Doctoral Thesis

OPERATIONAL EXPENDITURES MODEL FOR RENEWABLE PLANT

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ABSTRACT

In this dissertation, system identification methods are applied to characterize the dynamic components behavior of a renewable plant (Hydro – Solar – Wind-Geothermal). First, the relevant factors that are explicative of our models are extracted, to after use Markov Chain and Monte-Carlo simulations to get the more suitable algorithm-based models to optimize the operation cost (or other operative parameters) along the life span of the plant (even under the life time extension mode) we set up the Lost Production Factor (LPF) as an output,. This model will help to better operate the plants by using diagnostics-prognostics, condition monitoring, forecast and predictions, and control design (design to cost). It will help choose the best technologies for the plants and operate the already existing ones in the most profitable way. The application examples are motivated by real-world engineering challenges with renewable Plants under one of the large utilities in the world. The ISO 55000 series Standards are used as a guide, in order to be able to get the proper certification if needed in the future.

Firstly, a method is proposed to identify the relevant parameters and KPI´s (Key Performance Index) that better represent the plant's behavior, taking the IEC 61400 series as reference. Under this calculation, the most explicative variables are defined, to afterwards develop the model (X's), by defining our two key Y's, which are the LPF . This optimization function will let us take the best decisions related OPEX (Operative Expenditures) costs and previously to develop the Plant to better choose technology and invest in the best way CAPEX (Capital Expenditures), MTBF (Medium Time between Failures) and the LCoE (Leverage Cost of Energy among other variables.

These Algorithm-based Models will be built for each subsystem, to predict the model baselines in costs and outages forecasts. The conditions under the development allow using the condition base systems, the sensors, SCADA, and all the information and data coming from the different plants in the different levels (System, Turbine, Panel, Plant, Country and/or Fleet Levels).

Based on the models, several algorithms are developed to predict which activities should be performed to optimize the operations and the maintenance of each system, and when to perform them. Lastly, the thermal signature variances and its impact in relevant events in the generation units will be displayed in a fine tune analysis, using the new Nano-additive technology. Since the thermal signature (temperatures of the different systems) was proven a very high explicative variable for our models, Failure Modes Effect Analysis FMEA [IEC 60812], is the best approach to reduce the thermal impact in the Medium Time Between Failures (MTBF) and the Leverized Cost of Energy (LCoE).

Keywords: Lost Production Factor (LPF), Medium TimIe between Failures (MTBF), Medim Time between Inspections (MTBI), Medium Time to Return (MTTR), Failure Modes and Effect Analysis (FMEA), Levelized Cost of Energy (LCoE), Nano-Aditives.

RESUMEN

En esta disertación se aplican sistemas de identificación para caracterizar el comportamiento dinámico de los componentes y subcomponentes en las plantas renovables (Hidráulicas, Solares, Eólicas, Geotérmicas). Primero se definen cuáles son los factores que son explicativos de nuestro modelo, de entre la lista de señales que se reciben a través del sistema de adquisición de datos. Con estos resultados se construye un modelo para predecir el factor de perdida de producción (LPF) realizando un modelo estadístico basado en las cadenas de Markov y simulaciones de Montecarlo. Con ello pretendemos explicar el comportamiento de las plantas de generación de energía que tenemos como objetivo a lo largo de su vida útil. Se utilizar los principios descritos en la ISO 55.000 de gestión de activos, para confirmar que el modelo que se propone cumple con esta norma. Primeramente, se identifican los parámetros clave de comportamiento (KPI), de los activos renovables, vamos a usar la norma IEC 61400 con todos sus epígrafes, que está enfocada en las turbinas eólicas, y ver su grado de similitud con el resto de energías. Bajo estas premisas, se fija nuestra variable salida LPF, y se confirma la influencia de otros factores como el tiempo medio entre fallos (MTBF) el tiempo medio entre inspecciones (MTBI) y el tiempo medio de retorno (MTTR) así como su influencia en el coste medio operacional del activo. (LCoE).

Este modelo basado en algoritmos se ha construido para cada sistema y componente de las tecnologías de generación renovable objeto de este estudio, dado que hemos visto que la firma térmica es una variable muy explicativa de los modos de fallo. Se usan las señales que se reciben del sistema de adquisición de datos SCADA, y se desarrollan las predicciones y diagnósticos basados en toda esa información aplicando la IEC 60812 que define los modos de fallo y el análisis de sus efectos, (FMEA), para planificar las actividades de operación y mantenimiento en las cuatro tecnologías renovables objeto del alcance de esta disertación a lo largo de su vida útil.

Palabras Clave: Factor de pérdida de producción (LPF), tiempo medio entre fallos (MTBF), iempo medio entre inspecciones (MTBI), tiempo medio de retorno (MTTR), analisis y efectos de modos de fallo (FMEA), coste medio de la energía (LCoE), Nano-Aditives.

RESUMO

Nesta disertación aplicáronse sistemas de identificación para caracterizar o comportamento dinámico dos compoñentes e sub compoñentes nas plantas renovables que foron incluídas no alcance (Eólicas, Xeotérmicas, Hidráulicas, Solares). Primeiro definíronse cales son os factores que son explicativos do noso modelo, entre a lista de sinais que se reciben a traveso o sistema de adquisición de dados. Con estes resultados, construiremos un modelo, para predicir o factor de perda de produción (LPF), realizando un modelo estatístico baseado nas cadeas de Markov e nas simulacións de Monte Carlo. Con isto pretendeuse explicar o comportamento das plantas de xeración de enerxía o longo da vida útil da instalación. Introducíronse os principios descritos na norma ISO 55.000, de Xestión de activos, e confirmouse que o noso modelo cumpre con esta nova normativa. Primeiramente identificáronse os parámetros chave de comportamento dos activos (KPI), usáronse a serie de normas IEC 61400, que está enfocada nas turbinas eólicas e veuse o seu grado de similitude co resto das enerxías. Baixo estas premisas, fixamos a nosa variable de saída LPF, e confirmamos a influencia dos factores mais importantes, tempo medio entre fallos (MTBF), tempo medio entre inspeccións (MTBI) e o tempo medio de retorno (MTTR). Así como a súa influencia no coste medio operacional do activo, ou coste medio da enerxía. Este modelo baseouse en algoritmos, e construíuse para cada sistema e compoñente das tecnoloxías de xeración renovable obxecto deste estudio. Probouse que a firma térmica e unha variable moi explicativa dos modos de fallo polo que usáronse as sinais que se recibían no sistema de adquisición de datos SCADA, e desenvolvéronse as predicións e diagnósticos baseados en toda a información, aplicouse a IEC 60812, que nos define os modos de fallo e a análises dos seus efectos (FMEA), para ser capaces de planificar as actividades de operación e mantemento das catro tecnoloxías obxecto do alcance desta disertación o longo da súa vida útil.

Palabras Chave: Factor de perda de producción (LPF), tempo medio entre fallos (MTBF), tempo medio entre inspecions (MTBI), tempo medio de retorno (MTTR), analisis e efectos de modos de fallo (FMEA), coste medio da enerxía (LCoE), Nano-Aditivos.

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List of patents and publications related with this thesis

Patents

Alba Perez J., Anselmi A., Asensio Marquez J., Ayra V., Cabrera Escribano E., Garcia Lopez F., Governanti A., La Pegna L., Lopez Zubiri I., Moset Hernandez, A., Onofrj, F.; Paoli, S.; Sideris, G.; Vidal Rodriguez, J. Argenio F.
Método per la definizione e pianificacione parametrizzata di interventi di manutenzione Sistema di gestione manutenzione / M30P (Italy, 102017000129875)
Societa Italiana Brevetti accepted January, 30, 2020. https://www.sib.it/en/

Submitted to EPO
Josefa Fernández Pérez, Luis Miguel Varela Cabo, Fran García López, Mónica González Gómez *Renewable Assets Management System*
Invention Disclosure Letter for European Patent Office

Publications

Hubbard P. G., Xu J., Zhang S., Dejong M., Luo L., Soga K., Papa C., Zulberti C., Malara D., Fugazzotto F., Garcia Lopez, F., Minto C. *Dynamic structural health monitoring of a model wind turbine tower using distributed acoustic sensing* (DAS), Journal of Civil Structural Health Monitoring 11, 833–849 (2021)

García F., Argenio F., Asensio J., Varela, L. M. Lugo L., Fernández J. Analysis of the *Thermal Signature of Wind-turbine Generators: implications for their main Operative Parameters and future application of nanofluids* Abstract and Oral Communication NANOUPTAKE COST ACTION (CA 15119) Working Group Meeting, Naples, Italy, 28th – 29th May 2018

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1. INTRODUCTION

Sustainable energy, green energy or renewable is energy harvested from sources and does not affect the environment, does not end and is regenerated in a short timescale. In this work we will target energy produced by hydro, wind, solar and geothermal generation plants. Power is distributed for several usages, most significantly the generation of electricity, either hot or cool air and water thermal regulation, transport, and finally remote off grid energy distribution.

Following the REN21 report [1] released in 2017, renewable energy contribution was around 20% of the world's energy consumption by humankind in 2015. However, just one year later, in 2016 the rate had risen to almost 25%. These figures reveal that we are steadily transitioning to a mix of new energy sources.

Investment in these sources worldwide is approximately 300 billion dollars, and the ramp up percentage is 5% per annum. It is very interesting to see that Asia-Pacific, accounts for 50% of this investment, mainly China, while Europe and America accounts for the rest, split evenly between the two. In regard to the amount of job creation, the figures are close to 10 million. The transition from the fossil sources to renewable ones, makes the volume and the economies of scale appear to reduce the cost of the systems making them more efficient. In 2019 up to two-thirds of the total installed capacity accounts for renewable, while the consumption in fossil sources started to be reduced for the first time in 2020.

If we look to the country levels, more than 30 nations have renewable energy in their energy mix accounting for up to 20% of the total consumption. After several United Nations protocols signed by a vast majority of members, the trend is growth until 100%. If we consider electricity, Iceland and Norway have reached 100%, and close to 50 nations account for more than 50%. The majority of these have already set a target of 100% for 2030 or 2050. With the COVID pandemic, the situation has become even more important and Big Utilities are increasing the speed to reach values for 2025 or even sooner. A complete fossil energy sources cancellation will take place in Europe before 2030 [3]. There is a crucial characteristic that makes renewables very important for the future. Basically all lands or geographical regions have the capability to produce energy with renewable resources. Meanwhile fossil fuels, are concentrated in just some countries. This situation allows every country to harvest energy from their own resources, without having to depend on others. All of these factors raise the country's security and self-reliance, as well as giving all countries the same opportunities. For some time, international surveys have been launched to understand the public's opinion on this issue, and the results greatly support renewables [3].

Due the suitability and the location of energy sources, this type of energy is valid for distributed generation, rural access as well as huge consumption or high production demand from industry or cities. Another main advantage is the different generation options. This means, for example, that if heat is needed, you don't need to transfer it to electricity, making renewables scalable and being able to generate power discretely to later distribute anywhere [4].

Growth in renewable energy, and the developments in sustainability and efficiency deployed in the energy sector, becomes a key driver in security, easy access and economic benefits, together with less investment to get the same results. Reducing the carbon print, increasing sustainability and reducing investments have other subsequent outputs that are pollution and climate change reduction, which lead to improving the health of humankind.

Contamination hugely impacts people's health in some countries on people's health, and the cost of medical attention could be reduced if pollution is cut.

The change in climate conditions as well as global warming makes people more and more concerned as regards the way energy is generated. The growth, volume and economy of scale helps with economic and financial parameters making renewable energy more competitive than other forms. In 2019 a note was submitted from the International Renewable Energy Agency saying that renewable energy use will need to grow by a factor of six to reduce the world's average temperature.

1.1 THESIS MOTIVATION

In 2014 the ISO 55000 standard series was released, becoming an important way to understand how we should manage assets. It is vital due to changes in economic rules. It is important to fix the criteria to report the financial figures, item value, etc. in order to make the accounts among regions, countries or poles exchangeable. The importance of renewable energy assets and their location makes the way in which we manage the plants very relevant for several reasons. In the majority of the countries these are classified as public utility assets, so they should follow some rules, and due to strategic interest, should be grand the free information in order to be able the financial purchase among companies or shareholders and grant the asset knowledge for the stakeholders.

