Design and economic analysis of SCADA platform for remote supervision and operation of wind power plants

by

Sergio Pintado Miranda

Submitted to the Department of Electrical Engineering, Electronics, Computers and Systems
in partial fulfilment of the requirements for the degree of
Master of Science in Electrical Energy Conversion and Power Systems
at the
UNIVERSIDAD DE OVIEDO
July 2013

Author . . . .
Sergio Pintado Miranda.
E-mail: sergiopintadomiranda@gmail.com

Certified by. . . . .
Pablo Arboleya Arboleya
Associate Professor
Thesis Advisor

Certified by. . . . .
Sonia García Fernández
Remote Operations Technical Support at EDP Renewables
Thesis Co-Advisor

Design and economic analysis of SCADA platform for remote supervision and operation of wind power plants

by

Sergio Pintado Miranda

Submitted to the Department of Electrical Engineering, Electronics, Computers and Systems
on July 22, 2013, in partial fulfilment of the
requirements for the degree of
Master of Science in Electrical Energy Conversion and Power Systems

Abstract

Electric Companies usually have to manage several Wind Power Plants. Each of them can use wind turbine generators from different vendors, as they are selected by availability and technical characteristics for each location. Most vendors allow the remote operation the machines with their own SCADA System, which is different for each manufacturer. In this Master Thesis, a single SCADA system for different vendors is designed, from the functional and technical specifications to the standardization of the database. It can be concluded that this system is very advantageous in terms of increase of hours of operation of the Wind Parks, increasing the profit-earning capacity for the company.

Keywords: Renewable Energy, Wind Power, Communications, SCADA, Remote Operation and Control.

Thesis Advisor: Pablo Arboleya Arboleya
Title: Associate Professor

Thesis Co-Advisor: Sonia García Fernández
Title: RODC Supervisor at EDP Renewables

Acknowledgments

I take this opportunity to express my profound gratitude and deep regards to all my professors for their exemplary guidance, monitoring and constant encouragement throughout the course of this thesis. The blessing, help and guidance given by them time to time shall carry me a long way in the journey of life on which I am about to embark.

I would also like to express a deep sense of gratitude to Sonia García Fernández, Remote Operations and Dispatch Centre Supervisor at EDP Renewables, for her cordial support, valuable information and guidance, which helped me in completing this task through various stages.

I am obliged to all the staff members of EDP Renewables for the valuable information provided by them in their respective fields. I am grateful for their cooperation during the period of my assignment.

Lastly, I thank my parents and friends for their constant encouragement without which this assignment would not be possible.

Index

1. **Introduction** 17
   1.1. **The Wind Power: background** 17
   1.2. **SCADA Systems** 19
   1.3. **Objectives of the Master Thesis** 20

2. **State of the art** 22
   2.1. **Wind Power** 22
   2.2. **SCADA Systems** 23

3. **Scope** 26

4. **Design of the SCADA system** 29
   4.1. **Functional and Technical Specifications** 29
   4.2. **Global Network Infrastructure** 30
      4.2.1. **Components** 30
   4.3. **Database** 34
      4.3.1. **Real Time Database Sizing** 34
      4.3.2. **IEC 61400-25 Standard** 34
      4.3.3. **Standardization Methodology** 36

5. **Software Tools Design** 38
   5.1. **Visual Basic for Applications** 38

5.2. Energy Savings Tool Design 38
5.2.1. Input Data 38
5.2.2. Energy Savings Calculations Methodology 39
5.3. Money Savings Tool Design 39
5.3.1. Input Data 40
5.3.2. Money Savings Calculations Methodology 44

6. Economic Analysis 45
6.1. Methodology and initial considerations 45
6.2. Macro assumptions 45
6.3. Capital Expenditures (CAPEX) 46
6.4. Operational Expenditures (OPEX) 48
6.4.1. Staff costs 48
6.4.2. Maintenance 48
6.4.3. Total OPEX 49
6.5. Depreciation and amortization (D&A) 49
6.6. Recurring revenues 50
6.6.1. Increase in the production 50
6.7. Results of the Economic Analysis 51
6.7.1. EBITDA and EBIT 51
6.7.2. Free Cash Flow 52
6.7.3. Payback 54
6.7.4. NPV 56
6.7.5. Valuation: Discounted Cash Flow (DCF) 57
6.7.6. IRR 58
6.7.7. Ratios 59

7. Conclusions 61

8. Future developments 63
8.1. Extension of the project 63
8.2. Link the WTG reset data to automated database 63
8.3. Auto-import data to the analysis tools 63

9. Quality report 64

10. Bibliography and references 65

ANNEXES 66

ANNEX I: Tasks developed in the Host Institution 67
I. EDP Renewables 68
II. Remote Operations Dispatch Center 69
III. Work developed 70

ANNEX 2. External Master Thesis Evaluation Form 72

List of Figures

Fig. 1. Main components of a wind power system [1] 17
Fig. 2. Wind Power installed in Spain [3] 18
Fig. 3. HAWT and VAWT configurations 22
Fig. 4. SCADA Platform Schematic [8] 24
Fig. 5. Global Network Infrastructure 30
Fig. 6. Blade systems HP C7000 server 31
Fig. 7. EMC Clarion AX4 31
Fig. 8. CheckPoint UTM-1 Model 2073 firewall 32
Fig. 9. HP Z6000 Workstation 33
Fig. 10. Conceptual communication model of the IEC 61400-25 series 35
Fig. 11. Standardization Methodology 36
Fig. 12. WTG and WSUB components 37
Fig. 13 Energy savings calculations flow diagram 40
Fig. 14 Energy prices for Wind Energy (yellow) according to RD 661/2007 [9] 41
Fig. 15. Money Savings Calculation Methodology 44
Fig. 16. EDPR's installed technology portfolio, year 2011 68
Fig. 17. Location of the Technical Support Department in EDPR's Organizational Chart 69

List of Tables

Table 1.Total MW, WPP and WTG within the scope of the project 26
Table 2. WTG OEM and models 27
Table 3. HP Z600 Workstation components 32
Table 4. HP DC7900 workstation configuration 34
Table 5. Macro assumptions 46
Table 6. CAPEX (assets) 46
Table 7. CAPEX (BOP) 47
Table 8. Total CAPEX, including VAT reimbursement 47
Table 9. Scope of the services 48
Table 10. Yearly Maintenance Budget 49
Table 11. Total OPEX 49
Table 12. CAPEX Depreciation and Amortization 50
Table 13. Monthly and total energy savings estimation 50
Table 14. Yearly revenues 51
Table 15. EBITDA and EBIT Calculations 52
Table 16. Change in the working capital (WK) 53
Table 17. Taxes 53
Table 18. Free Cash Flow (FCF) and Terminal Value (TV) 54
Table 19. Payback 55
Table 20. Discounted Payback 56
Table 21. WACC calculation 60

Table of Symbols

Acronyms

CAPEX	Capital Expenditures
COD	Commercial Operation Date
CS	Concentrador Secundario (Secondary Concentrator)
DCF	Discounted Cash Flow
DCFROR	Discounted Cash Flow Rate Of Return
EBIT	Earnings Before Interests and Taxes
EBITDA	Earnings Before Interests, Taxes, Depreciation and Amortization
FCF	Free Cash Flow
HAWT	Horizontal Axis Wind Turbine
HMI	Human Machine Interface
ICS	Industrial Control System
IRR	Internal Rate of Return
NPV	Net Present Value
NPW	Net Present Worth
O&M	Operation and Maintenance
OEM	Original Equipment Manufacturer
OLE	Object Linking and Embedding
OMIE	Operador del Mercado Ibérico de Electricidad (Iberian Electricity Market Operator)

OPC OLE for Proccess Control

OPEX Operational Expenses

RD Real Decreto (Royal Decree)

REE Red Eléctrica Española (Spanish TSO)

RODC Remote Operations and Dispatch Centre

ROR Rate of Return

RTU Remote Terminal Unit

SCADA Supervisory Control And Data Acquisition

SMA Service and Maintenance Agreement

SOC Start Of Construction

TSO Transmission System Operator

TV Terminal Value

VAWT Vertical Axis Wind Turbine

VBA Visual Basic for Applications

WACC Weighted Average Cost of Capital

WK Working Capital

WPP Wind Power Plant

WTG Wind Turbine Generator

1. Introduction

1.1. The Wind Power: background

Wind energy is a renewable power source which comes from air current flowing across the earth's surface. The sun is the primary source of these currents, due to the fact that hot air has less density that cold air and it causes it to move. This wind potential energy has been used to pump water or to turn mechanical machinery (such as windmills) over hundreds of years. But nowadays, wind turbines are modern devices that are able to harvest this kinetic energy from the air and convert it into usable power by converting the rotation of turbine blades into electrical current by means of an electrical generator. The main components of a wind power system include the rotor and the blades, a gearbox (optional), an electric generator, the power electronics (optional), and a power transformer (*Fig. 1*).

Wind turbines range from small generators for residential use (hundreds of watts) to several megawatt machines for onshore and offshore wind power plants (WPPs). In general, energy costs decrease with the size of the turbine, so the trend is to design wind turbine generators (WTGs) with bigger blades, although this implies some supply difficulties. For residential use, there is a size constraint, and the trend is to use gearless direct drive generators so that smaller machines can be built.

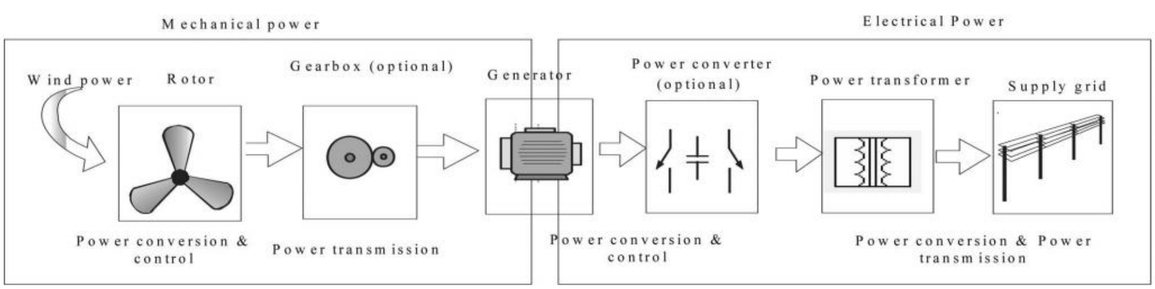

Fig. 1. Main components of a wind power system [1]

Compared with traditional fossil fuel based energies (coal, fuel, or combined cycle – and also nuclear-), wind power is cleaner, widely distributed and plentiful. It has a lower impact on the environment and climate (no CO_2 or other greenhouse gas emissions) and reduces dependence on fossil fuel imports. On the other hand, wind energy has traditionally been more expensive than fossil fuel based energies, but it is becoming more cost-effective thanks to the technological development of recent years, with more reliable and efficient wind turbines, and also thanks to the progressive increase in the cost of the fossil fuels.

Nowadays, wind power plays a central role in electric energy generation in a lot of countries all around the world. According to Global Wind Energy Council (GWEC), the international trade association for the wind power industry, the cumulative growth rates for the last 15 years average 28%, and the power installed sums up to 240GW. In addition to this, twenty two countries have more than 1GW of wind power plants installed [2]. Countries like Spain have strongly increased their installed capacity - from 760MW in 1996 (1.54% of the total of the country) to more than 22GW in 2012 (21% of the total) -, supported on advantageous energy policies (Fig. 2). Wind has become one of the most valuable energy resources in this country, particularly hard-hit by the external energy dependence. In fact, Spain is the leading generator of wind energy in Europe; wind power has reached the third place in the electric mix of the country, right after nuclear plants and combined cycles.

