58	EGUILLOR	IBR	11/02/2016	14:00:00	0	0	0	0	2	0	-2
59	EGUILLOR	IBR	11/02/2016	15:00:00	0	0	0	0	2	0	-2
60	EGUILLOR	IBR	11/02/2016	16:00:00	0	0	0	0	2	0	-2
61	EGUILLOR	IBR	11/02/2016	17:00:00	0	0	0	0	2	0	-2
62	EGUILLOR	IBR	11/02/2016	18:00:00	0	0	0	0	2	0	-2
63	EGUILLOR	IBR	11/02/2016	19:00:00	0	0	0	0	2	0	-2
64	EGUILLOR	IBR	11/02/2016	20:00:00	0	0	0	0	3	0	-3
65	EGUILLOR	IBR	11/02/2016	21:00:00	0	0	0	0	2	0	-2

Figure 4-8.Comparison of the Royal measures between DOMINA and REE

It is crucial to see what is happening, in order to comply with the requirements of the System Operator (in the end the billing is done with their data).

After some research done, with an Excel spreadsheet, it could be discovered that the formula that they were using for calculating the Active Energy Ingoing was the one that REE used before the implementation of the new one. The comparison can be observed in *Figure 4-8*.

A formal communication was done to the SO, and the problem was fixed.

4.3 CASE STUDY 2: HUMEN[6]

INTRODUCTION

The problem with this power plant was the ancillary services, which were not properly measured. The *Figure 4-9.Original Single Line scheme of Humen* illustrates what we found when analysed this mini-hydro.