Due to the H2020 and H2050 [4], the importance of the renewable energy assets became greater, and a white book was established to fulfill the Kyoto Protocol and other targets. This situation increased the interest showed by companies or holdings to enter the Energy business. These factors make the way to manage assets and information that should be provided very important. Some of the crucial points are the LCoE, Leverage Cost of Energy, CAPEX, Capital Expenditures and OPEX, Operational Expenditures [5]. The Public utility classification makes the cost of the renewable energy enter the price list index. The challenge is to optimize the cost in order to remove any uncertainty of price creation. Big Utilities like Enel Green Power, due to the migration from fossil to green energy, and internalization, make the optimization of the cost very important so as to put competitive prices in the international markets.

Due to this high importance in the energy mix, and after seeing that in renewable energy, the resource is not fixed, it becomes crucial to be able to plan and have Generation Units (GU) available. The assets only have 30% of activities planned and 70% unplanned. This situation makes it a challenge to reduce cost, unless we create the proper tool to convert this 30/70 into 90/10. The target is to prove that the Loss Production Factor is a valid output in which we can act. And study which variables we can gather are explicative of the LPF along with the relations among them in order to optimize the lost production factor.

The fundamentals of Renewable Energy plant management and the supporting system when integrated in the governance and risk frame of the working process of the Operator, will contribute with tangible benefits and leverage opportunities, as renewable asset management will translate the objectives of the organization into asset related decisions, plans and activities, using an approach based on risk. Renewable asset management enables the operator to realize the value from assets in the achievement of its organizational objectives while balancing financial, environmental and social costs, risk, quality of service and performance related to assets, in compliance with IEC-IEEE-IFRS-ISO standards.

The benefits of renewable asset management include, but are not limited to the following:

a) **Improved financial performance:** by established and operational expenditures baseline with the main factors and due to that we will include an algorithm in the system that will compare the baseline for each Renewable plant (with the KPI´s of each) with the actuals and the forecasted operational expenditures. In order to cover the gap and optimize in each condition the operational expenditures trend to maximize the benefits in the long term.

b) **Informed asset investment decisions**: enabling the organization to improve the decisions related to costs, risks, opportunities and performance in a collaborative way; to better make decisions to buy or develop Renewable assets in regions, poles or countries. Using the best in class approach to get the first market position to be the chooser.
c) **Managed risk:** reducing financial losses, improving health and safety, good will and reputation, minimizing environmental and social impact, can result in reduced liabilities such as insurance premiums, fines and penalties, due to the nature of the assets, the **Community Shared Value (CSV**) becomes even more important than other types.
d) **Improved operations and outputs:** assuring the performance of renewable assets can lead to improved service operations or products that consistently meet or exceed the expectations for the shareholders and stakeholders.
e) **Demonstrated social responsibility**: improving the organization's ability to fulfill ISO 26000 will help to have a non-paid market position within socially responsible and ethical business practices and stewardship that will allow the brand to enter high-regulated regions, pole or countries.
f) **Demonstrated compliance**: transparently conforming with legal, statutory and regulatory requirements, as well as adhering to renewable asset management standards, policies and processes, can enable demonstration of compliance, and as in the previous one it is possible to use the brand to enter some high regulated market environments.
g) **Enhanced reputation:** through improved stakeholder, shareholder satisfaction, stakeholder awareness and confidence;
h) **Improved organizational sustainability:** effectively managing short and long-term effects, expenditures and performance, can improve the sustainability of operations and the Operator;
i) **Improved efficiency and effectiveness**: reviewing and improving processes, procedures and asset performance can improve efficiency and effectiveness, and the achievement of organizational objectives.

A Renewable Energy asset is any plant that has technological components and subcomponents that transform a type of energy (wind, sun, water, geothermal, biomass) into electrical energy, which can be transported and used by end customers. The main difference with other types of assets is that it produces clean energy, so it is also used to fulfil regulations such as H2020, or energy mix limitations. After some years of ramping up in construction, and since the current portfolio is vast and has big commitments with European directives and world contest protocols due to climate change constrictions, it is time to put the spotlight on how those assets are managed and which is the best way to give certainty in regards to time, output and operative expenditures. With this management, the intention is to go out of short-term strategies to fix risk assessments, described in the ISO 31000 and to put long term strategies in place, looking to switch the energy mix and convert it mainly to pure renewable.

1.2. TYPES OF RENEWABLE ENERGY AND STATE OF THE ART

Renewable energy has three main uses (figure 1.1):

- **Power generation:**

  The renewable energy forecast for the next years shows that it will surpass fossil sources before 2040. These projections will be even higher due to the COVID 2020 pandemic [4], some countries set up stretched targets that make the already signed protocols softer than the real projections. Due to the flexibility in the generation, hybrid systems are used, combining wind and solar with battery storage, or other sources to balance the energy demand with production. For example, Iceland or Norway are 100% renewable, and some countries have already passed the 50% barrier.

- **Heating:**

  The use of solar sources for water heating contribute to renewable heat in many countries, China has close to 70% of the global total (180 GWth). A large portion of these devices are installed on buildings and make a huge contribution to avoid consumption. Close to 60 million houses have this system in that country. Worldwide, the figures are close to 70 million houses. It is used as well as biomass, and its consumption is growing, but is more country specific, like Sweden, which has passed oil and gas consumption. Direct geothermal use for heating is also growing but like biomass, it is very country specific. The newest addition to heating is from Geothermal Heat Pumps which provide both heating and cooling, and also flatten the electric demand curve and are thus an increasing national priority [4].

- **Transportation:**

  The use of bioethanol derived from plant fermentation of cellulosic biomass, derived from trees and grasses and now the renewable generation of hydrogen can also be used for transportation. Developing ethanol to burn in combustion engines, using hydrogen to mix with the actual fossil combustibles and in the fuel cells. A fuel like ethanol may be used in automation directly. Due to engine configuration, its common usage is as an additive to reduce emissions and increase octane grade.

  In the United States and in Brazil bioethanol was deployed due to its specific characteristics and Otto cycle engines were the major use for this kind of fuel. Similarly, Biodiesel is also used in two ways, directly to the engine, but it needs some kind of adaptation, and mixed or added to regular diesel in order to reduce emissions and the level of particle concentration that are toxic in the regular diesel cycle engines. This kind of fuel or additive depends on the usage and is created from fat or oil via a process that changes the organic group ester for an organic group alcohol, called transesterification. In Europe biodiesel is widely used.

  Solar energy could be used to power cells, which could be photovoltaic (PV). These cells that are located in panels convert the energy from the sun into electric energy. A solar vehicle implies the usage of this kind of energy to run all or part of the propulsion. It could also be used to power control boxes, communication or any auxiliary device. It is not deployed in the earth in a practical way, but the majority of the vehicles that are sent to other satellites or planets are moved by this type of energy. This kind of energy and technology is already commercial in boats.

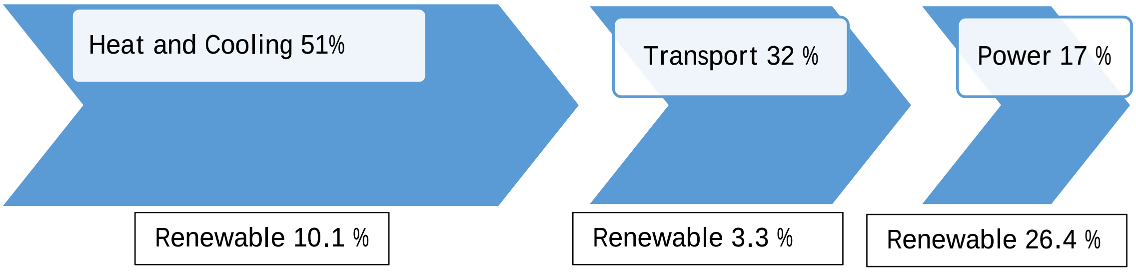


Figure 1.1. Usage of renewable energy per type of use in 2018 [5].

There are four main renewable sources that we use for energy production. We will also describe a fifth due to it becoming more widely known in the future. However, in this work we will focus on the principal four renewable sources.

Wind Power. In 2019, the worldwide installed capacity was up to 600 GW. The power range in the installed turbines moves from 600 KW to 15MW. Due to the Betz law the power that can be extracted from wind could be represented with a formula of the cube of wind speed, so as the speed increased the energy that could be extracted or the power that it is possible to reach increases to a limit that can be captured due to the load of the machinery. One important factor is turbulence intensity, so areas where the wind is stronger but has less turbulence due to the roughness factor, like offshore or high-altitude sites, could be more interesting for the installation of plants. The density and the temperature need to be taken into account to choose the sites correctly. It is typical to measure the plants with the percentage of capacity per year, and rates from 25 % to 60 % are suitable for the units.

The generation from wind accounts for 10% of global electricity demand in 2020 close to 750 GW install capacity and close to 90GW installed last year. Wind energy is leading the renewable sources in Europe, the US and Canada, and is the second largest in China. In European countries such as Denmark, account for more than 40%. Spain, Portugal or Ireland are in the 20% range.

Worldwide, wind energy potential entitlement is in the five-time range of the current world energy production. It will be required to install the plants in large land areas or offshore. In the case of the sea, due to the high speed and less turbulence intensity of the wind, it makes the second option more suitable [4].

Hydro power. In 2019, the global capacity for this power was around 1200 GW [6]. Due to the water having close to 1000 times more density than air, the speed of the flow is not as important as in air, so minimal flow speed but with enough volume has a lot of energy. There are several ways to take power from water

- Using the power of water conduction by the construction of large dams or reservoirs, to obtain electricity from them, was in use as an energy source a long time ago and still is in some countries. Three Gorges and The Itaipú Dams are the largest examples of these.
- Small hydro systems are similar to large ones but the power is around 50 MW. In these plants the flow comes from little rivers and the impact is less than larger ones, for that reason it is more suitable for countries that have more restrictions in regard to land. The country with most installations is China with close to 50.000 hydro installations of this type [2].
- The hydraulic plants that use the river flow running to take energy from them but without using large constructions or changing the river flow. Dams or reservoirs are not needed and the water is conveyed along the riverside by the use of pipes or channels and before the flow lets water falls in a penstock to drive a turbine. This kind of system is even more suitable for very restrictive countries, due to there being minimal impact on the environment, and with enough water flow it is possible to generate large amounts of energy.

This type of technology is used in more than 150 countries; the region of highest impact is Asia-Pacific with up to 35% contribution to hydropower globally. This technology in percentage is the first renewable source in the top 50 countries that most use sustainable energy. The countries that have most power are China, Brazil and Venezuela, due to vast rivers and land restrictions [6].

Wave power is another water technology that takes the energy of ocean surface waves, and tidal power. It is under development in this moment and has a high potential [2]. Another example is Blue Energy that is the use of river mouths and sea water mixture to act as a cell by applying reverse osmosis, making it possible to extract energy through Free Gibbs Enthalpy. It is exactly the same concept as salt plants but the other way around.

Solar Power. By the end of 2020 the installed capacity worldwide was close to 600 GW [4]. The energy, heat and radiation from the Sun can be harvested by applying several technologies such as solar heating, photovoltaics (PV), concentrated solar power (CSP), concentrating photovoltaics (CPV), artificial photosynthesis and a specific way to build called solar architecture. These technologies use the intervention of the sun in a passive or active way, depending on the type and how it channels the capture of energy. The passive solar type does not activate directly, but uses the distribution and configuration of the architecture etc. for its benefit. Some examples are the materials that have thermal mass or dispersion properties for light, the design of space with natural air circulation. The active technologies that are applicable to capture sun energy, act directly to get the sun energy either by using collectors to heat or to convert the power into electricity with photovoltaic cells or using concentrated solar power.

A photovoltaic cell transforms sunlight into electrical direct current (DC) using the photoelectric effect. Solar PV is the fastest-growing type of energy and it is very intense in the industry. Some of the challenges include increasing efficiency and reducing the cost. This is the energy that has most potential in some poorer countries, and is the most suitable together with battery storage to manage the domestic consumptions in remote areas. It has the most entitlement with regard to the energy mix in comparison with the rest of renewables. Concentrated solar power (CSP) technology uses the properties of sunlight to concentrate on a point by using lenses. It has some challenges like the cost and the technology, but it could be used in conjunction with other systems like Stirling or other steam turbines. CSP with the Stirling turbine is the most efficient technological combination that uses solar power.