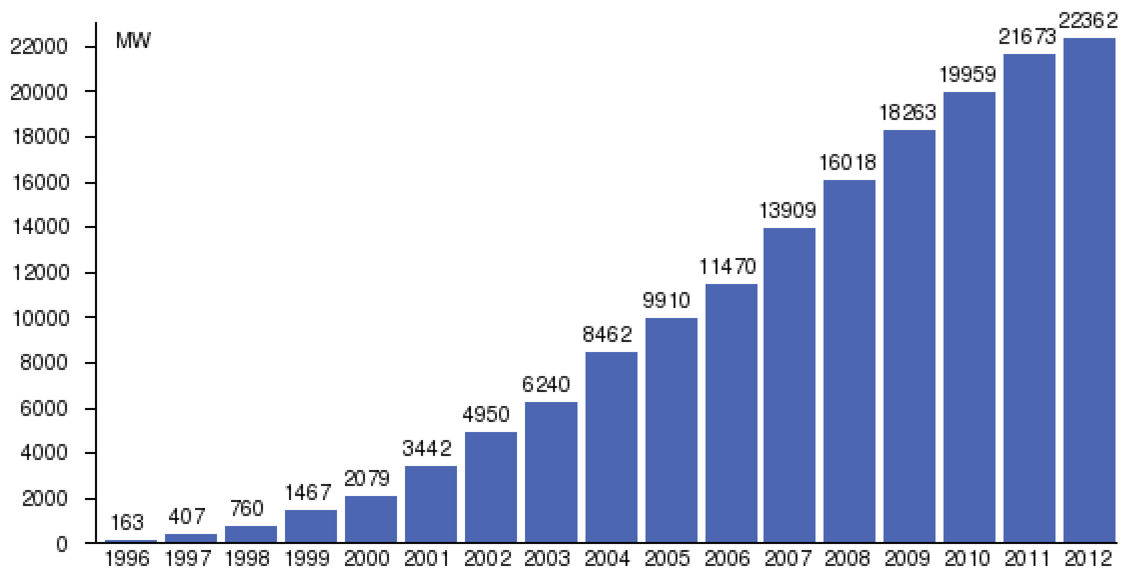

Fig. 2. Wind Power installed in Spain[3]

However, the economic background has caused that most European countries slowed down the installation of new wind power facilities. The crisis started in 2008 has decreased the power demand –mainly in the industry- and there also have been reductions in subsidies to renewable energies. For the last five years, China has been the main driver of the growth of the wind power, but now other countries like Brazil or Mexico are taking over.

1.2. SCADA Systems

The acronym SCADA stands for Supervisory Control And Data Acquisition. It is a type of Industrial Control System (ICS), that is, a computer controlled system that monitor and control industrial processes that exist in the physical world. However, ICS use to be restricted to short distances and places, while SCADA can be large scale processes involving multiple sites and long distances.

SCADA systems evolved from the industry (manufacturing, production, fabrication, refining, among others) to other facilities, such as infrastructures (**wind farms**, oil and gas pipelines, electrical power transmission) and even to buildings (airports, ships…) controlling heating, ventilation, air conditioning systems, energy consumptions, etc.

The most usual subsystems in a SCADA are the human-machine interface (HMI), that is the device from where the human operator monitors and controls the process, the supervisory system, which is a computer system that gets data and sends commands to the process, the Remote Terminal Units (RTU) that convert sensor signals to digital data in order to send it to the supervisory system, PLCs (programmable logic controllers) that are used as field devices, and the communication infrastructure that connects the supervisory system to the RTUs.

In a geographically distributed industrial process, like wind power generation, a real time centralized remote control, dispatching and performance management system is fundamental to improve assets profitability and operations quality. SCADA systems are becoming more and more important in the wind power sector, as they allow companies to save staff and operating costs. The decrease in the construction of new wind power plants in Europe cause that electric companies are trying to improve the management of the existing facilities.

In this context, there seem to be a big opportunity to increase efficiency in WPP by improving the operation. Electric and Renewable Energies Companies selected the most appropriate wind turbines for their wind power projects depending on availability, cost, wind speeds and other technical specifications, so they can have different vendor WTGs for each wind power plant. Most vendors can provide real time information about the operating conditions of their machines, and they also make possible to remotely operate and control the WTGs through their own SCADA System, which represents a huge advantage in terms of hours of operation of the WPP. However, this issue represents a huge challenge due to the fact that if the same electric company operates several WPP with different vendors' WTGs in each, it is not very efficient to manage different software for each manufacturer. Additional increases in hours of operation can be achieved if the signals provided by the vendors can be managed with a single software.

1.3. Objectives of the Master Thesis

EDP Renewables is interested in implementing a standardized SCADA system that allows the company to remotely operate and control different vendors' WTGs. The objective of this Master Thesis is to set the basis of this system, through the following tasks:

- **Set the functional and technical specifications for a standardized SCADA platform** with a real time object oriented database, user friendly Human Machine Interface (HMI) and able to support the specified communication protocols, for remote supervision and operation of WPP with heterogeneous data from different vendor WTGs.

- **Describe the architecture of the SCADA platform**, including the hardware components to be used and the interconnections between them.

- **Select the most appropriate components** for the above mentioned SCADA platform in terms of technical requirements, quality, cost and availability.

- **Collect and manage any technical documentation** of interest from the WTG vendors that have ever supplied EDP Renewables.

- **Create the vendor's WTGs signal lists and perform the standardization of the signals** in a new database in order to use them all in a single SCADA System.

- **Design a software tool in order to quantify the energy savings** derived from the use of the remote operation SCADA system.

- **Design a software tool in order to translate the energy savings into monetary quantities,** according to existing regulations and directives.

- **Design an economic analysis tool** in order to evaluate the viability of implementing this kind of SCADA platforms for the different dispatch centres of the company all around the world.

2. State of the art

2.1. Wind Power

Wind energy is an area of research interest and at present, in order to achieve the cost-effective utilization of this energy resource for quality and reliable power supply. During the last part of the XX century, wind turbines have increased in size from a few kW to a few MW, while nowadays larger wind turbines already are being developed. A lot of different designs have been designed and tested. Examples of important modifications involve construction (tower), mechanical (blades, transmission), electrical (generator, transformer), and control engineering (power electronics).

Actually, research is focusing a lot in offshore wind power plants, trying to increase the power in order to harness more energy in this kind of facilities, but also researching in new materials that can resist the sea conditions and also in anchoring systems or even floating systems for the WTGs [4],

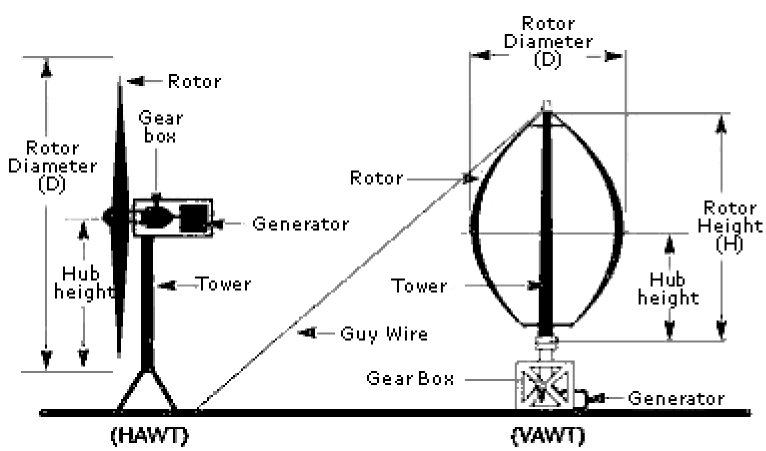

Fig. 3. HAWT and VAWT configurations

There are also quite a lot studies and researches about blade design and orientation of the shaft, trying to determine the best orientation of the shaft and also new prototypes. A turbine with a shaft mounted horizontally parallel to the ground is known as a horizontal axis wind turbine or (HAWT) [5]. A vertical axis wind turbine (VAWT) has its shaft normal to the ground. The two configurations have instantly distinguishable rotor designs, each with its own favourable characteristics, and one example of each can be seen in *Fig. 2*. VAWT have a low tip speed ratio and difficulty controlling rotor speed, and they have been believed until recently to be incapable of self-starting. On the other hand, VAWT requires no extra mechanism to face to the wind and it reduces tower loads, as it is mounted from the ground [6]. Focus is nowadays being made on HAWT due to its dominance in the wind turbine industry [6].

Regarding blades, the current research trend in design is the so called “Smart Blades”, which alter their shape depending on the wind conditions. Within this category of blade design are numerous approaches which are either aerodynamic control surfaces or smart actuator materials. The driver behind this research is to limit ultimate (extreme) loads and fatigue loads or to increase dynamic energy capture [6].

The two most common types of electrical machines used in wind turbines are induction generators and synchronous generators. Induction generators with cage rotor can be used in fixed speed wind turbines; wound rotor induction machines can provide a partial variable-speed operation with a small power electronic converter; and synchronous generators are excited by an externally applied dc or by permanent magnets (PMs). There is considerable interest in the application of the multiple-pole synchronous generators (either with PM excitation or with an electromagnet) driven by a wind-turbine rotor without a gearbox or with a low ratio gearbox [2].

Dealing with grid connection demands is becoming a major issue for WPPs. Grid connection requirements are becoming stricter and, for example, in case of a major grid disturbance, wind turbines have to remain connected and play an assisting role. Therefore, these machines are requiring a built-in capacity to behave like power plants. Power electronic technologies, as the interfaces for wind turbines and as flexible ac transmission systems (FACTs) devices, such as STATCOM, will be very important in developing new solutions for the future success of new power generation and control concepts [2].

2.2. SCADA Systems

First SCADA systems were simple telemetry system providing reports of field conditions just controlling measurement signals or state conditions in remote locations. This kind of system offered very simple monitoring and control issues, with displays based in lights. As long as technology developed, computers started to manage data acquisition, including control commands, and displaying information in CRT screens. Computers added the capacity to program the system in order to perform more complex control functions. The next step was to introduce specific application software in order to fulfil specific project requirements.

SCADA vendors design now systems oriented to solve different industries requirements, with specific software modules, and it can be found commercial SCADA software for a wide variety of applications.

SCADA systems are also becoming an integral part of corporate management. These systems are not seen nowadays simply as operation tools, but as important information resources. They provide information on systems and users out of the control centre, and in a lot of cases this is key information in order to take economic decisions [7].

Nowadays, this information may include, in addition to basic SCADA functions:

- Data acquisition & archiving
- Controlling from control centre
- Monitoring from control centre
- Reporting
- Fault localization
- Fault analyse
- Customer specific functions
- Distribution Management System (DMS)
- Network Management System (NMS)
- Manageable Metering and Measuring Systems
- Quality recording and analysing

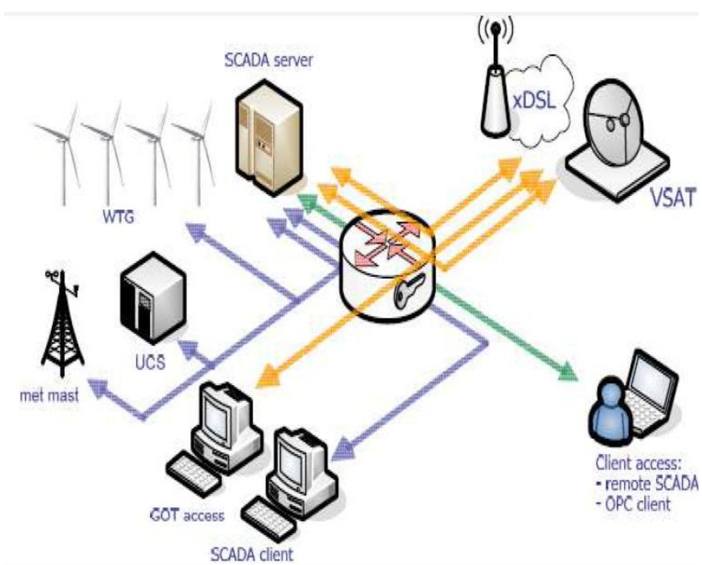

Fig. 4. SCADA Platform Schematic [8]

Regarding Wind Power, each vendor provides its own SCADA system, with its particular features, advantages and drawbacks. A typical scheme of a commercial SCADA system for WPP can be seen in *Fig. 4.*

The most popular SCADA systems developed by WTG vendors are the following:

- **SGIPE** is the SCADA system designed by **Gamesa.** As most of these platforms, it allows monitoring electrical and physical parameters of the WTGs. It generates alarms for the operators and allows the remote operation of the machines. Advantages: it can be mentioned that it has a friendly HMI and that it is flexible and scalable. Drawbacks: it does not provide multiple WPP supervision, it is not very robust, it’s difficult to retrieve historical data and there is some data loss, because it doesn’t incorporate full buffer options [8].