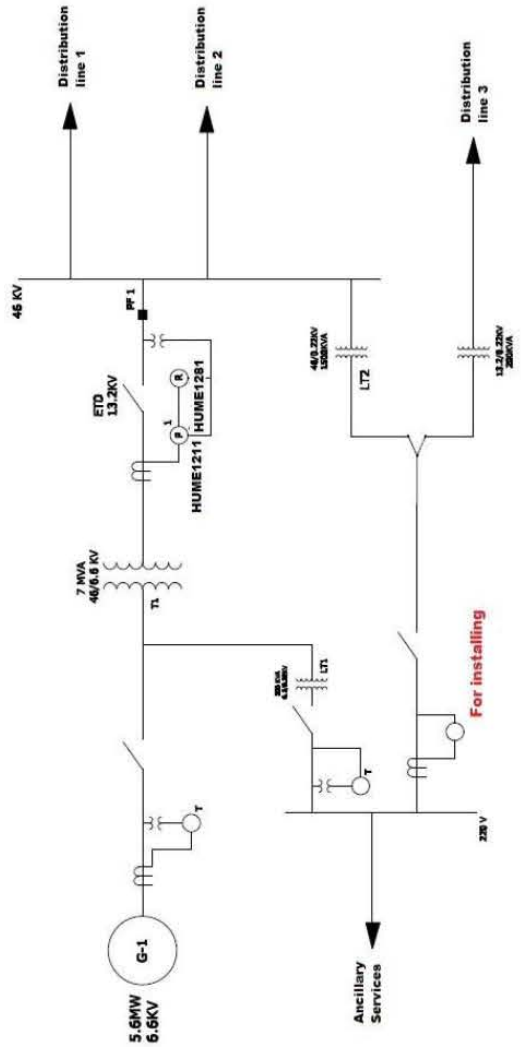


Figure 4-9.Original Single Line scheme of Humen

[6] Unreal name

PROBLEM DESCRIPTION AND SOLUTION PROPOSED

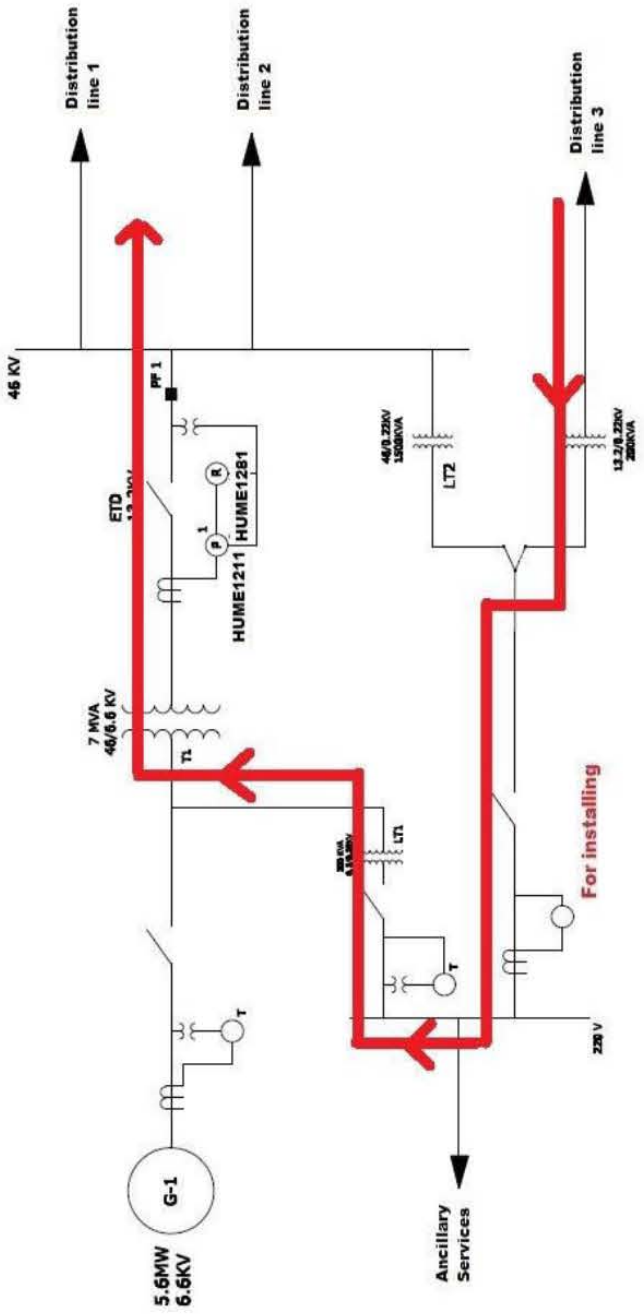


Figure 4-10.Possible flow of energy of the Humen Power Plant

The problem here is not so simple at first sight. The Power Station could buy energy for ancillary services at market price and sell it as if they were generating with a primed

hydro (receiving energy or capacity payments). The situation is graphically described in *Figure 4-10*.

This is strictly forbidden, so a new metering device has been installed in order to fulfil the regulation ("For installing", in *Figure 4-10*).

As anecdote, these power plants go to the market, so if the power plant would buy energy for ancillary services (at market price plus access tariff) and sell that energy at market price it would be losing money, but the installation of the metering device has been done anyway for complying with any future regulation that could be put in place.

IMPLEMENTATION AND TESTING

The final single line scheme is shown in the *Figure 4-11*.