Geothermal power. In 2020 the worldwide power installed using this technology was close to 20GW. This is the only sustainable energy of the so called surface ones that is actually from the earth formation. The theory is that the geothermal gradient is generated due to the difference between the core and the surface temperature. It is possible to use in every part of the planet, but only in some locations underground water reservoirs very close to the core heat exist, increasing the temperature of the water and making it viable as a source of energy [2].

The heat used for geothermal energy is in the core of the earth, at that point close to 6000 Km the temperatures are close to 5000º C. This heat goes to the rocks that are close by, the extreme pressure and the high temperatures cause the rocks to become fluid by melting. This rock is known as magma. Where water and magma are close, the crust heats up to 350ºC.

Geothermal technology that uses low temperature rates is called Low Temperature Geothermal and uses the outer crust as a battery. This technology could be used in the buildings to heat and cool them. There are other uses in the industry but do not use huge energy intercoolers, so should be addressed in low thermal interchanging demands. This technology uses a pump and a ground coupled heat intercooler to move heat energy to the earth for cooling, and out of the earth for heating. This system is seasonal so, when it needs to heat, it runs in one direction and the other way around if it needs to cool. This type of technology is similar to solar, in the sense that it is possible to use in the domestic sector, due to it being possible to have it in many places around the globe.

Bioenergy power. The total installed base was up to 140 GW in 2020 [7]. Biomass is the material derived from the living due to a biological process, and could also be organisms that were recently alive. The majority of them can be from plants or materials derived from them. This material can be used in two main technologies. The combustion process to produce heat, and after a process converted into biofuel, suitable to be used in already existing engines. It is possible to convert mass into fuel from grass or vegetables. There are different methods, which are mainly three; thermal, chemical, and biochemical. The most common energy source in this is wood, used from the very beginning of human kind. Plants or animal matter could be converted into fibers or other chemicals, like biofuel. There are several industrial biomass types grown from diverse kinds of plants. We should use those that are not suitable for human consumption, and we should also be very careful with the cost of opportunity. There is some controversy with regard to using the land to develop this biomass instead of human used ones, due to the price of the ton.

The energy produced by plants is generated from crops grown specifically to be used as fuel, offering a high amount of biomass per area. The transported fuels are often grain, while straw is used in the combustion process to generate heat or electricity.

Biofuels derived from biomass include a wide range of fuels. The biofuels classified as liquid are sorted by the type of main component. Alcohol produced in the clean process or through clean mass is classified as bioethanol. If the component is oil, the product is biodiesel. The ones classified as gaseous have been sorted as biogases, landfill and/or synthetic gases. The sucrose from plants in the sugar or starch cops is used as a component, and after being fermented generates the alcohol that becomes bioethanol. The main crops used are maize, sugarcane and sorghum, this grows more suitably in dry environments and at this moment is under investigation by the International Crops Research Institute for its suitability to generate this kind of fuel and food for animals in some of the most arid parts of the world, especially Asia and Africa.

In this work we address the renewable energy assets managed by Enel Green Power. In order to use the data base of 50.000 MW this company has and installed bases in more than 30 countries. The assets are sorted into Wind Energy, Solar Energy that hold the highest growth, and Hydro Energy, Geothermal Energy that has a slow growth.

1.3. COMPONENTS AND SYSTEMS IN RENEWABLE ENERGY PLANTS

In this document, we classified the different renewable energies and their generation units in a way that allows us to generate the algorithm based model to optimize operative parameters that operators want. Each plant or unit has different operation systems that can be classified as single components or groups of them, to make the organization of operations, maintenance activities, corrective actions, etc., easier. In addition, each system uses different physical laws, operation and maintenance factors that can be used as a categorization method to develop operating models for each system individually. In order to use it in a proper way, all the signals, data, parameters, etc., that go through the Programmable Logic Controllers (PLC) of each unit, after an integration provides alarm triggers or events that should be classified. There are many different combinations of PLC configurations, brands etc. Following the standards, we should develop a troubleshooting guide to address all triggers failures, events, etc. To match it and develop a quick knowledge database and knowhow, the components of each generation unit should be classified to reduce the problem. A PLC can have 1000 different signals, alarms or events, and assuming the different models, technologies etc., we may have thousands of PLCs, so millions of signals. In this dissertation, we reduce the problem to four systems and three components groups. The Component groups are the following:

- **Electrical Components**

All the components that obey electrical laws etc. such as, but not limited to, generators, motors, converters, inverters, transformers, switches, cell-boxes etc.

- **Mechanical Components**

In this case, all the components whose principal behavior is explained by mechanical laws particularly dynamic of movement, tribology, fluid dynamics, etc., such as, but not limited to, drive trains, pinions, gears, shafts, bearings, etc.

- **Structural Components**

Mainly those components whose physical behavior is described by static mechanic laws, little movements, rigid solid, vibrations and fracture-mechanics. This list includes towers, frames, steel and alloy structures, foundations, concrete constructions, and in particular, blades in all technologies, but with more importance in wind, due to cost and risk.

In order to operate the Generation Unit (GU) as a unique juncture of components there are systems that integrate the behavior in a way that it is possible to classify, reducing the problem for the troubleshooting guides. The system classifications are,

- **Electric System:** The electric system is feed the components inside the GU. Any alarm or event that affects the electric system should be classified and sorted.
- **Electronic System:** This system is composed of all the components that use electronic signals, thyristors, thermistors, relays, diodes, and any others, whose behavior can be explained using that theory. It is the most frequent component failure classification, as well as being the easiest to solve.
- **Hydraulic System:** In this group, we put all the components, subcomponents and parts that are fed by fluid pressure laws and hydraulic behavior. Listed, but not limited to pipes, valves, group of valves, hydraulic circuits, actuators, brakes, pitches, yaws etc.
- **Safety System:** Here we grouped all the safety related devices and their connections, joints etc., which are ruled by the Safety Machinery standard. It is important due to any algorithm or method to operate assets addressing the safety of the personnel and machinery safety.

1.4. ALGORITHM BASED MODEL RENEWABLE ASSETS MANAGEMENT SYSTEM

Our proposal for the algorithm based model is to use the main target output for those GU that could be AEP (Annual Energy Production), LPF (Loss production factor), etc. We developed our algorithm using the LPF as a target optimization output, but the RAMS that we propose can be easily modified and adapted to any other output.

Setting the LPF as a principal one among our Ys, along this document we will demonstrate which are the explicative variables (x) that we should consider in power plants. Together with the relations among all of them and the Y in order to generate a model that allows us to apply the mathematical and physical rules to explain the behavior of the assets.

We will base this study on some **articles** that lead us to understand some technicalities of the operations [9-11]. The **classification** that we mention in order to reduce the amount of info needed and be able to use the Enel Green Power database that rules more than 50 GW worldwide. The use of the **thermal signature** as a main indicator for failure detection [12], and finally the M30P patent [13] that is a methodology we want to improve in this work and extend to all renewable assets. In this work we have only focused on Wind technology operations. The complete list of inputs of the model are indicated in Table 1.

Table 1.1 Input list for the Algorithm based model.

INPUTS	**Variable name (one per each GU in the power plant)**	**DESCRIPTION**	**UNITS**
Model	*Safety_R*	Limitations on BTS due to safety restrictions	
Model	*Legal_R*	Limitations on BTS due to legal/contract restrictions	
Model	*Site_R*	Limitations on BTS due to specific site restrictions	
Model	*External_R*	External Scheduled downtime period	
Model	*Time_BTS#1*	time that one team needs for performing BTS#1 lubrication in one GU	hour
Model	*Time_BTS#2*	time that one team needs for performing BTS#2 Clearance and Adjustments in one GU	hour
Model	*Time_BTS#3*	time that one team needs for performing BTS#3 Torque and Tightening in one GU	hour
Model	*Time_BTS#4*	time that one team needs for performing BTS#4 Expert Inspection in one GU	hour
Model	*Time_BTS#5*	time that one team needs for performing BTS#5 safety in one GU	hour
Model	*BTS_Interventions*	Number of BTS interventions per year that the tool has to program. Each intervention can include 1 or more BTS activities	times
Model	*Time_TSG#1*	time that one team needs for performing TSG#1 Hydraulic in one GU	hour
Model	*Time_TSG#2*	time that one team needs for performing TS#2 Mechanic in one GU	hour

Model	*Time_TSG#3*	time that one team needs for performing TS#3 Electric in one GU	hour
Model	*Time_TSG#4*	time that one team needs for performing TS#4 Electronic in one GU	hour
Model	*Cost_BTS#1*	cost per intervention of BTS#1 Lubrication	€
Model	*Cost_BTS#2*	cost per intervention of BTS#2 Clearance and Adjustments	€
Model	*Cost_BTS#3*	cost per intervention of BTS#3 Torque and Tightening	€
Model	*Cost_BTS#4*	cost per intervention of BTS#4 Expert inspection	€
Model	*Cost_BTS#5*	cost per intervention of BTS#5 safety	€
Model	*Cost_TSG#1*	cost per intervention of TSG#1 hydraulic	€
Model	*Cost_TSG#2*	cost per intervention of TSG#2 Mechanic	€
Model	*Cost_TSG#3*	cost per intervention of TSG#3 electric	€
Model	*Cost_TSG#4*	cost per intervention of TSG#4 electronic	€
Historical	*Actual_Time_BTS#1*	Total time allocated into BTS#1 during the last 12 months. (One per each turbine)	hour
Historical	*Actual_Time_BTS#2*	Total time allocated into BTS#2 during the last 12 months. (One per each turbine)	hour
Historical	*Actual_Time_BTS#3*	Total time allocated into BTS#3 during the last 12 months. (One per each turbine)	hour
Historical	*Actual_Time_BTS#4*	Total time allocated into BTS#4 during the last 12 months. (One per each turbine)	hour
Historical	*Actual_Time_BTS#5*	Total time allocated into BTS#5 during the last 12 months. (One per each turbine)	hour
Historical	*Actual_BTS_Interventions*	Total BTS interventions during the last 12 months. Average	times
Historical	*Actual_Time_TSG#1*	Total time allocated into TSG#1 during the last 12 months. (One per each turbine)	hour
Historical	*Actual_Time_TSG#2*	Total time allocated into TSG#2 during the last 12 months. (One per each turbine)	hour
Historical	*Actual_Time_TSG#3*	Total time allocated into TSG#3 during the last 12 months. (One per each turbine)	hour
Historical	*Actual_Time_TSG#4*	Total time allocated into TSG#4 during the last 12 months. (One per each turbine)	hour
Historical	*Actual_Cost_BTS#1*	Total actual cost allocated into BTS#1 during the las 12 months	€
Historical	*Actual_Cost_BTS#2*	Total actual cost allocated into BTS#2 during the las 12 months	€
Historical	*Actual_Cost_BTS#3*	Total actual cost allocated into BTS#3 during the las 12 months	€
Historical	*Actual_Cost_BTS#4*	Total actual cost allocated into BTS#4 during the las 12 months	€