- **Vestas** SCADA is **VOB (Vestas Online Business).** The functionalities are very similar to the mentioned above, but improving the HMI, and adding the possibility of generating multiple reports easily. In addition to this, it has a powerful power plant control module. The main drawback is that any further development of the SCADA system for the customer would be very expensive [8].

- **General Electric** provides **Visupro.** It provides communication through a fibre optic ring and shows mostly the same parameters than other WPP SCADA systems. The main drawbacks of this system are that it is not scalable, it is expensive and doesn’t allow WPP commands. Among its advantages, it has a very powerful wind farm management system, suitable for regulation, and it is very robust (both hardware and software), a very important issue in order to avoid data loss [8].

- **Enercon** has developed **Enercon Scada Remote** that has a clean user interface and allows obtaining multiple reports and graphs related to the WPP. The main drawback is that it doesn’t allow customers to control the power plant [8].

- Among the rest of the vendors, it can be **found Argos and Arade (Ecotecnia), SCWNVT (Isotrol/Navantia), WPS (Siemens), INGSYS IT (Acciona), NC2 (Nordex) or SCPE (EDPR/Desa),** all of them slight variations of the ones described above [7].

3. Scope

The project covers Spanish wind facilities, with the number of WPPs and WTG showed in *Table 1* below:

Gross Installed Capacity	2355.92 MW
Number of WPP	94
Number of WTG	2107

Table 1.Total MW, WPP and WTG within the scope of the project

The portfolio of WTGs is currently composed of 7 Original Equipment Manufacturers (OEMs) and 28 different WTG models. All of them can be seen in *Table 2*:

OEM	Models
Gamesa	G42
	G47
	G52
	G58
	G80
	G87
	G90
	G93
Vestas /NM	V66
	V80
	V90
	V112
	NM48
	NM52
	NM72
	NM82

OEM	Models
GEWE	GE 1.5 csl
	GE 1.5 csle
	GE 1.5 cxle
	GE 2.5 xl
EDPR / Desa	A300
Siemens / Izar Bonus	IB 1.3 (B62)
	2.3
Ecotecnia/Alstom	ECO74
	ECO80
Acciona	AW70
	AW77
	AW82

Table 2. WTG OEM and models

It is within the scope of the project:

- The proposal of the infrastructure and the selection of the appropriate components, according to the functional and technical specifications described in *section 4.1*.

- The energy savings analysis derived from the increase of availability of the wind turbines.

- The economic analysis, in order to analyse the increase of the income (more energy sold) and the long-term profitability of the system, in terms of payback, internal rate of return and net present value

It is not within the scope of the project:

- To develop and provide the computer software needed in order to remote operate wind power plants. This work should be done by an external entity when needed.

- Design and sizing of the communication system between all the elements involved: WPPs, WTGs and meteorological towers and the remote operation dispatch centre. These communications already exist (WIMAX and/or terrestrial).

4. Design of the SCADA system

4.1. Functional and Technical Specifications

According to the needs of the company, the new SCADA system has to satisfy the following generic specifications:

a) Technical Specifications

- Have a high performance and high availability architecture.
- Be flexible, modular and tolerant to failures/errors and able to exchange information in an open and transparent way with other systems.
- The communications use standard components that are widely available on the marketplace. The equipment has to be of the latest generation at the time of purchase.
- Allow scalability and flexibility to include more WPPs in the future or to allow increases in installed power in an existing WPP.
- Be secure itself but also the applications that are part of it. The dispatch centre has to be protected with a firewall and they are part of global network security policy.

b) Functional Specifications

- Provide the main Alarms and Trips related to the operation of the WPP and allow easy and intuitive remote operation and control for the WPP.
- Assure a uniform, coherent, user-friendly and standardized HMI (both for signals and display elements).
- Possibility to connect workstations in order to be displayed in a video wall sited in the Dispatch Centre.

4.2. Global Network Infrastructure

The system is required to have a high performance and high availability architecture. According to this requirement, the proposed architecture can be seen in Fig. 5.

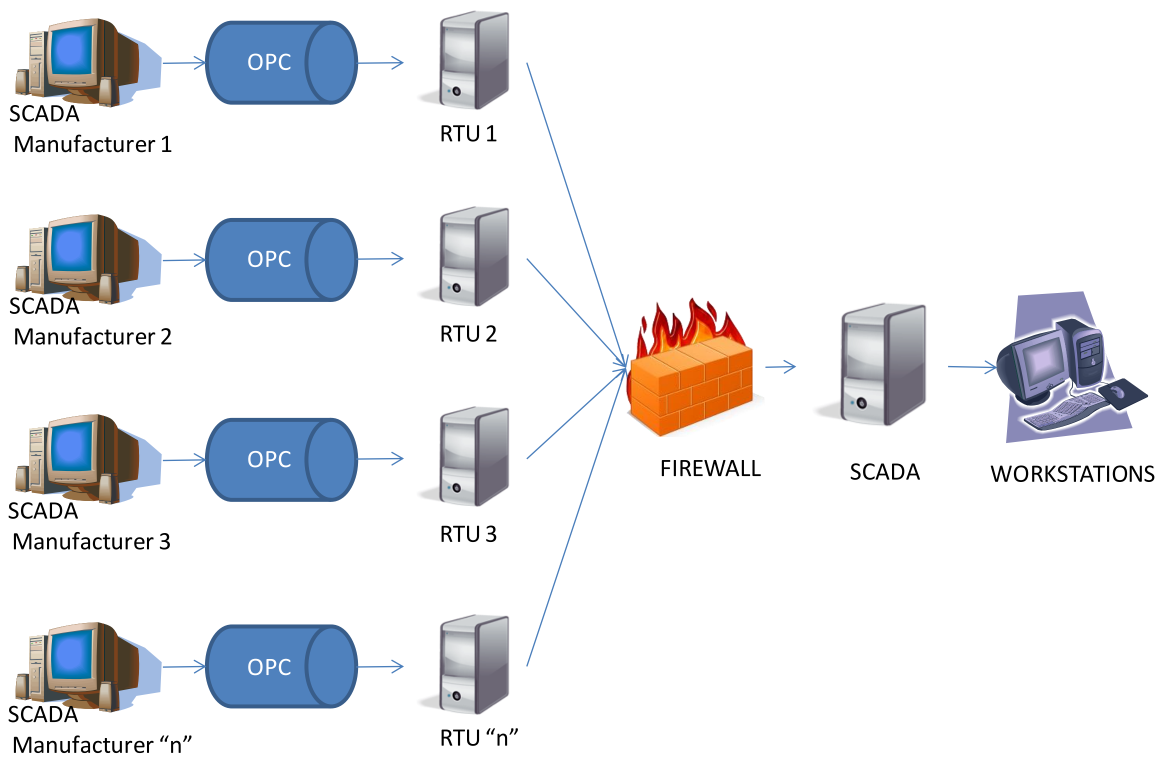

Fig. 5. Global Network Infrastructure

4.2.1. Components

Components of the remote operation system were chosen according to the functional and technical specifications and under criteria of energy efficiency, quality, cost, scalability and security.

In the subsections below the chosen components are described in detail.

4.2.1.1. Dispatch Centre Hardware – Servers

The Data Centre in Oviedo will be based on Blade systems HP C7000 class. Its enclosure provides all the power, cooling and I/O infrastructure needed to support modular server, interconnect and storage components throughout several years (*Fig. 6*).

Fig. 6. Blade systems HP C7000 server

In all cases, Blade Servers are protected by the redundant power and network internal devices of the C7000 Enclosure.

For the Storage Area Network, EMC CLARION AX4 will be the solution (*Fig. 7*), supporting up to 6Tb of useful capacity. Storage is connected to servers with Fibre Channel. HP enclosure includes 2 redundant Brocade SAN FC 4/8 GB switches permitting server blades with adapters to connect EMC Clarion AX4 storage.

Fig. 7. EMC Clarion AX4

4.2.1.2. Dispatch Centre Hardware – Protection and Data Security

For the Dispatch Centre firewall, Checkpoint Firewall appliances will be used. The chosen devices are two CheckPoint UTM-1 Model 2073 (*Fig. 8*).

Fig. 8. CheckPoint UTM-1 Model 2073 firewall

4.2.1.3. Workstations for Operators

The workstations models have high performance equipment regarding processing capabilities as well as graphical capabilities. The chosen device is the HP Z600 (*Fig. 9*) workstation. *Table 3* shows the main characteristics of this equipment. All the workstations provided can be connected to a video wall.

HP Z600 Workstation Base Unit
HP Z600 650W 85% Efficient Chassis
Microsoft Vista32 Downgrade to XP32B OS
Intel Xeon E5520 2.26 8MB/1066 QC CPU-1
HP 4GB(2x2GB)DDR3-1333 ECC 1-CPU Memory
NVIDIA Quadro FX580 512MB,1st Card
NVIDIA Quadro FX580 512MB,2ndCard
HP 160GB SATA 10K SFF,1st HDD
HP USB Keyboard
HP USB Optical Scroll Mouse
HP No Floppy Disk Kit
HP 16X DVD+/-RW SuperMulti SATA,1st ODD
HP Z600 Localization Kit
HP Delivery Service (Door/Dock) WS

Table 3. HP Z600 Workstation components

The HP Z600 combines very quiet operation and energy-efficiency in an unobtrusive, powerful and reliable mid-range system designed and engineered for the high performance.

Fig. 9. HP Z600 Workstation

4.2.1.4. Remote Terminal Unit

A Remote Terminal Unit (RTU) is a microprocessor-controlled electronic device that interfaces objects in the physical world (in this case, WPP) to a distributed control system or SCADA system by transmitting telemetry data to a master system, and by using messages from the master supervisory system to control connected objects. The RTU can manage both digital and analog inputs/outputs.

The RTU is located at the Wind Power Plant to increase reliability and flexibility of the solution to deal with different types of OEM and communication systems. The variety of OEM Systems makes that the WEMS is required to have the capability of dealing with a variety of data communication protocols, namely OPC XML DA and OPC DA (for wind power plants) but also Modbus, IEC104 and DNP (for substations).

Each RTU, at the WPP level, supports 50.000 tags, including internal computed tags.

At the WPP site, the RTU equipment proposed is an industrial HP DC7900 workstation with keyboard, 17'' inch monitor and switch (for local network). The equipment is placed in a 35U Rack or 22U wall mounted rack, where necessary. The main characteristics of this device can be seen in *Table 4*.