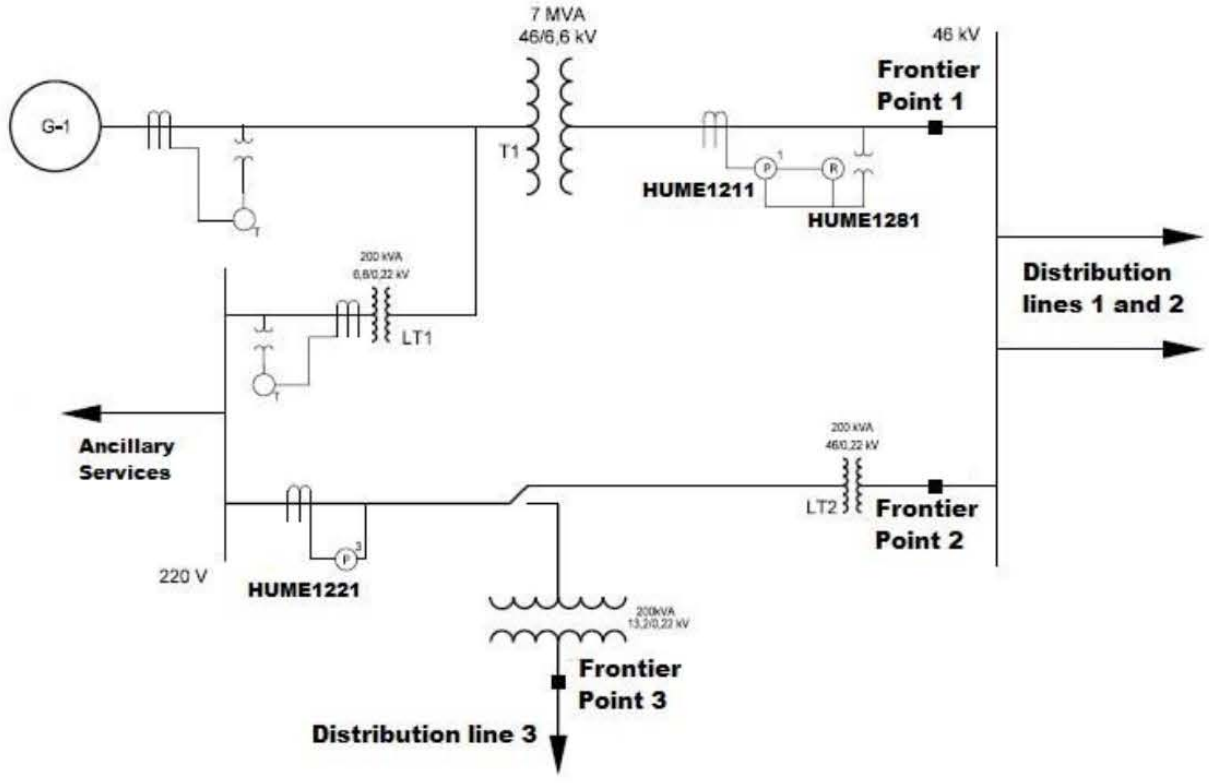


Figure 4-11.Humen final single line scheme

Now, through the measuring point HUME1221, the energy flux that comes from any of the distribution lines is measured properly.