Historical	*Actual_Cost_BTS#5*	Total actual cost allocated into BTS#5 during the las 12 months	€
Historical	*Actual_Cost_TSG#1*	Total actual cost allocated into TSG#1 during the las 12 months	€
Historical	*Actual_Cost_TSG#2*	Total actual cost allocated into TSG#2 during the las 12 months	€
Historical	*Actual_Cost_TSG#3*	Total actual cost allocated into TSG#3 during the las 12 months	€
Historical	*Actual_Cost_TSG#4*	Total actual cost allocated into TSG#4 during the las 12 months	€
Kpi	*MTBI*	Average time between planned interventions (BTS)	hour
Kpi	*MTTRi*	Average time to return after a BTS intervention	hour
Kpi	*MTBF Hydraulic*	Average time between unplanned interventions (TSG Hydraulic)	hour
Kpi	*MTBF Mechanic*	Average time between unplanned interventions (TSG Mechanic)	hour
Kpi	*MTBF Electric*	Average time between unplanned interventions (TSG Electric)	hour
Kpi	*MTBF Electronic*	Average time between unplanned interventions (TSG Electronic)	hour
Kpi	*MTTRf Hydraulic*	Average time to return after an intervention (TSG Hydraulic)	hour
Kpi	*MTTRf Mechanic*	Average time to return after an intervention (TSG Mechanic)	hour
Kpi	*MTTRf Electric*	Average time to return after an intervention (TSG Electric)	hour
Kpi	*MTTRf Electronic*	Average time to return after an intervention (TSG Electronic)	hour
Kpi	*EKC*	Compose EGP parameter per plant	
Kpi	*EQR*	Enel Quality Rate	
Kpi	*EA_int*	Internal Energy Availability	%
Kpi	*EA_ext*	External Energy Availability	%
Kpi	*LPF*	Lost production	MWh
SCADA	*GU_Temperature*	Ten-minute trend of temperature in the internal part of the Nacelle	ºC
SCADA	*Mechanical_Temperature*	Ten-minute trend of temperature in the internal part of the Gearbox	ºC
SCADA	*Electrical_Temperature*	Ten-minute trend of temperature in the internal part of the Generator	ºC
SCADA	*Structural_Temperature*	Ten-minute trend of temperature in the internal part of the Converter	ºC

SCADA	*Ambient_Temperature*	Ten-minute trend of temperature in the external part of the GU	ºC
SCADA	*Wind_Speed*	Ten-minute trend of wind speed in the nacelle sensor	m/s
SCADA	*Wind_Direction*	Ten-minute trend of wind direction in the nacelle sensor	m/s
SCADA	*Active_Power*	Ten-minute trend of Active Energy Output in the Energy Meter	MW
SCADA	*Reactive_Power*	Ten-minute Reactive Energy Output in the Energy Meter	MVAR
SCADA	*T_Trigger_Mechanical*	Means that Mechanical needs an inspection	on/off
SCADA	*T_Trigger_Electrical*	Means that Electrical needs an inspection	on/off
SCADA	*T_Trigger_Structural*	Means that Structural needs an inspection	on/off
SCADA	*T_Trigger_GU*	Means that GU needs an inspection	on/off
Domain	*Resource_Distribution*	historical annual resource Weibull distribution	Distribution
Domain	*Load_Factor*	Total amount of energy per year divide in total power	hours
Domain	*Average_Temperature*	Ambient temperature distribution	º Degrees
Domain	*Average_Density*	Air Density	g/cm3
Domain	*GU_Id*	functional location at GU level	
Domain	*Turbulence Intensity*	Percentage of Turbulence, or typical deviation (sigma)	%
Domain	*Age*	years form COD	
Domain	*GU Type*	Turbine manufacturer	
Domain	*historical cost per Functional Location (Component Level)*	annual cost allocated on each FL	
Domain	*Equipment per functional location*	Model and Brand of each major component	
Domain	*Energy Price*	Energy price forecast trend	€/MWh
FMEA	*Weibull Failure Distribution Mechanical UT/DT*	Failure Distribution Mechanical	% / year
FMEA	*Weibull Failure Distribution Electrical*	Failure Distribution Electrical	% / year
FMEA	*Weibull Failure Distribution Structural*	Failure Distribution Structural	% / year
FMEA	*Repair cost per Mechanical UT*	Cost per intervention average	€

FMEA	*Repair cost per Mechanical DT*	Cost per intervention average	€
FMEA	*Repair cost per Electrical*	Cost intervention average	€
FMEA	*Repair cost per Structural*	Cost intervention average	€
Data Base	*Cost Per €/MW*	Cost per Installed MW OPEX (*)	€/MW
Data Base	*Cost Per €/MWh*	Cost per generated MWh OPEX(*)	€/MWh
Data Base	*Impact on Profitability IoP*	Ratio between expenditures and the margin coming from energy sales	%
Data Base	*Economic Unavailability Factor EUF*	Ratio between the loss income and theoretical margin achievable	%

Using this complete list of inputs, we took all of them from the different renewable energy technologies and built the database. With this database we applied the statistical features to obtain the Pearson coefficient to see the relations between the variables. We concentrated on the group of variables that are more explicative of the LPF output and studied if we can affect those variables and how. The output model is as follows:

Two of the main contributors for the LPF that we can affect with our actions are the KPIs related failure occurrence, Medium Time between Failures (MTBF) and Medium Time to Repair (MTTRf)

$$MTBF = \frac{Time}{Number\ of\ Failures}$$ Equation 1.1

$$MTTRf = \frac{Total\ Failure\ Time}{Number\ of\ Failures}$$ Equation 1.2

Two main contributors for the LPF that is not so relevant as the failure related, but was demonstrated that are highly correlated with the above ones, are the KPI related inspections, Medium Time between Inspection (MTBI) and the Medium Time to Return after an inspection (MTTRi)

$$MTBI = \frac{Time}{Number\ of\ Inspections}$$ Equation 1.3

$$MTTRi = \frac{Total\ Inspection\ Time}{Number\ of\ Inspections}$$ Equation 1.4

Basically we open each KPI into the different activities that can be performed in a planned way (inspection) or in a corrective way (failure) in order to fine tune the tasks, times and efficiency of the work to repair and maintain the unit at the required quality level. At the beginning and after performing the correlation between activities and the impact on the main KPIs, we saw that there are activities that do not bring value, so we develop a Quality Inspection Plan, including the procedure, process and policy to be sure that the components, systems and assets are properly operated. We used the MIL-STD mentioned in the bibliography to develop the sample plans, rejections and all the statistical aspects of the plan. After being sure that every asset is at the correct level of quality making our study with a ceteris paribus condition, we then targeted the relation with our output target, the LPF.

$$LPF = \left[\frac{Total\ Period\ Time}{MTBF} \times MTTRf\right] \times CFf + \left[\frac{Total\ Period\ Time}{MTBI} \times MTTRi\right] CFi$$

Equation 1.5

1.5. OBJECTIVES

The purpose of this dissertation is to apply the latest developments in assets management regulated by different standards (ISO 55000 series) and focus them on renewable energy plants. We will structure our contributions in three main blocks.

a) Convert the unplanned into planned

In this PhD work a methodology based on IEC-IEEE-IFRS-ISO standards, mainly ISO 55000-55001-55002 was developed. Thus, we will use the terminology, acronyms, concepts etc. already set in ISO_IEC standards. With this approach we assure that any development can easily be integrated in a real life asset management system for renewable plants. It takes the same convention names, nomenclature and descriptions used in the listed standards. The assets to be focused on are renewable plants (hydro, wind, solar, geo and biomass). Mainly those that are already widely used to generate energy, but we do not close any other asset base in the renewable way to produce energy, once it reaches certain relevance. Therefore, we are focusing this PhD on existing and future plants, not on tests or pilots, which in our judgment should be managed with other considerations.

We developed the systems and adapted the operative instructions, local standards, safety rules and best practices to fulfill the main standards already mentioned, but described in a way that any operator, utility or third party company managing renewable power plants, will be able, using our results, to successfully apply IEC-IEEE-IFRS-ISO- standards to get all their benefits. With this exercise, we also want to provide some insight that goes beyond the standards and set the basis to develop a system that includes financial and economical Key Parameter Indicators as well as technical ones, to help operators perform and manage renewable assets according to their strategy, in order to revert the actual situation that only has 20 % of operations under some kind of plan, and where 80 % is completely unplanned. To target 90% planned and only 10% unplanned.

b) Develop a classification method for alarms, events and stoppages

Based on the classification we are proposing with the Structural, Mechanical and Electrical component groups, and four system integration Electric, Electronic, Mechanic and Hydraulic, we are able to classify any event of any of the target renewable generation units in a unique way allowing us to apply any result in any GU no matter the technology or the region. Therefore, the target audience are companies, or people that have interest as stakeholders, shareholders, management or operation of assets of renewable generation units. The growing global interest make this type of energy one of the most important.

We are in the middle of a paradigm change. This work wants to contribute eliminating uncertainties not only in EU-28 but also in the rest of regions or poles. Hence, the target audience include those that are willing to move swapping the energy mix to get the renewable energy as a main contributor in their horizon to limit the impact of the climate changes and fulfill the new world strategy already signed in the **United Nations** and in the **European Union**.

The adoption and development of ISO / IEC standards enables the target audience of the dissertation to achieve their objectives through the effective and efficient management of renewable plants. The use of asset management system [ISO 55001] assured that those objectives can be achieved consistently and sustainably over time, gaining certainty, mainly in the risk management and in the operative expenditures [IAS16], allowing decision-taking in an early environment, and successfully projecting across time the mission-vision strategies and policies of the company that manage the assets. The algorithm-based operating conditions designed/tested/ system in this thesis will help to forecast any risk in the life spam of the assets, together with optimization management-chosen ones, such us production, life extension, operational expenditures, cost, Leveraged Cost of Energy, Energy Availability etc. without compromising the safety operation that was described in the IEC-IEEE-IFRS-ISO Standards for Renewable Assets. Our classification is in compliance with the mentioned standards.

c) Modeling the LPF for the Renewable Assets Management System

This doctoral work also allows all the stakeholders to understand how a renewable energy asset could behave under different regulatory scenarios. In the current energy environment and due to globalization, we are facing new challenges in the energy producers. Climate change and the zero-emission commitment places a big question mark on the old utilities highly dependent of fossil resources. In Europe and America, the scenario is to adapt the current portfolio of assets to the new regulations. On the other hand, in the growing markets such as Asia and Africa the challenges are to accomplish growth in compliance with the new protocols. We create a new model to manage the energy plants, emphasize, in those KPIs that are more important in each case, bringing some clarity and reducing uncertainty. Due to the inclusion of risk management, the lifetime extension, etc. we are able to calculate the different year scenarios for each case being able to model the energy mix of a company in a certain environment. Due to risk and uncertainty, this kind of management is of utmost importance, as we are in constantly changing scenarios. It is necessary to assess and manage risk in each individual case.

The intention is to create an algorithm-based model to be able to operate the Generation Unit of any kind of Renewable Assets. This operation using the model described in this dissertation can be optimized per variable or per group of variables, in order to obtain the most convenient output, which, as described, could improve the MTBF or LCOE, LTE etc. In this case we targeted the improvement of the LPF of any asset by acting over those variables that we can act, mainly the technical activities that are developed to improve the time to return after a failure and optimizing visits, performing the activities that are needed, or adding some value.

This dissertation will provide the audience with an algorithm based protocol to manage any renewable asset that produces energy. This algorithm and the subsequent process and procedures for each renewable technology will allow the operator to optimize the outputs that the owner deems most interesting. Those outputs can be production, benefits, lifetime, loads etc. or a combination of all of them, to get a unique competitive advantage in the renewable energy market. The algorithm based protocol will use the assets data used in the industry, without any additional input or sensors. The results obtained are in the range of 99% of confidence level, statistically speaking. In our opinion it is the best model that can be applied for all the renewable energy industry.

The dissertation aims to create uniform and unique guidelines for the Operation of the Renewable assets algorithm based, using a statistical model developed for that propose that will be tested in the real asset to prove the confidence level of the solution. The guidelines will be focused on mapping all the different assets components and systems, aiming to create an operational procedure for them that can be applied by any local operator.

The aim to form a generic Operational Strategy that can be used internally or externally to ensure a smoother operation of the asset and high-quality Operational actions in the Renewable asset. Internally, the Operator will be able to maintain the assets on a factual basis and ensure unobstructed power production. The personnel will increase their knowledge on the asset related issues, and the overall Operational decision-making will be self-dependent according to the particularities of the assets. Consequently, the dependency on other external factors and partners will decrease, as the improvement on the technical knowledge in the organization will lead to more qualified operational decisions. Externally, the operator will be able to contact

OEMs on a more qualified approach, as the technical expertise will have increased, and the operational statistical model that can be created is owned by the operator.

d) Develop the relation between explicative variables.

We will use the statistical analysis events, signals, from SCADA, Condition Monitoring Systems located at component or subcomponent level, historical data, and digital reports from the established operation and maintenance strategies. Condition monitoring is the use of data to determine the behavior of a system or plant, detection of performance degradation, estimation of remaining component life, or identification of component faults.