HP Compaq dc7900 CMT Base Unit PC
dc7900 CMT chassis w / 85% PSU
Window s Vista Custom Downgrade to XP Pro
Intel Core 2 Duo E7400 Processor
2GB PC2-6400 (DDR2-800) 2x1GB Memory
80GB SATA 3.5 1st Hard Drive
80GB SATA 3.5 2nd Hard Drive
RAID Configuration
PS/2 Standard Keyboard
HP PS/2 Optical Mouse
SuperMulti LS #1
3/3/3 CMT Warranty
HP dc7900 Country Kit
SATA Cable 2nd CMT Cable Kit
HP Door/Dock Delivery Desktops
HP L1710 17-inch LCD Monitor

Table 4. HP DC7900 workstation configuration

4.3. Database

4.3.1. Real Time Database Sizing

The size of the Real Time Database will be 1.200.000 tags for the remote operation centre. Each RTU, at the WPP level, supports 50.000 tags, including internal computed tags.

4.3.2. IEC 61400-25 Standard

In order to reach interoperability, the data provided by the different OEM has to be standardized, so that the new SCADA system can use and read the same language for all of them. This is done by means of the IEC 61400-25 standard (Communications for monitoring and control of wind power plants, TC 88), that focuses on the communications between WPP components and SCADA systems. The intention of the IEC 61400-25 series is to enable components from different vendors to communicate with other components, at any location.

The IEC 61400-25 series addresses vendors (manufacturers, suppliers), operators, owners, planners, and designers of wind power plants as well as system integrators and utility companies operating in the wind energy market. It is intended to be accepted and to be used world-wide as the international standard for communications in the domain of wind power plants. It defines wind power plant specific information, the mechanisms for information exchange and the mapping to communication protocols. In this regard, the IEC 61400-25 series defines details required to exchange the available information with wind power plant components in a manufacturer-independent environment.

All information of a wind power plant defined in the IEC 61400-25 series is name tagged and a concise meaning of each data is given. So, the application area of this standard covers the components required for the operation of WPP, not only the WTG but also the meteorological towers, the substation and the WPP management system as a whole.

The IEC 61400-25 standard is a basis for simplifying the roles that the wind turbine and SCADA systems have to play. The crucial part of the wind power plant information, information exchange methods, and communication stacks are standardized. They build a basis to which procurement specifications and contracts could easily refer.

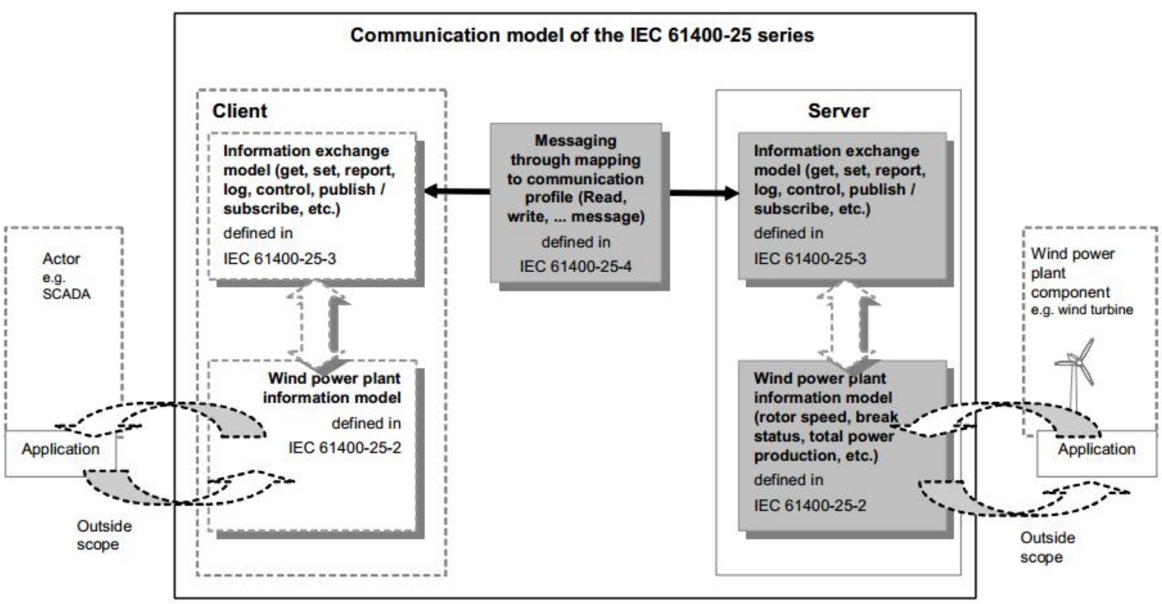

Fig. 10. Conceptual communication model of the IEC 61400-25 series

To reach interoperability, all data in the information model need a strong definition with regard to syntax and semantics. The semantics of the data is mainly provided by names assigned to logical nodes and data they contain, as defined in this part of the IEC 61400-25 series. Interoperability is easiest if as much as possible of the data are defined as mandatory. In *Fig. 10*, it can be seen the model of the 61400-25 series.

4.3.3. Standardization Methodology

The database uniformization and harmonization is based on object-oriented principles. Also, The Object Model conventions from the IEC61850 and IEC61400-25 norm were used to determine the data normalization formulas and to create a uniform database for WTGs and wind power plants data.

Fig. 11 below shows the tag structure standard*. Fig. 12* shows the different systems of a WPP, as per the IEC 61400-25 norm and gives an indication of the standardization principles applied:

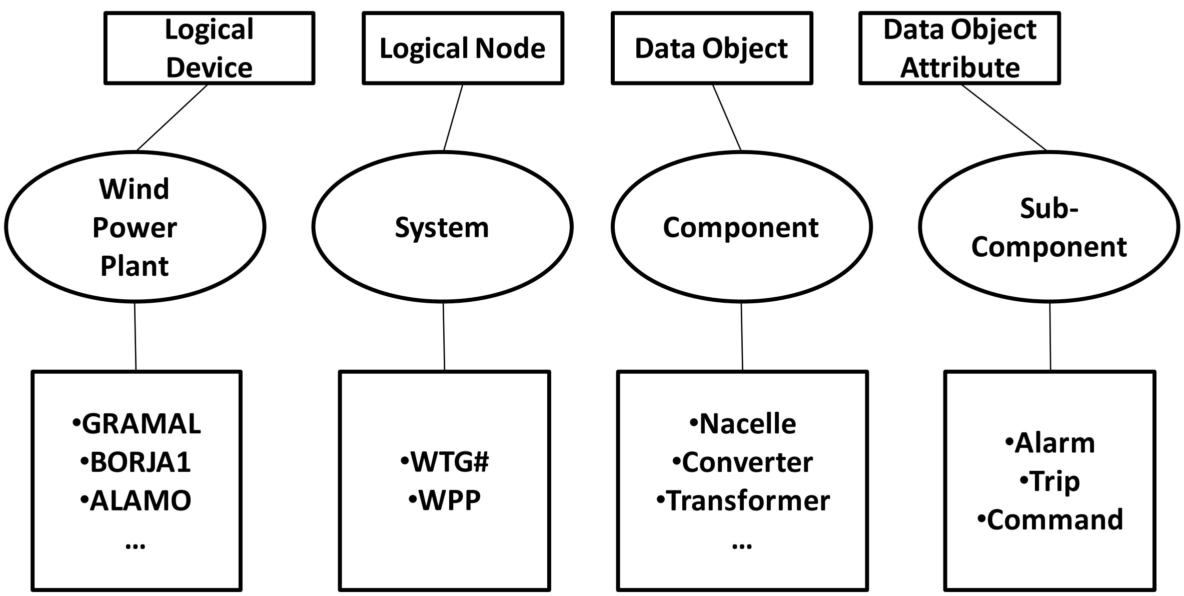

Fig. 11. Standardization Methodology

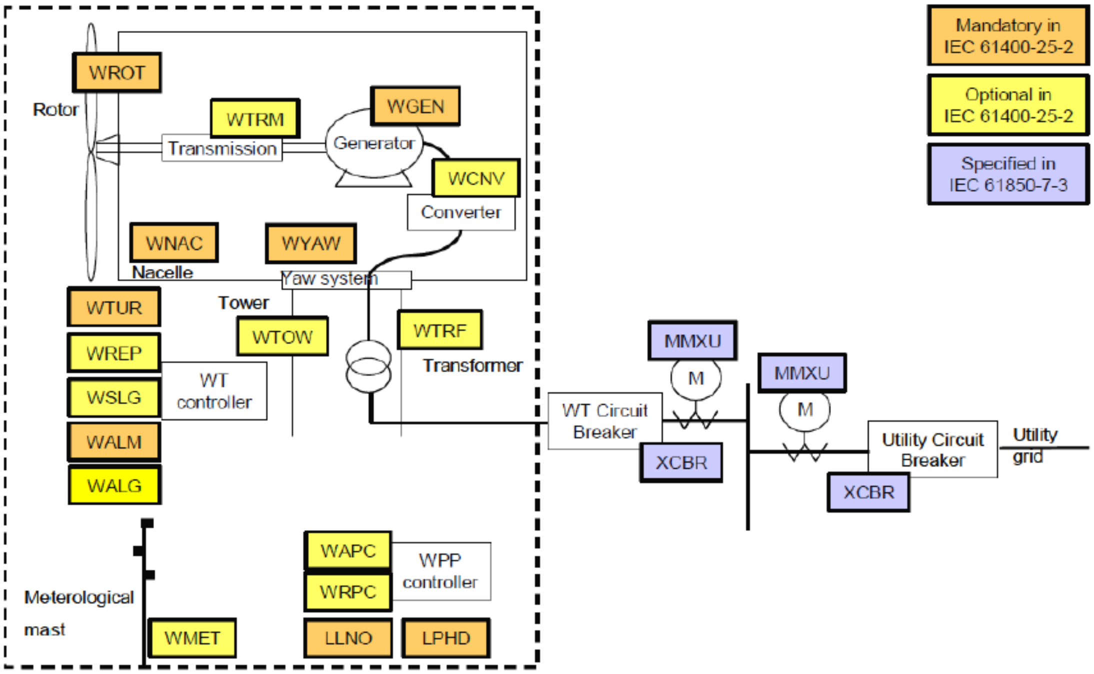

Fig. 12. WTG and WSUB components

5. Software Tools Design

5.1. Visual Basic for Applications

Visual Basic for Applications (VBA) will be used for designing and programming the decision tools. VBA is the event-oriented macro language of Microsoft Visual Basic and it allows users to enhance Microsoft Office's programs functionalities. Its main utilities are the automation of common tasks and creating applications and Desktop database services.

The software tools will be Microsoft Excel based and will provide the necessary calculations and data processing in order to evaluate energy savings, money savings and expected profitability.

5.2. Energy Savings Tool Design

The energy savings tool will provide the user with energy savings data derived from remotely operating the WPP instead of manual resetting. The energy savings are the essential input data for the money savings calculations, but can also be used for other purposes, as energy efficiency reports.

5.2.1. Input Data

The energy savings calculations will be based on the data provided by the dispatch operators (WTG reset register) and the secondary concentrator (CS).

According to Spanish Royal Decree RD 1110/2007, a CS is a measurement device used for capturing, storing and, if necessary, treating the electrical data for subsequent delivery to the Mains operator or other CS. Those responsible for reading the measurements will receive and treat the information and will make it available to the system operator.

In this case, data downloadable from the CS includes, for each WPP and hour (among other data fields):

- The name of the WPP and a code associated to it
- Date and time of the measurements
- Hourly energy production of the WPP

This data can be exported from the device in a digital format and imported from an Excel file in order to use it for energy savings calculations or other purposes.

On the other hand, dispatch centre operators shall include some data in a database (WTG reset register) each time a WTG fails and is remotely reset, including number of WTG reset, date and time of the reset and name of the operator.