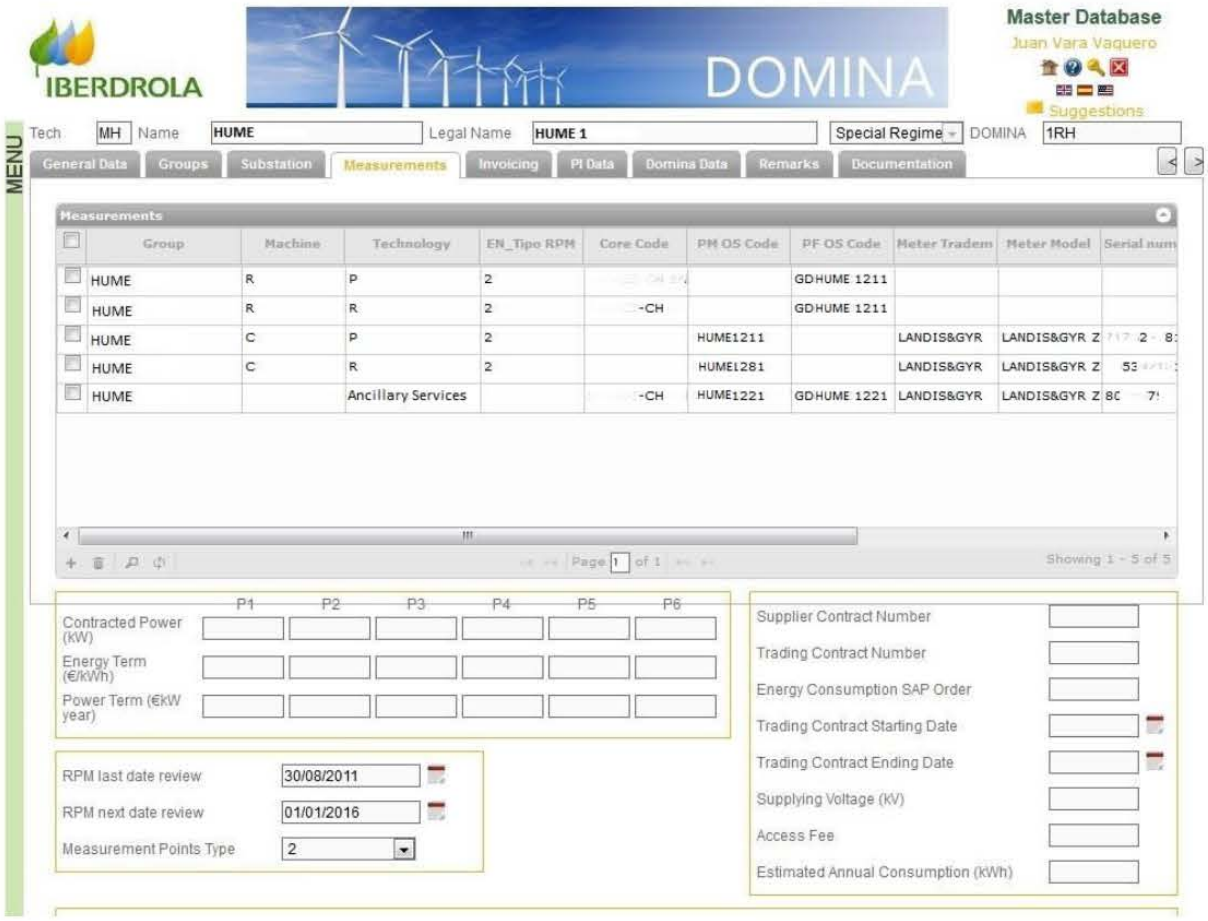


Figure 4-12.Humen implementation in DOMINA web

The final tests show us that the energy measured by the System Operator and the energy extracted from DOMINA are the same.

4.4 CASE STUDY 3: ARCTIC[7].

INTRODUCTION

The problem with this power plant was that the ancillary services were not properly measured. There was only one metering device for the measures of both the generators and the power plants.

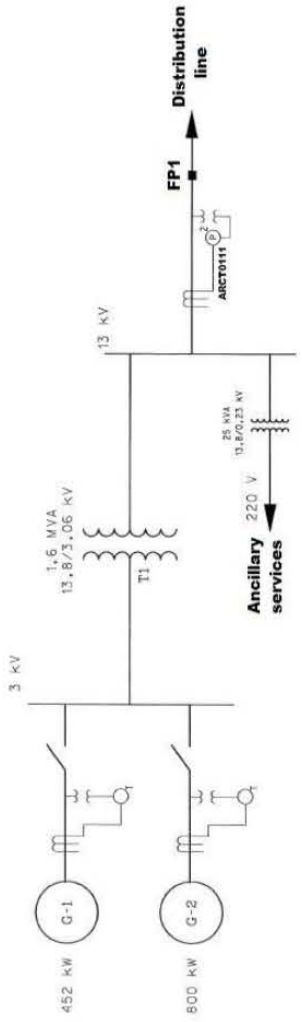


Figure 4-13.Initial situation of Arctic power plant

[7] Unreal name

This configuration may provoke problems, because there is not a real control of what is happening after the node.