Systems for monitoring and conditioning assets can be direct models based on physical inspections, or indirectly based models by performing inspections [14-28]. For modern machinery, and especially for renewable energy plants, the existing data records of machines in operation probably represent one of the greatest untapped assets of the companies. Intelligent renewable plant condition monitoring and early fault detection are necessary for modern systems to prevent unsafe operation, early detection of degradation, and identification of equipment faults. These diagnostics allow scheduled maintenance to prevent serious accidents and equipment failure [29]. The cost of unplanned service interruption is usually significantly higher than the cost of performing preventive maintenance. In fact, it is quickly becoming necessary for manufacturers to develop the internal capability to perform remote diagnostics to remain competitive. Diagnostics, early detection of degradation and/or failures not only enable scheduled, preventive maintenance, but also predict remaining service life. The prediction of service life for major components such as wind turbine major components is also generating great interest: on one hand minimizing the likelihood of catastrophic failure, and on the other maximizing time before overhaul or component replacement. Some of the most commonly studied indicators of turbine/component condition and health are temperatures [30]. In the area of wind turbines, one of the most widespread approaches is the statistical analysis of field measurements to determine health indices, by comparing observed performance with a reference Generation Unit (GU) model. These component health parameters are typically functions of multiple variables such as stage pressures, temperatures, own areas, and machine specific performance data. When trended over time or compared to a nominal "healthy" generation unit model, these parameters give owners, operators, and manufacturers, insight into the condition of the turbine. In practice, only subsets of the measurements required to estimate fluid flow condition related parameters are instrumented outside of a dedicated test stand. Additionally, these measurements may be corrupted by noise, inferred from indirect measurement with inherent uncertainty and susceptible to instrumentation and actuation faults. Of all condition monitoring methods, the model-based approach is viewed by many as the most promising method for the real-time and trend base condition monitoring of such complex systems as wind turbines. Often, transient measurements prove more useful than steady state measurements due to limited instrumentation on units in service. In addition, many generation units' faults contribute little to performance deviations at steady state conditions, but significantly in transient processes. The notion of transient fault signatures has been identified in generation turbines by some previous studies.

To avoid those kinds of disturbances, the GU failure distribution is classified into components, subcomponents and groups in order to classify the possible error sources (PE) methods and the least squares (LS) estimator [31-33]. For the purpose of condition, monitoring, archival data is typically treated as a bulk data set for statistical analysis, machine learning, or neural network type model. We follow the FTA and the FMEA failure mode classification and the failure tree analysis that is included in the IEC standards. [IEC 61025 Fault tree Analysis] and [IEC 60812 Failure Mode and Effect Analysis]. The dynamic and transient information in the data is not fully exploited in these methods. While machine learning, neural network, or similar modeling techniques are capable of dealing with the many complex and nonlinear parameter interactions, the resultant models are difficult to interpret and interrogate. The model details are usually confidential, or only the initial and final layers are publicly shared. Moreover, the tools to extract useful information from these models is still in its infancy compared to the well-established linear approximations, such as Bode plots in the frequency domain and step-responses in the time domain. For example, one cannot easily extract and relate model parameters to system features or behaviors. One example where parameters can be related to system features are poles and zeros of a linearized dynamic model, which can behave both in the time and frequency domain. Regardless of the model type, data used for identification must be sufficiently informative. In the case where the reference model identifies dynamic behavior, there is a requirement that operating conditions prevailing during the collection of this data should be succinctly perturbing to reveal the system dynamics with suitable fidelity, otherwise known as persistence of excitation. Using these observations, model-based diagnostics that consider both the dynamic response, information content of the data, and steady state operation should provide more comprehensive platform for condition monitoring. The relevant questions are how to obtain these algorithm-based models with the available data, what types of models are suitable for diagnostics, what the result is, how much the LPF has improved, and how far the confidence level has been reached.

e) Develop the Thermal Signature model for the GU diagnosis.

Finally, using the Enel Green Power database and the data from the SCADA system regarding the status of the component, temperature, pressure, density, etc., we will develop the model to use the thermal signature or the relation between the temperature and the other status signals from the different parts of the GU to check for variances and make a proper diagnosis of each. Having more than 50 million data points regarding these signals and 4 million activity reports we will demonstrate, with over 99% confidence level that any temperature variation is a condition for the wellness of the component. Due to this relation, we develop a procedure to test nano-additives in the cooling liquid of the electrical components in order to increase the cooling capability without making any investment [12].

We structured the PhD thesis with the following chapters. In the prologue, we included all the publications, proceedings and patents involved. The next chapter is the methodology that we proposed, the systems and software that we use, the database and the mathematical tools to reach our targets. In the next chapters, we present the results and their discussion. Lastly, in the conclusions we discuss possible future work linked to this thesis.

2. METHODOLOGY

2.1. Renewable asset management system principles

The factors which influence renewable asset management, follow the scope described in the IEC 60050 (Vocabulary) and the IEC 61850 (abbreviations) (listed in the bibliography). With the approach we ensured that any development can easily be integrated in a real-life asset management system for renewable plants. All these standards are in compliance with ISO regulations. We take the same convention names, nomenclature and descriptions named in the listed standards. The assets we will focus on are renewable plants (hydro, wind, solar, geo and biomass). We developed a classification in component groups and systems to be adapted to the operative instructions, local standards, safety rules and best practices to fulfill the main standards already mentioned, but described it in a way that any operator, utility or third-party company managing renewable power plants, will be able, using our results, to successfully apply IEC-IEEE-IFRS-ISO-IFRS-IEEE standards to get all their benefits. In this work the output will be based on the lost production failure (LPF) optimization. We use the listed variables in Table 2.1. Additionally, we will use the ISO 55000 standard for assets management to ensure that our algorithm base meets the latest management standards.

In order to organize how we managed this; we included the following items:

- Owner Strategy (Utility, Independent Power Producer, Financial Firms etc.).
- Operation Framework (Region, Pole, Country)
- Regulation applicable in the Framework, as well as the Company Strategy.
- Stakeholders and Shareholders interests
- Community Shared Value (ISO 26000).

The operation and maintenance factors should be taken into account if establishing the renewable asset management system is needed. It is also needed to implement and maintain together with the continuous improved processes. To have the control and the governance under the effectivity it is important to produce the value by the use of a balance between the opportunities and the risks. To achieve the baselined cost and balanced with the desired performance and acceptable risk it is also necessary to use the risk and opportunity matrix. The frame regulation and legislation that ruled the operation of the organizations is a challenge, due to the changes, and the continued movement to follow international protocols in this business. This risk affects renewable assets in a specific way. The pillars of the support system and the renewable management for the plants, which is explained in this work when it is included into a more comprehensive governance and framework risk from the operator, will put a set of contributions with benefits and opportunities. The renewable asset management will transfer the objectives of the organization and convert it into decisions, actions, and plans taking into account the risk approach.

The life span or lifetime is the period from the development or when the asset is created to the end of its life. The life of the renewable asset could not be the exact period which an organization is responsible for it. It is possible that a renewable asset provides potential value for several organizations in its life, and changes its value, over the duration of its operation.

An entity can choose the management of its assets in an individual way or as a group, following its own needs, to achieve the optimized benefits, in one or another choice. The groups that could be generated are usually sorted by renewable asset systems, renewable asset portfolios and renewable asset types. To be able to manage the renewable assets the entity management should deploy the mission and vision, as level zero, then the policies and strategies as level one following the plans in level two; the processes in level three and the procedures in level four. This setup by levels should include the actions addressing the plan and control, such as monitoring actions or activities in order to perform and operate under an acceptable level of risk. The renewable asset management uses the leverage cost of energy [34], the leverage price of energy, and the difference between the two values becomes the opportunity to be achieved with the balanced risks to be taken in order to perform the renewable assets with the entity objectives. This balance must be considered over different schedules or periods to be able to leverage the strategy by region, pole or country, carrying out renewable assets by groups, technology, fleet or portfolio, as well as autonomously. The renewable asset management helps the operator to evaluate its needs, the performance and the systems of its renewable assets at several levels. In addition, it makes it possible to apply an analytical approach to manage the renewable asset from a listed of stages in its life.

a) Fundamentals

Renewable asset management has developed a set of pillars, described in the [ISO 55000], we will use the definitions in the standard and adapted to the special case of the assets we set in this work.

i) Value:

Renewable assets should provide value to the operator and its stakeholders [35]. Renewable asset management is focused on the value that it brings to the entity and not in the renewable asset itself. The value in our case is financial, which includes the lifetime duration of the renewable asset. The resource that we will use and its load across its lifetime, and finally the performance of the technical systems to convert the resource into electrical energy, this comprehensive circle will bring a kind of financial figures in order to modulate the way to perform. It is crucial to calculate very accurately the value of the renewable asset; in each moment, as well as to have good forecast of this value to take the correct decision such as selling or investing in it, extending its life by retrofitting or overhauling, investing in capital expenditures to improve. With all these considerations, we set the LPF optimization as our target, but we optimized any other variable included in the list we provide. In order to address the value of each renewable asset we should consider:

1. A statement of how the renewable asset management objectives are aligned with the entity objectives.
2. Use an approach based on life cycle management, in order to convert the value from renewable assets.
3. Establish the rules and create a process, in order to take decisions reflecting the stakeholder's needs and defined values.

ii) Alignment:

The management of the renewable assets should transmit organizational objectives converted into technical and financial decisions, developing the plans and activities. The decisions that could be technical, financial and operational for the Renewable asset management to achieve the entity objectives include:

1. Deploy a risk-based process to be driven by the data and the information extracted in order to develop plans and processes lead by smart decisions to transform the entity objectives into renewable asset management plans with the help of the developed strategy.
2. Integrate the functional management such as finance, human resources, information systems, logistics and operations with the renewable asset management processes.
3. Specify the renewable asset management system for the design and the implementation.

iii) Leadership:

To realize the value of a renewable asset, leadership and culture displayed in the workplace are crucial. Getting the involvement of the different hierarchical levels and leaders of the entity is essential to be able to implement, operate and improve the management of renewable assets in the entity.

1. Define the roles, responsibility and authorities in a clear way.
2. Endorse and consult the renewable asset management with the employees and stakeholders.

iv) Assurance:

The assurance of the purpose requirements is given by renewable asset management. In order to perform in an effective way, the entity governance needs to ensure that the requirements should be fulfilled. In order to do that we list the following points:

1. To develop and to deploy the process to connect the purposes and the performance with the entity objective for the renewable assets.
2. Deploy and guarantee the process capability for the lifetime of the renewable assets.
3. Deploy the process to monitor the continuous improvement.
4. Provide the competency and the resources to the personnel to demonstrate the assurance to undertake the renewable asset management activity and operate the renewable asset management system.

The entity uses a renewable asset management system to coordinate and control the renewable asset management activity in a direct way. The control of the risk and ensuring organization objectives can be improved on a consistent basis. Not all the activities belonging to the renewable asset management can be included in the renewable asset management system, culture or the leadership together with motivation or the behavior will have a huge influence in the renewable asset management objectives but should be managed by the entity outside of this system. Figure 2.1 shows the relation between the key renewable asset management terminologies.

The renewable asset management system which interacts and is interrelated in an entity, with the function to establish the policies under the renewable asset management and set the targets and the objectives. To achieve the objectives, the process, procedures, rules etc. need to be set up. For renewable asset management to govern that task, it is necessary to develop a set of tools, policies and plans together with the systems that manage the data to revert into valuable information and be integrated to assure the renewable asset management activities will be properly delivered.