5.2.2. Energy Savings Calculations Methodology

Remote resets could save energy from 19:00 to 9:00h, when there is not staff at the WPP. For each operator WTG remote reset, the next possible scheduled manual reset date is calculated, knowing that manual resets can be done from Monday to Friday at 9:00 am. The difference of dates determines, according to the data stored by the secondary concentrator, the increase in generated power due to the remote operation of the WPP.

Power data generated between the real reset and the scheduled manual reset is copied from the secondary concentrator, approximating the first hour proportionally to the number of minutes affected by the reset. All this power data are summed up adjusted to the number of WTGs affected by the reset.

These values are stored for further use and represent the energy saved by resetting remotely instead of waiting for the next manual reset at the WPP. *Fig. 13* describes the loop.

5.3. Money Savings Tool Design

The money savings tool will provide the information related to the increase in the monetary quantities derived from the remote operation of the WPP. It will be used for calculating the recurring savings used in further calculations in chapter *6. Economic Analysis.*

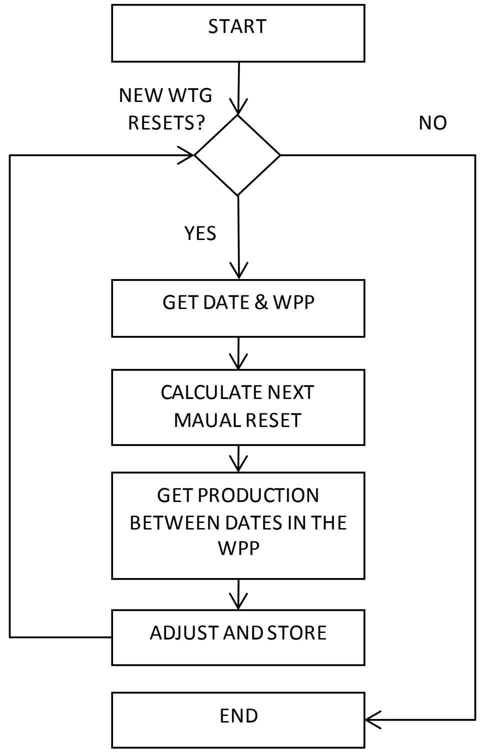

Fig. 13 Energy savings calculations flow diagram

5.3.1. Input Data

5.3.1.1. Types of WPP according to ascribed RDs

According to the corresponding Spanish RDs and regarding to energy prices, WPPs can be divided in 4 categories:

- WPPs ascribed to RD 661/2007 under daily electricity market sale option
- WPPs ascribed to RD 661/2007 under regulated tariff sale option
- WPPs ascribed to RD 436/2004 under daily electricity market sale option
- WPPs ascribed to RD 436/2004 under tariff sale option

5.3.1.2. RD 661/2007 (daily electricity market)

According to RD 661/2007, the reference price for wind power plants that apply for the Market option is the hourly price of the daily electric market.

In order to perform the approximated calculations of Market WPPs, expression (1) below is used:

$$M = E \cdot (P + P') \qquad (1)$$

Being

M	Earnings (€)
E	Produced Energy (MWh)
P	Monthly mean of the daily energy market hourly price (€/MWh)
P'	Prime (20,142 €/MWh)

It must be taken into account that the sum of the monthly mean of the daily energy market hourly price plus the prime must be within the limits specified in the RD, that is, between 79.103 €/MWh and 94.273 €/MWh. So, the condition in expression (2) below must be added:

$$79.103\,€/MWh \leq (P + P') \leq 94.273\,€/MWh \quad (2)$$

The monthly mean of the daily energy market hourly price is available at OMIE (Iberian Energy Market Operator) webpage.

Grupo	Subgrupo	Potencia	Plazo	Tarifa regulada c€/kWh	Prima de referencia c€/kWh	Limite Superior c€/kWh	Limite Inferior c€/kWh
b.1	b.1.1	P≤100 kW	primeros 30 años	48,8743			
		100 kW<P≤10 MW	primeros 30 años	46,3348			
		10<P≤50 MW	primeros 30 años	25,4997			
	b.1.2		primeros 25 años	29,8957	28,1894	38,1751	28,1936
			a partir de entonces	23,9164	22,5515		
b.2	b.2.1		primeros 20 años	8,1270	2,0142	9,4273	7.9103
			a partir de entonces	6,7921			
	b.2.2*				9,3557	18,2009	

Fig. 14 Energy prices for Wind Energy (yellow) according to RD 661/2007 [9]

The energy prime can be obtained from *Table 3. Prime, Tariff and Limits* table from RD 661/2007 under the category *b) Renewable Energies*, *b.2.1 Wind Energy.* The updated prices can be consulted from Industry, Energy and Tourism Spanish Ministry webpage (See *Fig. 14*).

5.3.1.3. RD 661/2007 (regulated tariff)

For the regulated tariff, and according to the aforementioned table, the formula below is applied (3). See *Fig. 14* for details:

$$M = E \cdot T \qquad (3)$$

Being

M Earnings (€)
E Produced Energy (MWh)
T Regulated Tariff (81.270 €/MWh)

5.3.1.4. RD 436/2004 (daily electricity market)

RD 436/2004, in its article 34, establishes the economic regulation for Wind Power Plants. The values are set as percentages of the mean electric tariff (reference tariff), which in force value is 76.588 €/MWh, from January 1st 2006.

For 5MW or less power WPPs, the percentages are the following:

- Tariff: 90% the first 15 years and 80% onwards
- Prime: 40%
- Incentive: 10%

For more than 5MW, the percentages are the following:

- Tariff: 90% during the first 5 years, 85% during the 10 following years and 80% onwards.
- Prime: 40%
- Incentive: 10%

In this case, tariff is not considered, because the sale option is daily electricity market. The prime and the incentive are the same whatever the installed power of the WPP is, so the sale price is calculated according to the formula below (4).

$$M = P + P' + I \qquad (4)$$

Being

M	Sale Price (€/MWh)
P	Daily Market Price (€/MWh)
P'	Fixed Prime (40% · 76.588 €/MWh)
I'	Fixed Incentive (10% · 76.588 €/MWh)

The daily marked price can be obtained following the same methodology than in chapter *5.3.1.2*.

5.3.1.5. RD 436/2004 (tariff)

For the regulated tariff, and according to the aforementioned table, the formula below is applied (5):

$$M = E \cdot T \qquad (5)$$

Being

M	Earnings (€)
E	Produced Energy (MWh)
T	Regulated Tariff

5.3.1.6. Energy Savings

In order to calculate the increase in the earnings by using the remote operation system, it is necessary to determine the energy savings derived by its use.

In the case of WPPs, this energy savings are previously calculated with the energy savings tool, described in section *5.2 Energy savings tool design.*

Energy savings by improvements related to the remote operation are available from a database. From that database, it will only be considered the energy produce within the 3 hours after the reset (this is the mean time that the staff would take to reach the substation in order to perform a manual reset).

5.3.2. Money Savings Calculations Methodology

The money savings calculations consist of summing all the energy savings up for each park and then multiply each of them by the sale price per MWh according to the corresponding ascribed regulation.

This process can be seen in detail in *Fig. 15.*

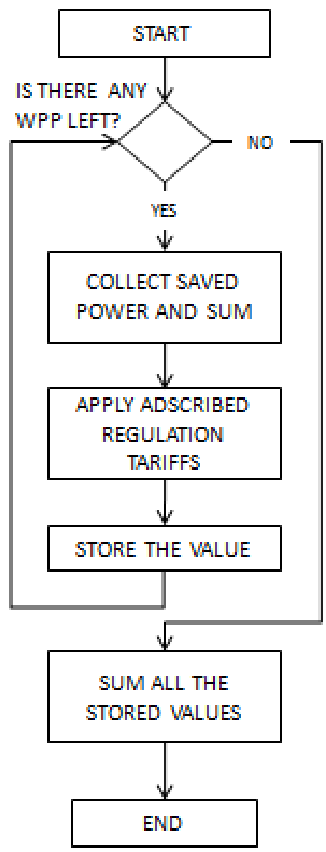

Fig. 15. Money Savings Calculation Methodology

6. Economic Analysis

6.1. Methodology and initial considerations

The methodology used for the design of the Economic Analysis is straight forward. It starts from some macro assumptions, related to macro parameters as growth rate, VAT, corporate taxes and interest rates. Some project data are also required, such as starting date, investments needed (CAPEX), operational expenditures (OPEX) and energy prices.

It will be considered that all the investments are made at two different milestones, one at the start of the project (50%) and the other at the start of operation (50%).

The lifetime of the WPP projects is usually 20 years. The first 5 years they are under guarantee coverage and they are remotely operated by the vendors with their own SCADA systems. After the 5th year, WPPs would start being operated by EDPR, so the lifetime of the SCADA project is 15 years. The number of years for depreciation and amortization of the assets will be also 15.

Although not all the WPPs of the company have the same commercial operation date (COD), it will be considered so, in order to evaluate the profitability as a whole.

It will be calculated the EBITDA (Earnings Before Interests, Taxes, Depreciation and Amortization) and subtracting D&A, EBIT. Taking in account the change in the working capital, the free cash flow (FCF) will be obtained.

Starting with the previously calculated data, NPV, IRR and payback will be obtained as a final result, so that it can be discussed whether it is a good investment or not. The part of the enterprise operating the SCADA system will also be valuated.

6.2. Macro assumptions

Macro assumptions are showed in *Table 5* below. It was chosen as growth rate and inflation rate the average of the increase of the IPC (Ìndice de Precios Consumo) of Spain for the last 10 years. The data point was extracted from Spanish Institution INE (Instituto Nacional de Estadística). The rest of the data are corporate data (working capital) or country data (taxes). The real interest rate is the nominal interest rate without the effect of inflation.

Growth Rate (g)	%	2,76%
Corporate Tax	%	30,0%
VAT	%	21,0%
Inflation Rate	%	2,76%
Nominal interest Rate	%	5,5%
Real interest Rate	%	2,7%
Working Capital		
Receivables	days	45
Payables	days	30

Table 5. Macro assumptions

6.3. Capital Expenditures (CAPEX)

Capital expenditures (CAPEX) are expenditures creating future benefits. A capital expenditure is incurred when a business spends money either to buy fixed assets or to add to the value of an existing fixed asset with a useful life extending beyond the taxable year. In the analysed case, all the necessary equipment is considered CAPEX, according to *Table 6* below (base year 2013).

CONCEPT	**UNITS**	**VALUE**
Oviedo Dispatch Centre	'000€	291,0
Installation in WPPs	'000€	681,0
TOTAL ASSETS	**'000€**	**972,1**

Table 6. CAPEX (assets)

The balance of plant (BOP) consists of all the assets and services that are not included in the primary system itself, but are necessary in order to install and operate the system. In this case, for example, wiring, connections between control centre and WTGs or software licenses (*Table 7*).

CONCEPT	UNITS	VALUE
Dispatch software lic.	'000€	988,1
WPP software license	'000€	832,2
Connection WPP/DC	'000€	551,0
Other expenses	'000€	561,3
TOTAL BOP	**'000€**	**2932,6**

Table 7. CAPEX (BOP)

The payments are set to be done in two milestones: at the start of the project (50%) and after the provisional acceptance (50%) that is planned to be in early 2014 (*Table 8*). It has to be taken in account that at the moment of the payments, VAT has to be paid, but it is reimbursed by the government the year after, due to the fact that enterprises are only affected by corporate taxes.