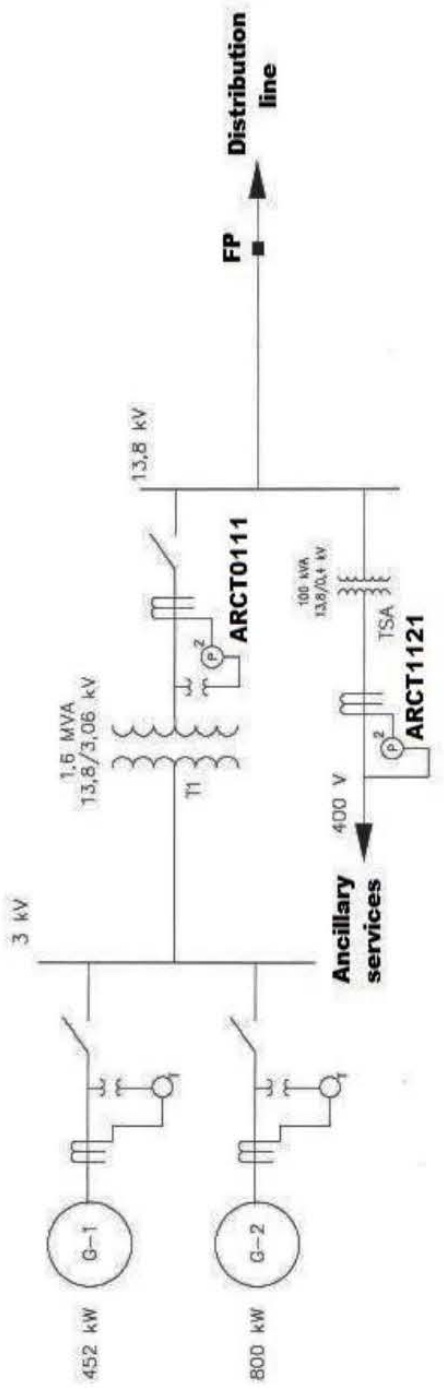


Figure 4-14.Single line scheme of Arctic after the alteration

The situation is kind of similar to what was happening with the *Humen* mini hydro. The ancillary services, despite they only can consume energy, are not really well measured.

It is not a usual situation, but it could be happening that for whatever reason the ancillary services could be producing energy and pouring it to the network as if the hydro power stations were generating energy, with the problems this could raise in case there are energy payments due to regulation.

IMPLEMENTATION AND TESTING

The final measure point was named as ARCT1121, and from the time being all the energy flows are controlled.

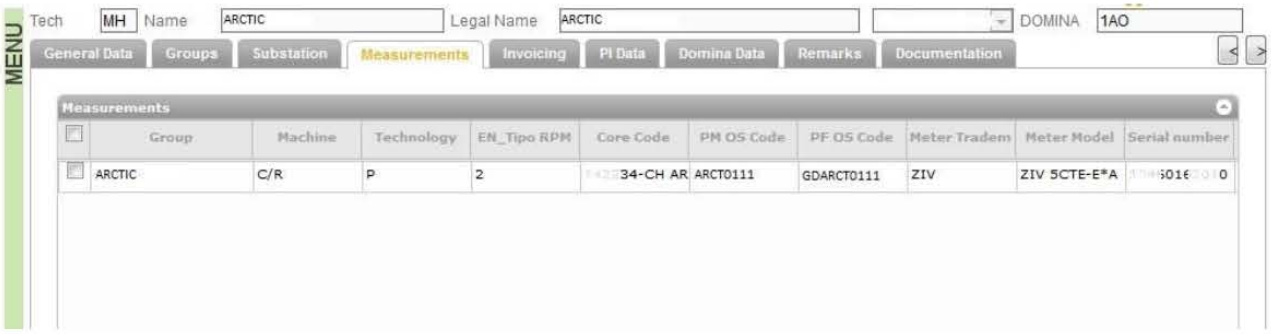


Figure 4-15.Arctic implementation in DOMINA web

The final tests show us that the energy measured by the System Operator and the energy extracted from DOMINA are the same.

Chapter 5 CONCLUSIONS

5.1 GENERAL PERFORMANCE OF THE ADAPTATION

After implementing all the mini hydro power plants that were expected, it is remarkable that the adaptation is complying with all the quality standards that a project of this class requires, and the results are being as expected.

The previous research has been later proved to be very useful for the development of the thesis. Dealing with the single line schemes has involved other departments and, in the end, from our position we have had an overall view of the situation of what was happening. The most involved departments have turned out to be the distribution division of the firm, the people belonging to engineering and construction (because they draw the schemes), and the actual people in charge of the power plants. They all have been very implied in updating the plants for complying with the regulation.

The weaknesses of the management of the mini hydro have been successfully solved, and now a reliable method for following the metering has been put into place. With the adaptation of DOMINA, in a couple of clicks anyone can download the measures of all the generators and see if there is some measure missing in less than fifteen minutes. The quality of the measures[8] is checked with the same instruments than the ones used for the wind farms, so from now on not only the missing of measures is audited, but also that the numbers representing the kWh generated make sense from an engineering point of view.

The solution proposed has been flexible enough to comply with the expectations, and if in the future more hydro power plants must be included, now there is a quick and effective method that assures their integration.

[8] To know more about checking the quality of measures see Annex 2.

The integration in DOMINA makes very simple the changes if future developments are done. The power plants are there, and if there are addition or withdrawal of metering points the change will be simply done.

Access to information is now straightforward for any user. The data in DOMINA is displayed in the website, or it can be downloaded to an Excel file and manage it.

The final results have been as expected. If we download the valid metering information from any power plant (the valid one is the information that will be finally billed), it corresponds to the one given by the System Operator. If not, the measures can be analysed and changed in order to know all the time which is the correct information.