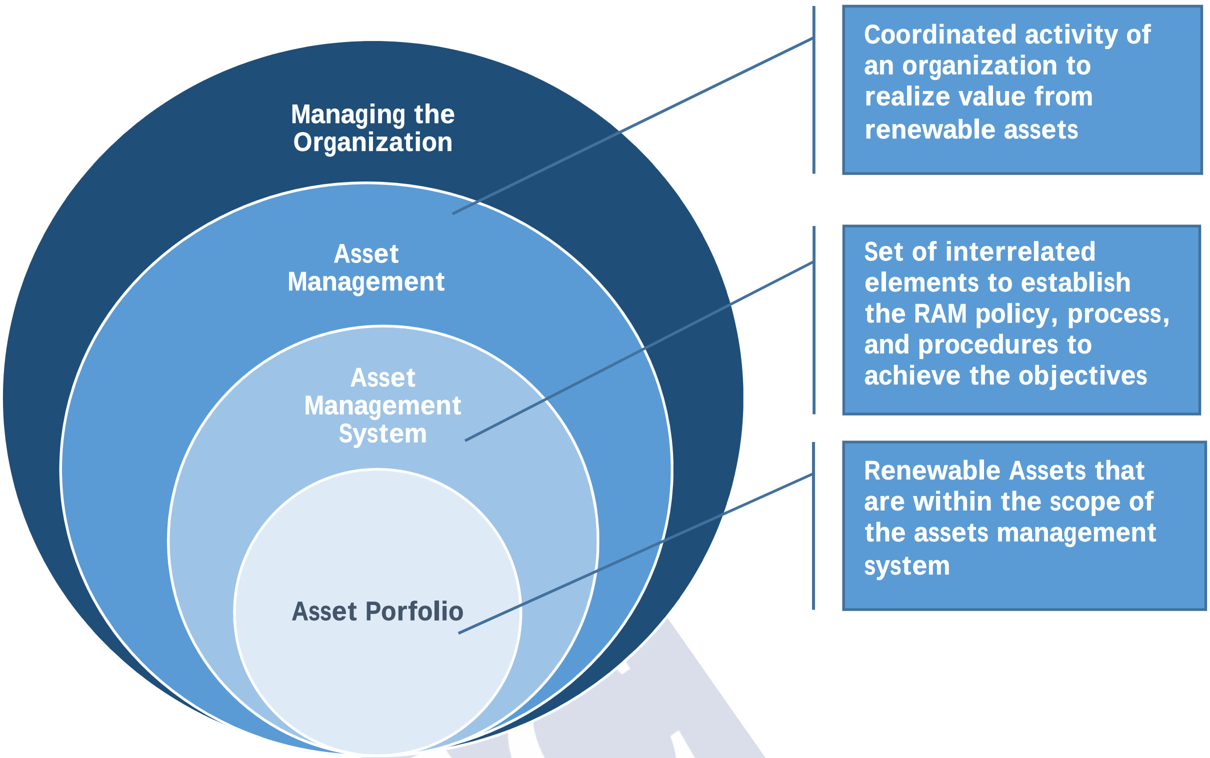


Figure 2.1. Relationships between key terms.

The first part is the data acquisition that came directly by the SCADA system, which provides two different groups of information. The status of the Renewable asset, together with the indicative signals the resources and the environmental situation allow us to calculate or forecast the resource and the prevision of income per resource, be it wind, hydro, solar or others. There is another group of information including the events and errors coming directly from the generation systems. All this information will be stored in a database allowing the projection of both groups of information to develop effective OPEX baselines trends to predict conditions and outputs. We will use the Energy Utility Company (EUC) data base that received around 100 tags per asset every 10 minutes. The EUC has more than 50.000 MW of renewable energy assets installed in over 30 different countries. This means more than 50 Million data 10-min data values per year, and around 2 million digital reports per year to confirm the actions taken on each asset.

The renewable asset management could support several functional units and functions in the entity organization and provide meaning for the coordinated contributions and interactions among all these related units.

The renewable asset management plan enables the entity to create links between the renewable management system (described in ISO 55001, 55002 as an extension of the ISO 55000) and several specific, renewable asset management requirements. The list of elements is included in the ISO standards but also in other frames of technical notes, at all levels of standardization pole, region, country etc. These standards provide the necessary data to develop the strategy, improve the design or the construction and define materials or process etc. [36,37].

Table 2.1. Definitions and acronyms of renewable asset management ISO 55.000.

Acronyms and Key words	Description
Key Performance Indicator (KPI)	Numeric index for monitoring the production process of a system, with reference to plant operation and maintenance. The KPIs defined in this document are issued to be uniquely quantifiable and measurable. They are used for monitoring the performance and for verifying the achievement of the targets
Generating Unit or Unit (GU)	Single unit for energy generation, including the equipment and accessories necessary for its operation; for Hydro it is synonymous of "group", for Wind it stands for “Wind Turbine Generator” (WTG), for Solar it is synonymous of an inverter interconnected with strings of solar modules, etc. The Generating Unit can be also called Unit
Plant	Industrial system to produce electrical energy that includes everything from the equipment used for intercepting and conveying the natural resource to the devices for connecting and delivering the energy to the electric grid. A Plant can consist of several GUs
Commercial Operation Date (COD)	Commercial operation start-up date for a Plant, normally coincident with the first connection to the grid. The COD may also be partial, with part of the GUs still under construction
Hand-Over (HO)	Handover between different units that usually establishes a new phase in the plant's life cycle (e.g. development, construction, operation, refurbishment, etc.). From O&M point of view the Hand-Over normally means the transfer of the plant from Engineering and Construction to O&M Local Unit at the end of a construction phase. This step establishes the date when the O&M Local Unit takes over the full responsibility for the Plant and its performance. The Hand-Over date may not coincide with the COD date. The Hand-Over could also be partial, i.e., to concern only a fraction of the plant (in terms of GUs or operating power).

b) Operating States of the Generating Units

An operating state is a particular condition of a unit/plant affecting its performance. The possible states are those listed in the following paragraphs.

i) Inactive state

A generating unit is defined Inactive when it is not able to provide services for a prolonged period of time, in any case not less than 3 months, for reasons that could be originated by causes of unavailability listed in Annex A (e.g. disasters) or others; in particular:

a) It is unavailable for service and it is not expected to return to service in the future because it has been retired for any reason.
b) It is temporarily unavailable for service due to causes whose resolution normally involves other functions for carrying out directly the activities or for supporting O&M (e.g. Engineering and Construction for plant refurbishments, developments for renewals or modifications of permits and authorizations, etc.). The return to service of the plant, at the end of the process, must be certified by a Hand Over or a communication of O&M Local Unit.
c) It is partially out of service, i.e., not able to operate at full capacity, since its activation, due to significant infrastructure problems (e.g., related to the grid connection or other construction issues). The partial out of service ends with the

resolution of all the issues and restrictions. This particular circumstance for the Inactive state can be taken into consideration only after the Hand-Over.

The inactive units, or their inactive shares, are in the population of those not being reported for the calculation of the technical KPIs; in any case they are monitored and represented in the official reports. For this reason, the inactive units and capacity must be clearly identified and declared.

The inactive states, as well as possible exceptions to the general rules, must be submitted and agreed upon with the specific Competence Center, who will approve and officially communicate them to the Operational Performance Improvement Team.

ii) Active state

The active state is that of a unit that is capable to provide service; the active units are in the population of those being reported for the calculation of the technical KPIs. The following sub-states can be identified:

- **Available:** the available state is when a unit is capable of operation regardless of whether it is in service or not, and regardless of the capacity that it can provide. An available unit can be de-rated or not-de-rated:
    - **Not-de-rated**: when it can operate at maximum capacity.
    - **De-rated**: when it cannot operate at maximum capacity because the operation is compromised or the existence of equipment failures, restrictions from external domains, testing, work being performed, adverse conditions, etc.

  A further distinction within the available state, whether de-rated or not-de-rated, is the following:
    - **In-Service-generating-mode**: when the unit is connected using electrical coupling to the system and it is performing generation function.
    - **In-service-non-generating-mode**: when the unit is connected by electrical coupling to the system but is performing non-generating functions, such as the pumping or synchronous condensing mode.
    - **Reserve shutdown**: when the unit is ready to operate (available), but it is not yet in service.
- **Unavailable:** The unavailable state is when a unit is not available for service.

iii) Table of the states

All the possible states are organized in Table 2.2, showing the association with the different technologies and KPIs affected.

Table 2.2. States of the generation units for different technologies.

GU State: 1st Level	GU State: 2nd Level	GU State: 3rd Level	GU Substate	Description	Technology: Wind	Technology: Hydro	Technology: Geo	Technology: Solar	Technology: Bio	KPI: Time	KPI: Capacity	KPI: Energy
Inactive				The inactive sate is when a unit is: Unavailable for services and it is not expected to return to service. Temporary unavailable for service but it is expected to return to service. Never been available for service but it is expected to return to service.	X	X	X	X	X			
Active	Unavailable			The unavailable state is when a unit is not capable to operate because of operational or equipment failures, external restrictions, testing, work being performed, adverse conditions, etc. The unavailable state persists until the unit is made available for operation, either by being synchronized to the system or being placed in the reserve shutdown state.	X	X	X	X	X	X	X	X
Active	Available	Derated	Reserve Shutdown	The Derated-Reserve-Shutdown state is when a unit is not in service but ready to operate, not at its full capacity due to the derating.		X					X	
Active	Available	Derated	In Service Generating Mode	The Derated-In Service-Generating-Mode State is when a unit is electrically connected to the system and performs generating function, but not at its full capacity due to the derating.	X	X	X	X	X		X	X
Active	Available	Derated	In Service non Generating Mode	The Derated-In Service-non Generating Mode state is when a unit is electrically connected to the system and does performs generating functions, but not at its full capacity due to the derating. Not generating functions are; pumping mode and synchronous condensing mode.		X						
Active	Available	Not Derated	Reserve Shutdown	The Non-Derating-Reserve-Shutdown state is when a unit is not in services but ready to operate as its full capacity.		X						

			In Service Generating Mode	The Non-Derating-In Services-Generating-Mode State is when a unit is electrically connected to the system and performs generating function at its full capacity.	X	X	X	X	X			
			In Service non Generating Mode	The Not-Derated-In services-Generating-Mode state is when a unit is electrically connected to the system and does perform not-generating functions at its full capacity. Non Generating functions are pumping mode and synchronous condensing mode.		X						

iv) Flow chart of the states

The unit states are represented in the flow chart represented in Figure 2.2 whereas the classification of the causes of un-availabilities and de-ratings is indicated in Figure 2.3.

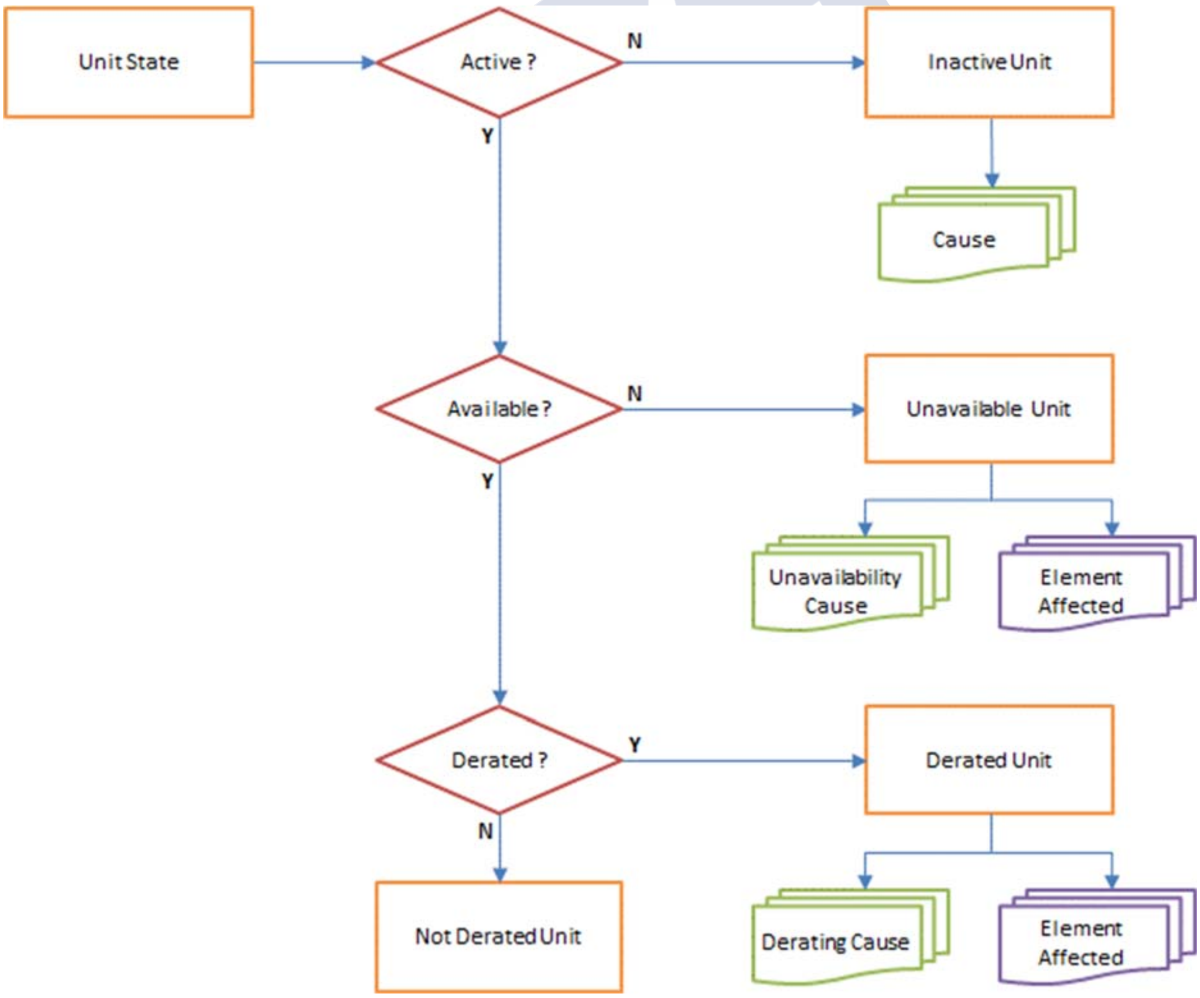


Figure 2.2 Flow chart of the states.