Year		2013	2014	2015	2016
Capex Milestones		50%	50%	0%	0%
WTG	'000€	486	499	0	0
BOP	'000€	1.466	1.507	0	0
Total Capex exVAT	**'000€**	**1.952**	**2.006**	**0**	**0**
VAT	'000€	410	421	0	0
VAT Reimbursement	'000€	0	-410	-421	0
Total Capex incl VAT	**'000€**	**2.362**	**2.018**	**-421**	**0**

Table 8. Total CAPEX, including VAT reimbursement

6.4. Operational Expenditures (OPEX)

An operating expense or operating expenditure (OPEX) is an ongoing cost for running a product, business, or system. In this case, staff and maintenance costs are considered for the analysed project, according to the subsections below.

6.4.1. Staff costs

It would be necessary to hire a total of 8 extra shift operators in order to work at the remote operations centre 24h/day. It is considered a mean gross salary of 40.000 €/year (including assurance), updated according to inflation.

It will also be considered a control centre responsible, with a cost of 60.000 €/year (including assurance), three support engineers with a cost of 30.000 €/year and three part time internship students (estimated yearly cost 5500 € each).

The total staff costs would be 486.500 €/year.

6.4.2. Maintenance

The scope of the services is showed in *Table 3*. It includes preventive and corrective maintenance, emergency support onsite, access to experts, and engineering support. The budget for maintenance is showed in *Table 10*.

Item	Description	Total
Preventive Maintenance	As per Preventive Maintenance Activities Chapter	NA
Corrective Maintenance	2 man days onsite per Dispatch Center (includes Performance Management component located at Dispatch Center Site)	6 man days / year
	Man days per remote access for the WPPs	60 man days / year
Emergency support onsite	2 man days onsite per Dispatch Center (includes Performance Management component located at Dispatch Center Site)	6 man days / year
Access to experts	Consultancy for complex diagnoses	5 man days / year
Engineering support	For Evolutive maintenance	160 man days / year

Table 9. Scope of the services

Support and Maintenance Fees	142.500 €
Remote Infrastructure Management	106.176 €
Engineering Support	38.400 €
Dispatch centre Monitoring	45.838 €
WPPs Monitoring	53.490 €
TOTAL	**386.403 €**

Table 10. Yearly Maintenance Budget

6.4.3. Total OPEX

The total OPEX is the sum of the staff costs and the maintenance. These costs can be seen over the lifetime of the WPP in *Table 11* below.

Year		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
SMA	'000€	386,4	397,1	408,0	419,3	430,9	442,8	455,0	467,5	480,4
Staff	'000€	486,5	499,9	513,7	527,9	542,5	557,4	572,8	588,6	604,9
Total Opex	**'000€**	**872,9**	**897,0**	**921,8**	**947,2**	**973,3**	**1000,2**	**1027,8**	**1056,2**	**1085,3**

Year		**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
SMA	'000€	493,7	507,3	521,3	535,7	550,5	565,7	581,3		
Staff	'000€	621,6	638,7	656,4	674,5	693,1	712,2	731,9		
Total Opex	**'000€**	**1115,3**	**1146,1**	**1177,7**	**1210,2**	**1243,6**	**1277,9**	**1313,2**		

Table 11. Total OPEX

6.5. Depreciation and amortization (D&A)

Most assets lose value over the years when they are used, and it has to be reflected in the company accounting. In fact, depreciation and amortization can also be used when calculating the profitability of a project, and it is advantageous because it reduces the amount of taxes to be paid. The period of amortization usually is the expected lifetime of the asset, but there is some flexibility for the enterprises to choose the time. The most usual period chosen for WPP assets is 15 years. In this case, it was chosen linear amortization over that period, as seen in *Table 12*.

Year		2013	2014	2015	2016	2017	2018	2019	2020	2021
2013 Capex D&A	'000€	0	130,2	130,2	130,2	130,2	130,2	130,2	130,2	130,2
2014 Capex D&A	'000€	0		133,7	133,7	133,7	133,7	133,7	133,7	133,7
Total D&A	**'000€**	**0**	**130,2**	**263,9**	**263,9**	**263,9**	**263,9**	**263,9**	**263,9**	**263,9**

Year		2022	2023	2024	2025	2026	2027	2028	2029	2030
2013 Capex D&A	'000€	130,2	130,2	130,2	130,2	130,2	130,2	130,2	0	0
2014 Capex D&A	'000€	133,7	133,7	133,7	133,7	133,7	133,7	133,7	133,7	0
Total D&A	'000€	**263,9**	**263,9**	**263,9**	**263,9**	**263,9**	**263,9**	**263,9**	**133,7**	**0**

Table 12. CAPEX Depreciation and Amortization

6.6. Recurring revenues

6.6.1. Increase in the production

Energy savings are estimated using the energy savings tool with data from the last year WTG stops and considering that the problems were solved in an average time of 15 minutes. Energy savings are considered to be constant along the lifetime of the WPP.

Data can be seen in *Table 13* below.

	January	February	March	April	May	June	July
Total prod. Spain (MWh)	421.524	553.870	457.430	588.596	435.407	463.749	370.517
Reset estimated prod. WTGs (MWh)	4737	5966	790	2561	898	2467	1695

	August	September	October	November	December		Total
Total prod. Spain (MWh)	381.581	457.575	367.214	515.191	582.596		5.595.255
Reset estimated prod. WTGs (MWh)	2.115	1.813	2.132	2.253	4.127		31.553

Table 13. Monthly and total energy savings estimation

These energy savings are translated to monetary savings when they are multiplied by the corresponding regulated tariff (€/MWh), according to Spanish Royal Decree 661/2007 (81.27 €/MWh). This tariff will be updated yearly according to inflation rates. Taking 2013 as base year, yearly income would be 8.436.900 €. In *Table 14* it can be seen the evolution of the revenues derived from the remote control over the lifetime of the WPP. It has to be remarked that the first and the last year are affected to the number of months of operation. It has also to be said that energy prices are increased yearly according to inflation.

Year		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Production	MWh	31.553	31.553	31.553	31.553	31.553	31.553	31.553	31.553	31.553
Production %	%	8,3%	100%	100%	100%	100%	100%	100%	100%	100%
Adjusted Prod.	MWh	2.629	31.553	31.553	31.553	31.553	31.553	31.553	31.553	31.553
Energy Prices	€/MWh	81,3	83,4	85,7	87,9	90,3	92,7	95,2	97,7	100,3
Revenues	'000€	213,7	2.632,7	2.702,9	2.775,0	2.849,0	2.924,9	3.002,9	3.083,0	3.165,2
Year		**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**		
Production	MWh	31.553	31.553	31.553	31.553	31.553	31.553	31.553		
Production %	%	100%	100%	100%	100%	100%	100%	92%		
Adjusted Prod.	MWh	31.553	31.553	31.553	31.553	31.553	31.553	28.924		
Energy Prices	€/MWh	103,0	105,7	108,6	111,4	114,4	117,5	120,6		
Revenues	'000€	3.249,6	3.336,2	3.425,2	3.516,5	3.610,3	3.706,5	3.488,3		

Table 14. Yearly revenues

6.7. Results of the Economic Analysis

6.7.1. EBITDA and EBIT

According to energy savings derived from the use of the remote control SCADA system, a yearly cash flow is generated. Subtracting the OPEX from the Revenues, EBITDA (Earnings Before Interests, Taxes, Depreciation and Amortization) is obtained, and subtracting D&A, EBIT (Earnings Before Interests and Taxes) is obtained. The yearly quantities can be seen in *Table15*.

Year		2013	2014	2015	2016	2017	2018	2019	2020	2021
Revenues	'000€	213,7	2.632,7	2.702,9	2.775,0	2.849,0	2.924,9	3.002,9	3.083,0	3.165,2
Total Opex	'000€	-72,7	-897,0	-921,8	-947,2	-973,3	-1000,2	-1027,8	-1056,2	-1085,3
EBITDA	**'000€**	**141,0**	**1735,7**	**1781,1**	**1827,8**	**1875,6**	**1924,7**	**1975,1**	**2026,8**	**2079,9**
Total D&A	'000€	0,0	-130,2	-263,9	-263,9	-263,9	-263,9	-263,9	-263,9	-263,9
EBIT	**'000€**	**141,0**	**1.605,5**	**1.517,2**	**1.563,9**	**1.611,7**	**1.660,8**	**1.711,2**	**1.762,9**	**1.816,0**

Year		2022	2023	2024	2025	2026	2027	2028	2029	2030
Revenues	'000€	3.249,6	3.336,2	3.425,2	3.516,5	3.610,3	3.706,5	3.488,3		
Total Opex	'000€	-1115,3	-1146,1	-1177,7	-1210,2	-1243,6	-1277,9	-1203,8		
EBITDA	**'000€**	**2134,3**	**2190,2**	**2247,5**	**2306,3**	**2366,7**	**2428,6**	**2284,5**		
Total D&A	'000€	-263,9	-263,9	-263,9	-263,9	-263,9	-263,9	-263,9		
EBIT	**'000€**	**1.870,4**	**1.926,3**	**1.983,6**	**2.042,4**	**2.102,8**	**2.164,7**	**2.020,6**		

Table 15. EBITDA and EBIT Calculations

6.7.2. Free Cash Flow

The Free Cash Flow (FCF) is the cash flow available for distribution among all the shareholders of an organization. It’s obtained subtracting from the EBIT taxes, changes in Working Capital (WK) and Capital Expenditure, and summing up Depreciation and Amortization.

6.7.2.1. Change in the working capital

The working capital (WK) represents the difference in cash flows derived from the delays of receivables and payables. By instance, if receivables are set to be received in ‘X’ days, the following accounting year the company will receive the proportional quantity of receivables (X/365) corresponding to the year before. Similarly, if payables are set to be paid in “Y” days, the next accounting year the company will have to pay (Y/365) corresponding to the present year.

The total WK is the sum of the working capital corresponding to receivables (negative) and payables (positive).

The change in the working capital is the difference between the WK of one year and the WK of the year before.

All this quantities can be seen in *Table 16* below.

Year		2013	2014	2015	2016	2017	2018	2019	2020	2021
Receivables	'000€	-26,3	-324,6	-333,2	-342,1	-351,2	-360,6	-370,2	-380,1	-390,2
Payables	'000€	6,0	73,7	75,8	77,9	80,0	82,2	84,5	86,8	89,2
Total WK	**'000€**	**-20,4**	**-250,9**	**-257,5**	**-264,3**	**-271,2**	**-278,4**	**-285,7**	**-293,3**	**-301,0**
Change in WK	**'000€**	**-20,4**	**-230,5**	**-6,6**	**-6,8**	**-7,0**	**-7,2**	**-7,3**	**-7,5**	**-7,7**

Year		2022	2023	2024	2025	2026	2027	2028	2029	2030
Receivables	'000€	-400,6	-411,3	-422,3	-433,5	-445,1	-457,0	-430,1	0,0	
Payables	'000€	91,7	94,2	96,8	99,5	102,2	105,0	98,9	0,0	
Total WK	**'000€**	**-309,0**	**-317,1**	**-325,5**	**-334,1**	**-342,9**	**-351,9**	**-331,1**	**0,0**	
Change in WK	**'000€**	**-7,9**	**-8,2**	**-8,4**	**-8,6**	**-8,8**	**-9,0**	**20,8**	**331,1**	

Table 16. Change in the working capital (WK)

6.7.2.2. Taxes

Taxes are obtained from applying the corporate tax percentage to the EBIT. *Table 17* shows taxes along the lifetime of the project.