5.2 *ECONOMIC IMPLICATIONS*

The main economic implication of DOMINA adaptation is that the metering and the billing can be done from a single place.

Figure 5-1.Closeout sales window in DOMINA

The secured flux of information allows performing the closeout sales as safe as possible. Once the metering is closed, the billing is done directly. Knowing the amount of energy produced, with only the price of the electricity the expected revenues are known instantly.

If a PPA[9] is signed, it is even easier, because you know beforehand the price of the electricity the generators are producing.

There is also another important economic implication for the company after implementing the hydro power plants in the tool. From now on, all the measures can be controlled in an hourly basis.

If we take into account that all the hours are reviewed, there is not a loss in the revenues of these generation facilities.

Making some draft numbers, if we know that more or less 50 power plants have been adapted, and usually there are two measures lost per power plant per month (as an average), and considering that they produce an average of 800 kWh, this makes a total amount lost per year of 960 MWh. (0.8MWh/measure x 50 power plants x 2 measures/month x 12 months/year). When considering an average price of electricity of 40€/MWh, the potential money not lost per year amounts 38.400€.

5.3 FUTURE DEVELOPMENTS AND TRENDS

The final objective of this adaptation is to manage all the renewables installations from a single place. Assuring that the information of the measures is stored in a single data base accessible from any computer with internet connection, and knowing that the validate values will be the billed ones, it makes easy for a new user to operate the data in a simple way.

In the end what is tried is to solve all the managing workload in a manner that avoids the human error as much as possible and, at the same time, saves the maximum waste of time, which for the company is traduced in a better performance of the assets (both tools and people).

If new power plants must be included in the tool (or changed because there is a regulatory modification), this adaptation has set a precedent and will be used to know which are the

[9] PPA: Power Purchase Agreement

steps that must be taken, and how to deal with the different departments involved and the (always present) System Operator.

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Chapter 7 ANNEXES

7.1 ANNEX 1: RULES OF VERIFICATION OF THE METERING EQUIPMENT

According to the RDL 1110/2007, of August 24th, the frontier and measuring points are classified as follows:

Kind of Point	Characteristics
Point 1	▪ Power contracted > 10 MW ▪ Apparent power > 12 MVA ▪ Energy exchanged > 5GWh per year
Point 2	No being classified as 1, comply: ▪ Power contracted > 450 kW ▪ Apparent power > 450 kVA ▪ Energy exchanged > 750 MWh per year
Point 3	Cannot be classified in any other category.
Point 4	▪ Power contracted < 50 kW and > 15 kW
Point 5	▪ Power contracted < 15 kWh ▪ Apparent power < 15 kVA

Figure 7-1.Characteristics of the different measuring points

The verification and inspection of the equipment must be done by an entity without an economic interest implied in the measure. It is usually performed by the System Operator.

According to the regulation, frontier points of kind 1, 2 or 3 must be verified following the next table:

Kind of point	Periodicity (years)
1	2
2	5
3	5

Figure 7-2.Verification periodicity of the different measuring points

Due to the characteristics of the mini-hydro power plants, the measuring equipment named in *3.3 Adaptation of DOMINA* is reviewed each five years.

7.2 ANNEX 2: HOW TO CHECK HE QUALITY OF MEASURES

The aim of this annex is to describe the method used to analyse and control the production measures of the renewable power plants. The steps taken for that purpose are:

1. Download the monthly data of the renewable plants from DOMINA. This data is collected and stored in CORE, and DOMINA gets the information from it.

2. Preliminary review: It is checked that the relationship between the principal counter and the redundant one does not exceed the threshold of validation of the measurements, which is set in $\pm 0.2\%$.

3. Review of the measurement quality: This check is done in an hourly basis. Each measure has associated eight parameters of quality joined to the counter. These can be invalid lecture, overflow, feeding value, etc. In case there is a failure in the principal measure, is should be substituted for the redundant measure.

   If both the principal and the redundant fail, the measure will be determined by the PI, which are the values given by each generator.

4. Review of invalid measures: Independently of the previous revisions, if in one month one power plant has more than 10 invalid measures the entire measure of the month must be reviewed in order to know what is happening in that power plant. Usually the metering device is out of class, or there have been problems with the substation.