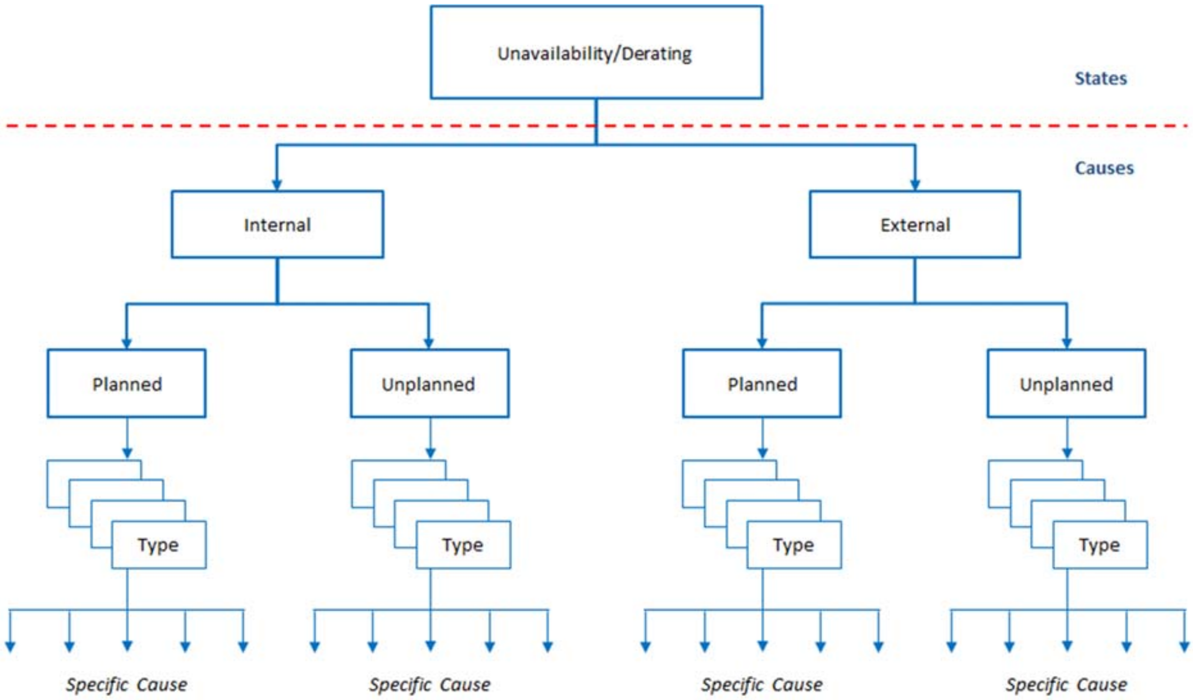


Figure 2.3. Causes of Un-availabilities and De-ratings. EUC Operative Procedure

Annex A lists all possible causes of unavailability's and de-rating. In Table 2.3 an extract of these causes is presented.

Table 2.3. Description method of the causes of unavailability's and de-rating EUC Operative Procedure.

Cause Classification			Cause Name	Cause Code	Description	Technology				
Int / Ext	Plan / Unplan	Type				Wind	Hydro	Geo	Solar	Bio
External	Unplanned	other	Natural Disaster	99	Natural disaster, earthquakes, floods, landslides, fire, etc., with effect on plant operation.	X	X	X	X	X
			Vandalism	98	Vandalism, damages thefts, with effect on plant operation.	X	X	X	X	X

			Labor strike or Social Disorder	97	Strikes or social disorders with effect on the plant operation.	X	X	X	X	X
			Third Parties interference	96	Interferences from third parties with possible effects on plant operation, such as activities in the proximity of the plant, transports, traffic restrictions, handlings, disputes etc.	X	X	X	X	X
			Legal prescription	95	Fulfillment of legal environmental or regulatory prescriptions, inspections, or other law requirements, etc.	X	X	X	X	X
			Automatic action	94	Automatic actions for self-diagnostics and settings, hydraulically, electrical and or mechanical self-checks, with possible temporary deratings or shutdowns.		X		X	
			Accident	93	Injury of personnel with effect on the plant operation.	X	X	X	X	X
			Punch List completion	92	Activities for the completion of the construction punch list, usually in the period between provisional and final hand over.	X	X	X	X	X
		Ambient	Ice and or Snow	91	Presence of ice or snow with effect on the plant operation.	X	X	X	X	X
			Lightning	90	Lightning strike event affecting the plant operation.		X	X	X	

			high Wind Speed and gusts	**89**	**Wind speed exceeding the maximum design value or gust, resulting in Generation unit derating or shutdown. The lost production of a GU due to high wind speed is accounting only during the hysteresis when it returns to operation after a stop for high wind speed.**		**X**			

The list is organized in the following way:

- **Classification of causes**: it is used to classify the causes of stoppages in a homogeneous way based on the following three main characteristics:
  - *Int/Ext*: the cause is internal when it is manageable by O&M or External when it is not manageable by O&M.
  - *Planned/Unplanned*: distinguishing the causes between those planned in advance and those unplanned.
  - *Type*: further grouping according to specific needs.
- **Cause name**: name of the cause;
- **Cause code**: numeric code univocally associated with a cause;
- **Cause description**: detailed description of a cause with even the mention of possible examples;
- **Technology**: cause applied to technologies [38,39].

A special cluster of causes consists of those that give rise to the Not Producible Energy, which is the amount of resource that cannot be used because of permanent clauses and/or constraints of the contract for the energy sale. The major improvement that we introduce in this work is the extended classification that we carry out by component, sub component and systems, in order to group all possible causes of failure in four Systems (Electric, Electronic, Hydraulic and Mechanic) and three component groups (Structural, Mechanical and Electrical) to allow the model to use cross technology data, and increase the data points in a certain technology no matter the software version or the type, brand etc. of the generation unit.

In some circumstances, multiple causes of unavailability may occur simultaneously; in these cases, it is necessary to select only one. The main scenarios to be considered are:

- concurrent causes;
- new causes happening after an already existing one;
- external restrictions for the maximum power injectable into the grid, simultaneously with other causes of unavailability/de-rating.

These three scenarios are better analyzed in the following paragraphs.

1) Concurrent causes

This is the case of simultaneous causes that may all result in outages or de-ratings (e.g., a grid issue, contemporary to adverse weather conditions and also to other events occurring at GU level). In case of difficulty to identify the root cause of the unavailability the criterion is based on the "code hierarchy" of the cause, according to the column "cause code"; a higher cause code prevails over a lower one.

2) Preexisting causes

This scenario refers to outages started in the past and already associated to a cause, after which other possible causes appear. The general criterion used in this circumstance is based on the "time hierarchy", i.e., the prevailing cause is that one occurred first, until its resolution, regardless of its code.

Although the general rule consists in locking the initial cause until its resolution, the following exceptions can be applied:

- When a GU is de-rated because of a fault and then another fault happens causing the complete out of service, the entire unavailability is attributed to the cause of the full outage; in other words, a cause of internal de-rating ends when a cause of full outage starts.
- In the case that, at the end of a scheduled maintenance, a fault happens during the start-up of the plant the unavailability classification will change from "Planned maintenance" to "Fault".
- In case particular conditions occur after that a GU was stopped for an initial cause (e.g., fault), making it impossible to proceed with the restoration activities, the total duration of the outage can be split into multiple components with different classifications.

The initial cause is considered until the condition arises, then the classification changes consistently with the particular condition; afterwards, as soon as it ends and the activities can restart, the classification changes again to the initial cause until the end of the outage.

This mechanism can be applied only if there is a clear cause-effect relation between the condition and the stoppage of the activities, and it results in an extension of the outage of at least 5 days (120 hours).

In case changing the classification means a reallocation between Internal to External, LU shall identify the exception by submitting a justificatory report to the specific Competence Center. The Competence Center shall evaluate the request that, after approval, will be submitted to Operation Performance Unit for final approval.

3) De-ratings for External Causes

A scenario requiring special attention is the presence of external de-ratings, intended as limits to the maximum load acceptable for the grid, some examples:

- Grid constrains, grid curtailments, grid faults, grid maintenance.
- Plant upgrade that makes the plant capable to produce a greater capacity than that licensed.

In all these circumstances the maximum allowed capacity may be saturated despite some GUs being out of service.

With the aim to take into account the external de-rating and, at the same time, not losing information on the internal state of the plants it is convenient to calculate the availability of KPIs according to two views: the plant view and the grid view.

- **Plant View:** In this view the internal plant un-availabilities have priority over external de-ratings for the attribution of the causes.
- **Grid View:** In this view the external de-ratings have priority over internal plant un-availabilities for the attribution of the causes. This means that some internal un-availabilities of the plant can be overshadowed by the external de-ratings.

The two views have no effect on total Lost Production Failure LPF (and External Availability Failure EAF) but only on its distribution between external de-rating and internal causes. These views are applicable to all the technologies and, considering that the GUs of the same plant can affect each other during their operation, the grid view must be applied to the plant in its entirety. The plant view approach is mainly used to evidence the internal conditions of the plant, whereas the grid view approach evidences the external limitations due to grid issues. The grid view is the one normally used to monitor the achievement of the targets by the development of a non-critical system that could be reliable for end test reporting. The tasks described in the reliability programs, which are used more frequently are included in some standards such as MIL-STD-785 (Military Standards) and IEEE 1332 (Institute of Electrical and Electronics Engineers). The report made after the failure analysis and to create the task to correct them are also used in the process to monitor the reliability of a renewable asset

c) Master Data and KPIs

KPIs are performance indicators calculated based on the master data. Their values normally range between 0 and 1 (normalized values) and they can refer to time, capacity or energy. Master data, on the other hand, is data required for the calculation of the KPIs. Normally they are the results of the direct measure of time, capacity or energy.

Master data is listed in a chart containing its acronym, name, description, and unit of measurement, formulas and technologies applied (Table 2.4):

Table 2.4. Extract of the master data required for the calculation of the KPIs. EUC Operational Procedure.