Year		2013	2014	2015	2016	2017	2018	2019	2020	2021
Taxes	**'000€**	-42,3	-481,7	-455,2	-469,2	-483,5	-498,2	-513,4	-528,9	-544,8

Year		2022	2023	2024	2025	2026	2027	2028	2029	2030
Taxes	**'000€**	-561,1	-577,9	-595,1	-612,7	-630,8	-649,4	-606,2		

Table 17. Taxes

6.7.2.3. Free Cash Flow and Terminal Value calculation

The FCF along the lifetime of the project can be seen in *Table 18*. The terminal value (TV) represents the value of the going concern or the residual value of the investment, according to formula (6).

$$TV_n = \frac{FCF_n \cdot (1+g)}{(WACC - g)} \qquad (6)$$

Where

TV_n	Is the Terminal Value at moment 'n'
FCF_n	Is the Free Cash Flow of year 'n'
g	Is the growth rate
WACC	Is the weighted average cost of the capital

Year		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Free Cash Flow	'000€	-2.284,0	-994,0	1.740,7	1.351,8	1.385,1	1.419,3	1.454,4	1.490,4	1.527,3
Terminal Value	'000€									
FCF +TV	**'000€**	**-2.284,0**	**-994,0**	**1.740,7**	**1.351,8**	**1.385,1**	**1.419,3**	**1.454,4**	**1.490,4**	**1.527,3**

Year		**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Free Cash Flow	'000€	1.565,2	1.604,1	1.644,1	1.685,0	1.727,0	1.770,2	1.699,1	331	
Terminal Value	'000€							45.470		
FCF +TV	**'000€**	**1.565,2**	**1.604,1**	**1.644,1**	**1.685,0**	**1.727,0**	**1.770,2**	**47.169**	**331**	

Table 18. Free Cash Flow (FCF) and Terminal Value (TV)

6.7.3. Payback

Payback period refers to the time required to recover the initial investment. It is quite useful because:

- In negotiations with bank, it gives the bank an idea of how long could it take to repay the debt in case the initial investment is fully financed

- It's a measure to compare investments: the shorter the payback, the better the investment

- It also a measure to compare industries: each industry has different needs in terms of investment; however payback is a standard way to compare them.

- It is intuitive and easy to calculate

However, it has some limitations, among them:

- It ignores time value of money (usually cash flows used are not discounted for payback calculations).

- It disregards timing of cash flows within the payback period.

- It ignores cash flows beyond payback period.

The analysed case presents a normal payback (not discounted) of **3.13 years**, as it can be seen in *Table 19* below:

Year		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Accumulated FCF	'000€	-2.284,0	-3.278,1	-1.537,4	-185,6	1.199,6	2.618,9	4.073,3	5.563,7	7.091,0
Payback	**years**	**3.13**	**years**							

Table 19. Payback

Payback period (discounted) refers to the time required to recover the initial investment, factoring in the time value of money. The discounted payback is a little higher than the normal payback*,* **3.53 years** *(Table 20).* It is calculated by applying the discount factor to the Free Cash Flow (this is, to bring the Free Cash Flow yearly quantities to the present, according to inflation). In any case, the payback is very low because the revenues are very high compared to the total expenses, so the free cash flow becomes positive very soon in time.

Year		2013	2014	2015	2016	2017	2018
Discount factor		1,00	0,94	0,89	0,84	0,79	0,75
FCF (discounted)	'000€	-2.284	-932	1.532	1.116	1.073	1.031
Accumulated FCF (discounted)	'000€	-2.284	-3.217	-1.685	-569	504	1.535
Discounted Payback	**years**	**3.53**	**years**				

Table 20. Discounted Payback

6.7.4. NPV

One of the key principles in valuation is that cash flows of different projects have to be compared at the same point in time. Bringing future cash flows to the present is called to “discount” and reflects the time value of money and the investment risk. Bringing present cash flows to the future is called to “compound” [10]. The relationship between future values (FV) and present values (PV) of a cash flow is given by equation (7).

$$PV = \frac{FV_t}{(1+r)^t} \qquad (7)$$

Where:

r is the discount rate
t is the period in time

In finance, the net present value (NPV) or net present worth (NPW) of a time series of cash flows, both incoming and outgoing, is defined as the sum of the present values (PVs) of the individual cash flows of the same entity (8).

$$NPV = \sum_{t=0} \frac{CF_t}{(1+r)^t} \qquad (8)$$

NPV is a central tool in discounted cash flow (DCF) analysis and is a standard method for using the time value of money to appraise long-term projects. Used for capital budgeting and widely used throughout economics, finance, and accounting, it measures the excess or shortfall of cash flows, in present value terms, above the cost of funds.

NPV can be described as the “difference amount” between the sums of discounted cash inflows and cash outflows. It compares the present value of money today to the present value of money in the future, taking inflation and returns into account

The rate used to discount future cash flows to the present value is a key variable of this process. A firm's weighted average cost of capital (WACC) is often used, but many people believe that it is appropriate to use higher discount rates to adjust for risk, opportunity cost, or other factors. A variable discount rate with higher rates applied to cash flows occurring further along the time span might be used to reflect the yield curve premium for long-term debt. According to company politics, in this case WACC is used for NPV calculations.

The result of the NPV calculation is **9.347.960€.** It is very high, because the yearly income of the project is so big compared with the investment needed and the expenses. In order to calculate it, it was used the free cash flow (FCF) plus the terminal value. Free cash flow represents the cash flow available for distribution among all the shareholders of the company. It takes on account the depreciation and amortization and the working capital (WK) that accounts the effect of the difference of days in payables and receivables.

6.7.5. Valuation: Discounted Cash Flow (DCF)

Discounted Cash Flow is the most accepted valuation method. It is based on the discount of Free Cash Flows generated by a project or company after tax, D&A, Capex and after working capital needs and assuming that there is no debt. It is calculated according to formula (9) below.

$$Enterprise\,Value = \sum_{i=1}^{n} \frac{FCF_i}{(1+WACC)^i} + \frac{TV_n}{(1+WACC)^n} \qquad (9)$$

Where

FCF_i	Is the FCF at year *i*
TV_n	is the Terminal Value
WACC	is the weighted average cost of capital

According to DCF valuation method, the company created with this project is worth **25.701.320 €.**

6.7.6. IRR

The internal rate of return (IRR) or economic rate of return (ERR) is a rate of return used in capital budgeting to measure and compare the profitability of investments. It is also called the discounted cash flow rate of return (DCFROR) or the rate of return (ROR). In the context of savings and loans the IRR is also called the effective interest rate. The term internal refers to the fact that its calculation does not incorporate environmental factors (e.g., the interest rate or inflation).

IRR calculations are commonly used to evaluate the desirability of investments or projects. The higher a project's IRR, the more desirable it is to undertake the project. Assuming all projects require the same amount of up-front investment, the project with the highest IRR would be considered the best and undertaken first.

The internal rate of return on an investment or project is the "annualized effective compounded return rate" or "rate of return" that makes the net present value (NPV) of all cash flows (both positive and negative) from a particular investment equal to zero. It can also be defined as the discount rate at which the present value of all future cash flow is equal to the initial investment or in other words the rate at which an investment breaks even.

In more specific terms, the IRR of an investment is the discount rate at which the net present value of costs (negative cash flows) of the investment equals the net present value of the benefits (positive cash flows) of the investment. It represents the maximum return on investment; in other words it is the discount rate at which the Net NPV equals zero (10) meaning that if IRR < r, the NPV would be negative and value would be being destroyed with that investment, therefore investment projects shall only be accepted if IRR is greater than the return demanded by investors, that is, if IRR > r.

$$0 = -\mathrm{I}_0 + \sum \mathrm{CF}_t \,/\, (1 + \mathrm{IRR})^t \qquad (10)$$

Where:

Io is the initial investment
CFt is the cash flow in year t
IRR is the internal rate of return

A firm (or individual) should, in theory, undertake all projects or investments available with IRRs that exceed the cost of capital. Investment may be limited by availability of funds to the firm and/or by the firm's capacity or ability to manage numerous projects. The resulting IRR for the selected investment is **36.54%.** It's extremely and unusually high because the investment is extremely profitable.

6.7.7. Ratios

6.7.7.1. IRR/WACC

The weighted average cost of capital (WACC) is the rate that a company is expected to pay on average to all its shareholders and banks to finance its assets.

The WACC (11) is the minimum return that a company must earn on an existing asset base to satisfy its creditors, owners, and other providers of capital, or they will invest elsewhere. Therefore, this parameter is used by the companies to see if the investment projects available to them are worthwhile to undertake. The WACC is calculated taking into account the relative weights of each component of the capital structure.

The main use of the WACC is to analyse if a project is worthwhile to undertake:

- If a project WACC > project IRR, it will cost more to finance it than the return and I will be destroying value.

- If a project WACC < project IRR, I will be creating value

$$WACC = Ke \cdot \left[\frac{E}{D+E}\right] + \left[\frac{D}{D+E}\right] \cdot Kd \cdot (1-t) \qquad (11)$$

Where:

Ke	is the cost of equity (risk free rate + beta * risk premium)
Kd	is the cost of debt (risk free rate of debt + spread)
D	is the amount of debt
E	is the equity
t	is the corporate tax rate

The risk free rate is the return of an asset with no risk. Usually the nearest thing to a zero risk asset is usually represented by the German Government Bond with a maturity of 10 years. The Beta (β) of a stock/asset is a number describing the correlated volatility in relation to the volatility of the benchmark that said asset is being compared to (for example, a correlation of publicly traded Renewable companies in Spain), and the risk premium is the spread of the return of an asset compared to the Risk Free asset.

On the other hand, the Risk Free Rate of debt represents the interest rate at which banks lend money to each other. This is usually represented by the Euribor, Libor or for longer periods Midswap 10 years. The spread represents the percentage that banks always charge over cost the debt. *Table 21* below show the assumptions used for the calculation of the WACC. Data was provided by the economic team of the company.

Cost of Equity		
Risk Free Rate	%	1,8%
Beta		1,05
Risk Premium	%	6,5%
Total		**8,63%**
Cost of Debt		
Risk Free cost of debt	%	2,0%
Spread	%	5,5%
Total		**5,25%**
Leverage		
Equity	%	40,0%
Debt	%	60,0%
WACC	**%**	**6,60%**

Table 21. WACC calculation

In the case of this project, the ratio IRR/WACC is equal to 5.54. It's extremely high (it is normally between 1 and 2) because the project is extremely worth. It has to be taken into account that the total investment is less than 4 million Euros and the yearly revenues are more than 2.5 million Euros, during 15 years.

7. Conclusions

SCADA systems allow the remote operation of energy facilities such as wind power plants. In fact, most wind turbine vendors have designed and developed their own SCADA system in order to perform the control of their machines. Vendors assume the remote operation of wind power plants up to 5 years, but afterwards, the responsibility of the correct performance of the devices lies with the owner of the WTG. At that time, and if the company manages several WTG vendors, it is convenient to implement their own unified SCADA system in order to save money in terms of simplicity, time savings and increase of hours of operation.

In order to achieve this goal, there are several previous tasks to be done. Firstly, the scope has to be set and the functional and technical specifications defined. According to these issues, the necessary devices have to be selected. In addition to this, signals from different vendors have to be standardized in order to interconnect and operate every technology from a single SCADA HMI.

Having all this works valued and all necessary devices and installations budgeted, an economic analysis can be performed in order to evaluate profitability. But it is still very important to estimate the energy savings derived from the implementation of the new system. In this context, it is necessary to access the available historical WTG performance data from the company.

Once performed, it can be seen that remote operation of wind power plants is not only convenient but necessary. The profitability, in terms of percentage, is very high, much higher than the WPP projects themselves. It generates value for the company and increases the whole project profitability, affecting all the facilities involved. It generates very high yearly revenues compared to the investment that is relatively low and affordable for the company.

Maintenance and operation expenses, although high, get widely compensated by the increase in the production, and therefore by the increase in the energy revenues.

It can be concluded that remote 24h/day operation of WPPs with a unified SCADA system is very advantageous compared with on-site operation by WPP staff, subjected to displacements, timetables and deep knowledge of technologies.

Although the results have been favourable, it has to be pointed out some limitations. This project has considered that every WPP had the same commercial operation date, in order to simplify the economic calculations. The results represent the profitability for the whole set of WPPs in Spain, but it can't be disregarded in single facilities.

It has also to be said that the calculations start from some macro assumptions that can't be assured, especially in the present economic situation, in which some of this parameters could change soon (growth rate, corporate tax, VAT, etc.).

Other issue that has to be mentioned is that for energy savings calculation, it was used only one year data, and considered as representative. Ideally, it would be necessary to get more years data in order to get the mean values of yearly energy savings, but it wasn't possible at the date of the end of the external master thesis.

8. Future developments

8.1. Extension of the project

This pilot project covers the company's facilities in Spain, but the company has wind power plants in other European countries, Brazil and North America. One possible future development is to extend the project to these areas, being then able to calculate the economic savings derived from using a remote operation tool in order to control and operate WPPs.

Other possible future development is to add to the SCADA system also photovoltaic facilities and electrical substations. The standard for substations is the IEC 61850.

8.2. Link the WTG reset data to automated database

The next step could be linking the designed tools to the PI database. PI is a database centralization system that registers all signals and measurements providing from the SCADA system, including WTGs reset data (number of WTGs reset, date and time).

Linking the tools to the database would save some work to the dispatch centre operators, because at the present time they have to introduce this data manually when they perform a WTG reset.

It couldn't be done at the date of the end of the period because, according to the company policies, it should be assigned some permission in order to manage the aforementioned database.

8.3. Auto-import data to the analysis tools

Data is manually copied from the reset file and the secondary concentrator to the analysis tools. But in fact, it could be automatically imported.

In the future, this data will be available in the PI database, so that it will be available for using it in the designed tools.

9. Quality report

First of all, I'd like to thank EDPR Dispatch Centre and Technical Support staff for their kind support during the development of this master thesis. They were always available to solve any doubts that could come up, and always eager to help to the extent of their possibilities. Nevertheless, some data was very difficult or couldn't be got as it was affected by confidentiality company policies. This issue will be very difficult to be solved in next years, because even the company staff has sometimes difficulties to have the permissions granted to access some specific folders or to have some software programs installed.

Also, I would like to point out that, at the time of the practices at the external institution they didn't have any needs for extra staff and consequently, they didn't have any specific projects to be developed. Some meetings with the advisor were needed in order to negotiate and fix the scope of the external master thesis, and because of availability issues, the start of the thesis was delayed in time. The fact that they didn't need staff did also affect my performance in the external institution, because I couldn't contribute -as much as I would have liked to- with the specific knowledge acquired during the Master, and I couldn't even demonstrate my ability to learn and perform a good work. This issue could be solved in following years by the coordination of the Master, assuring that the external institution has a real need of extra staff.

10. Bibliography and references

[1] Zhe Chen, Josep M. Guerrero, Frede Blaabjerg, *"A Review of the State of the Art of Power Electronics for Wind Turbines", IEEE Transactions On Power Electronics, Vol. 24, No. 8, August 2009 pp. 1859 1874*

[2] Global Wind Energy Council (GWEC), *"Global Wind Energy Outlook 2012"*

[3] Red Eléctrica Española (REE) – Elaboración gráfica por Wikipedia

[4] J. Jonkman, S. Butterfield, W. Musial, and G. Scott, *"Definition of a 5-MW Reference Wind Turbine for Offshore System Development", National Renewable Energy Laboratory (NREL), 2009*

[5] Hau, E. *"Wind Turbines, Fundamentals, Technologies, Application, Economics", 2nd ed.; Springer: Berlin, Germany, 2006*

[6] Peter J. Schubel, Richard J. Crossley *"Review: Wind Turbine Blade Design", MDPI Energies Journal 2012, 5, pp. 3425-3449*

[7] Otín Marcos, A., *"SCADA basado en labview para el laboratorio de control de ICAI", Universidad Pontificia de Comillas*

[8] EDP Renewables, *"Learning series: Wind Turbine SCADA systems",* 2011

[9] Ministerio de Industria, Energía y Turismo, 2013

[10] Apraiz, G. *"Economic and market analysis",* Master EECPS, 2013

ANNEXES

ANNEX I: Tasks developed in the Host Institution

I. EDP Renewables

EDP Renewables (EDPR) is a renewable energy company that designs, develops, manages and operates power plants using renewable energy sources.

The company is the third generator of wind energy globally. EDPR's business includes wind power and solar power, and operates in Europe, Brazil and the United States, having more than 10GW of wind power capacity installed in more than 270 wind power plants. Its portfolio of WTGs is currently composed of 11 different Original Equipment Manufacturers (OEM), but most of the utilities use Vestas, Gamesa, GE, Enercon Suzlon or Acciona WTGs (Fig. 16). The company is currently working on the improvement of the remote operation and control of the existing WPP while exploring the possibilities of building new plants in other countries.

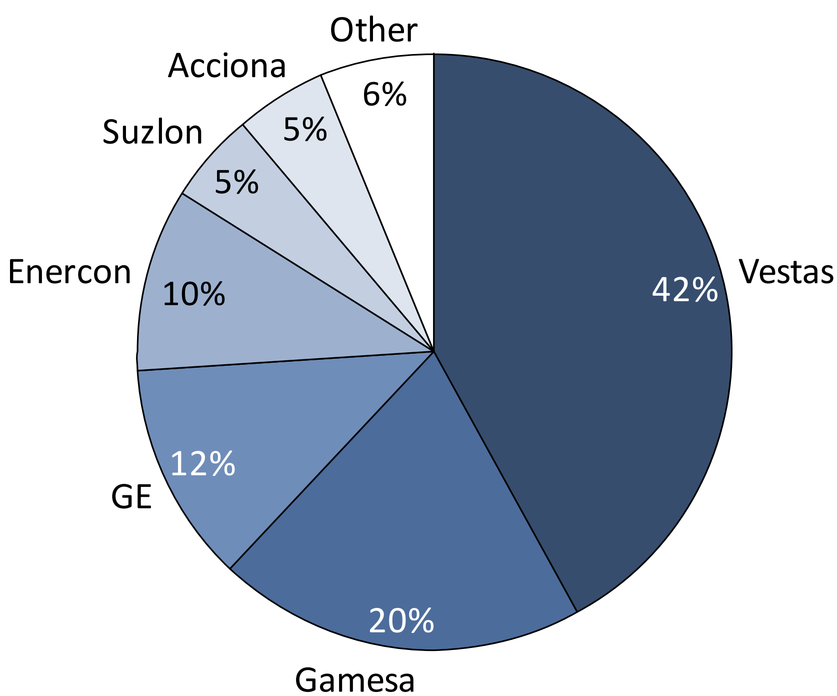

Fig. 16. EDPR's installed technology portfolio, year 2011

The company presents a hierarchical structure. In the Organizational Chart, the dispatch centre is under the Technical Area department, at the same level than Engineering and Construction and Operation and Maintenance (O&M).

The scheme can be seen in Fig. 17 below.

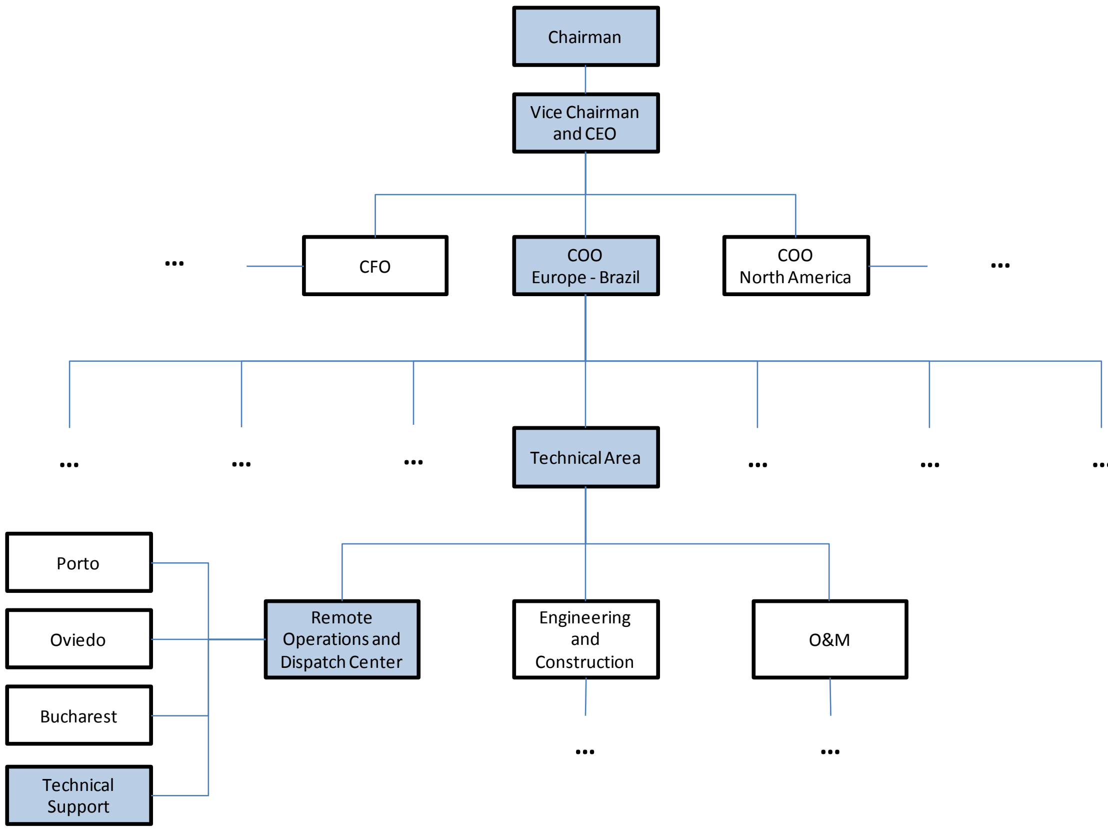

Fig. 17. Location of the Technical Support Department in EDPR's Organizational Chart

II. Remote Operations Dispatch Centre

The mission of the Remote Operations and Dispatch Centre is to contribute, in a tangible way, to increase EDPR's long-term profit earning capacity by assuring the real-time remote control, grid operations management and commercial operations coordination of the Company's wind assets worldwide, guaranteeing regulatory compliance and best practices.

Activities carried out by RODC can be grouped in three main concepts:

- **Management of Wind Assets:** Activities related with the services supplied to O&M mainly (but in general to all the technical areas of the company) for Assets Operations.

- **Grid Operations:** Activities related with the operating interface between TSOs/DSOs and EDPR regarding Grid Code Compliance of wind farms operation

- **Commercial Operations:** Activities related with information gathering and operating interface with Traders/Offtakers for commercial selling of energy.

III. Work developed

The work was developed in the Remote Operations and Dispatch Centre (RODC) sited in Oviedo, being part of the Technical Support Staff under the supervision of Sonia García.

a. Substations Data Standardization

This task consisted of standardizing substations server tags according to IEC standard, for substations in Poland, Romania, France, Belgium and Spain.

b. Substations Main Status Signals Selection

Each substation should have its corresponding status led, that indicates if it is working correctly, it is totally or partially down, or there are any communication failures. This leds are linked to the activation of some specific alarms and trips that have to be selected for each substation.

c. WTGs Data Standardization

This task consisted of standardizing WTGs server tags according to IEC standard.

d. Substation Display Standardization

This task consisted of detecting mistakes and correcting substation displays, according to the single line diagrams available.

e. VBA Macro programming support

In this company, some office routines are automated with VBA macros. Some of this macros needed to be programmed according to the needs of the companies, and other needed to be optimized.

ANNEX 2. External Master Thesis Evaluation Form