Acronym	Name	Description	Unit of Measure	Formulas	Technology				
					Wind	Hydro	Geo	Solar	Bio
CAF	Capacity Availability Factor	Ratio between the net available capacity (NAC) and the net maximum capacity (NMC).	%	CAF=NAC /NMC	X	X	X	X	X
CLF	Auxiliary consumption and Losses Factor	Ratio between plant auxiliary consumption and losses, and gross actual production.	%	CLF=(GAAP-NAAP) /GAAP	X	X	X	X	X
CUF	Capacity Unavailability Factor	Ratio between the unavailable capacity (UC) and the net maximum capacity (NMC).	%	CUF=UC /NMC= 1-CAF	X	X	X	X	X
EAF	Energy Availability Factor	Fraction of deliverable producible energy that could be provided if limited only by outages and deratings (GAAP). It is assumed as a key measure of the quality of plant operations. The	%	EA=GAAP /DPE=(1-LPF)	X	X	X	X	X

		dependence of EA from performance can be considered linear, the limit values for EA are 0% and 100%, respectively corresponding to zero a maximum performance.							
EGAAPH	Equivalent Gross Production Hours	Number of hours during which a plant or a GU should operate at its gross maximum capacity to produce the gross actual production.	Hour	EGAAPH= GAAP / GMC	X	X	X	X	X
ENAAPH	Equivalent Net Production Hours	Number of hours during which a plant or a GU should operate at its net maximum capacity to produce the net actual production.	Hour	ENAAPH= NAAP/NMC	X	X	X	X	X
GCF	Gross Capacity Factor	Gross actual production GAAP as a fraction of the gross maximum production GMW	%	GCF=GAAP/GMP	X	X	X	X	X
LPF	Loss production Factor	Ratio between lost production due to deratings and planned and unplanned outage and deliverable producible energy.	%	LPF= LP/DPE =(1-EAF)	X	X	X	X	X
MTBF	Mean Time Between Failures	Average time elapsed from one failure to the next.	Hour		X	X	X	X	X
MTTR	Mean time to repair	Average time required to repair something after a failure.	Hour		X	X	X	X	X
NCF	Net Capacity Factor	Net actual production NAAP as a fraction of the net maximum production NMP.	%	NCF= NAAP / NMP	X	X	X	X	X

The KPIs with their definitions, calculations and technologies applied are listed in the chart (Table 2.5).

Table 2.5. Extract of the performance indicators KPIs. EUC Operational Procedure

Acronym	Name	Description	Unit of Measure	Formulas	Technology				
					Wind	Hydro	Geo	Solar	Bio
AEC	Average Energy Coefficient	Ratio between the gross energy produced and the volume of source used at average head.	kWh/ m3		X				
AH	Available Hours	Number of hours a unit was in the available state.	Hour	AH=(RSH+ SH+SHNG)	X	X	X	X	X
AUS	Attempted Unit Start	Action of trying to bring the unit from shutdown to the in services state. - Repeated failures for the same cause without attempted corrective actions are considered a single start. - Repeated initiations of the starting sequence without accomplishing corrective repairs are counted as single attempt. - In case of abandoned startup attempts with the unit remained shut down for repairs when it is started at a future time two startup attempts must b reported. Attempted unit starts are classified according to the services required, generating GAUs and non-Generation NGAUS; AUS=GAUS+NGAUS	Num		X				
CP	Energy Consumption for Pumping	Energy used by pumping storage plants in a given period for functioning in pumping mode.	MWh		X				

DPE	Deliverable Producible Energy	Maximum energy that would be produced with the resource that flows through the plant under optimum conditions, during a given period of time. The DPE depends on resource and capacity; assuming the capacity as a constant, the DPE can be considered representative of the mean resource flowed through the plant during a given period. DPE can be calculated by adding the lost production to the Gross Annual Production	MWh		X	X	X	X	X
DS	Delta Storage	Variation of the resource storage in the reservoirs. It is not accounted in the lost production.	Mwh		X				

Most of the listed Key Performance Indexes (KPI) can be grouped into several categories:

- Time-based KPIs
- Capacity-based KPIs
- Energy-based KPIs
- Quality-based KPIs
- Cost-based KPIs
- Safety-based KPIs

In the Annexes of the thesis, there is more information on KPIs reported.

d) Reliability

A big percentage of the failures that occur in the machinery likely originated due to human error. It is also true that humans could detect these failures and make corrective actions, as well as set an improvised approach if these situations happened.

The policies that take out the actions made by humans in the design or production phases are not effective. The best-balanced situation is that one that addresses the actions to the actor, using either machine or man in each case.

In addition to human managing mistakes, the data and information can also be huge contributors for the lack of reliability. This is one of the main causes of the high level of no reliability in complex systems, and the only way is to develop and establish very strong process for engineering designs, plans and execution to validate the activities. In order to create a culture around the reliability concept it is necessary to properly share data and create protocols as was done to safety. The prediction in reliability includes [40]:

- Creation of a proper reliability model, in our case for renewable assets.
- Develop the key parameter indexes for the model; define the limits and the triggers of each KPI with the actions in case of trigger.

- Deploy the limits and triggers for each KPI, at the proper level, in our case for the generation unit, for each component group and for each system group. Could be extended as well in organizations with an ERP to all functional locations.

To set targets and make the organization accountable for them, it is very important to create a fair way to measure, quantify and qualify, to make the reliability targets achievable. These achievements could not imply huge investments, or expensive systems, in the majority of the cases, just deploy the proper culture within the actual organization to benefit from reliability measurements. It is important to create a ceteris paribus model in order to evaluate the data properly and to agree on which actions should be taken. The design phase is very important in the reliability system, not only for the organization but for the product or service in order to include any deviation coming from the data. Its need to challenge any deviation in the operations, and check if it is due to product or action, to solve it in the appropriate phase. It is important to feed the designers with the unreliability challenges to remove it, or to improve it. Having the model, and the reliability process established to all the product phases, it is important to be accountable for any measurement, in order to not play with the numbers. It is very frequent in some organizations that share the responsibilities, not to act as a unique and accountable owner. This situation, usually generates tensions to address responsibilities with regard to reliability numbers, failure rates, MTBFs etc. It is important to note that the reliability concept is a strategy, so it is necessary to measure it by trends in large time periods, it is very common to act as a fire fighter, searching for a quick result. This situation is not possible in reliability, or in safety, quality etc.

In our case, we will use the reliability concept in the major component groups, structural, mechanical, and electrical, and in the systems, electronic, electric, hydraulic, and mechanic. It is possible that due to the nature of the organization the feedback to the design phase is limited, but we should guarantee a way to communicate with the OEMs if any deviation is found in the renewable assets.

The conclusion is that performing a fine-tuned prediction with a high accuracy using the available data or testing is not possible. It is important to understand that the objectives should be in the same range. Having predictions with hourly time frames but getting response times in daytime frames does not match and happens very frequently. For that reason, it is very important to coordinate the timeframes and any other targets and frames of targets or objectives.

One exception could be the wear out failures, or the ones involved due to fatigue. In the standard MIL-STD-785 it is mentioned that reliability prediction needs to be taken with caution and not only compare KPIs and take actions. A comprehensive approach is needed. In the proposed model, we use the MTBF and MTTR linked to each system or component group, in order to have four sets of KPIs for the systems, calculating the number of hours that a GU is stopped due to a failure, and grouped by system. The same exercise is performed for the component group, but we found a correlation between the TSG (troubleshooting guides for systems) and the impact in the LPF, so we choose the systems. With regard to the component failures, we use the Weibull distribution for each group as a prediction of component intervention, either by exchange or repair, which also affects the LPF but is more relevant in the LCoE. Regarding the algorithm-based model with the LPF output we do not include the component group classification. If we want to take the leverage cost of energy (LCoE) into account, we should include it since the OPEX cost is relevant in this case.

The process that includes the procedures and the tools to ensure the reliability in a given product is called Design for Reliability, and as is mentioned in this work it is necessary to take into consideration not only the design elements but any other data or information available from product use.

i) Statistic Based Approach (MTBF System and Component)

To develop a fault tree analysis is the initiator of the reliability design. This FTA is regulated by a standard included in the bibliography and provides a means to evaluate the relations among parts, systems, components and group components. It could take predictions from failure rates addressed by historical data, as mentioned it is not an exact science but shows valuable information for the different alternatives in design or maintenance parameters, one of the main KPIs used is the Mean Time to Return (MTTR).

The causes of the failures and its mechanisms should be analyzed and identified with the proper tools. Statistical or engineering tools are used to this end, developing the knowledge to be transferred to the designers using the FTA, or root cause analysis (RCA) as well as failure modes and effect analysis (FMEA) included in some standards in the bibliography. It is very important for them to reduce stress in parts if this may cause a failure in the future. The lifetime cycle of a component or a system, maintenance factors, etc., should be considered in order to better design products under the reliability point of view. Validating in a proper way the loads and testing performance is needed as well. Digital twins, models, or data from the actual fleet could be used in the portfolio. In case of a large portfolio as is this case, it is very important to have good data management to convert the data into valuable information to be transferred to the stakeholders of the assets, including the designers in the OEM, and the rest of designers that provide components.

Another technique that is possible to apply in the design phase is redundancy, which could mean having double components in the critical paths, or to be able to use a shortcut in case the system fails. A backup system could be used as well. This is not an alternative that the designers want to use as a first option; due to at times being very difficult to have data that evidences the reliability of a new system or component. Getting the data is sometimes expensive and or impossible to achieve. Redundancy combined with a high control in the failure monitor, and applying the techniques like FMEA, FTA, avoiding the frequent failures, making a system run into a high confidence level of performance. It is not necessary to test the reliability in such cases. It is important to use the ceteris paribus conditions, so if we are using these techniques but have different suppliers or different manufactures for the components in the same system, it is possible to put additional noise into the equation. The redundancy concepts can be applicable as well in data, or other knowledge base activities, to prevent calculation failures, or missing steps in a process. Another activity that can be proposed is to perform predictions on degradation to prevent the unscheduled downtimes for failures, using programs such as the Reliability Centered Maintenance as an important measure to achieve the objectives (Table 2.6).

Table 2.6. Regression for the LPF Hypothesis

Regression Statistics	
Multiple Correlation Factor	0.99
R^2 R-Squared	0.98
R^2 Adjusted	0.97
Typical Error	0.00
Observations	5000

As was commented in the introduction and using only the explicative variables in our analysis, we compare the hypothesis if we can predict the LPF as a linear combination of each variable listed in the input model table. The result shows that we can accept this hypothesis, assuming that we can predict the LPF with our model. Additional studies have been carried out to measure how each variable impacts the result and to find the relationships between each variable in order to build a decision matrix that will be provided to the GU operator to optimize the output. The next steps are to automatize the decision matrix, machine learning methods and to generate the plan activity models automatically using the variables and the reports of each task that are performed in the GU, measuring their impact by means of the thermal signature, and finally updating the weekly and annual plans.

2.2 Equipment monitoring methodology

The method we used in this work was described in four stages. We started with studying the documents and literature regarding the component based, either national or international. We use the FMEA and FTA standards to develop the failure tree, with the related causes, the different failures or faults and the main causes to stops the renewable asset, and which component or group accounts for the stoppage. The second stage is the part that take into account the experience in the different entities operating and maintaining the renewable assets in order to discover which the best combination is, the strengths and the weakness of each classification, if it is possible to classify the components for different technologies, the tasks the activities and so on. This is a classification that we did not see in any other document. Basically, we developed a unique system that classified the components and the activities in the same way for all these technologies under the renewable asset management, and each activity should be addressed through a report, planned or preventive activities (BTS), unplanned or corrective activities (TSG) and planned or major corrective activities (AVS). The third stage is focused to apply the knowledge, the information and the direct observation, reports, checks etc. That allows us to make it more specific and concretized the activities under the renewable assets management system. In the fourth stage the behavior and the performance of the components is measured and monitored using inspections, direct sensors, or indirect measurements. Some examples are vibration and oil analysis, thermography or blade inspection, drones check etc. the description by phases are:

- Phase 1—Diagnosis: It is carried out by an operational expert where the RAMS will be deployed. The targets will be to collect operational data, realize the behavior of the people by observance to be able to set the strategic master plan. After the data collection, a diagnostic report should be released with the recommended actions, analysis, discussions the approved adapted activities presented in the renewable asset management.
- Phase 2—Strategic Master Plan: it is developed to search the opportunities as well as the objectives defined in the Diagnostic report from the phase 1. It is prepared by a reliability center maintenance expert, presented, analyzed, deployed and approved by the board of directors, in the renewable asset management of the entity, and choose the people involved in the program to define the needs and targets as well as the areas in which the program will be deployed.
- Phase 3—Training: In this stage the knowledge of the team members will be improved in order to develop the program internally. For the leader roles, pillar coordinators and steering committee personnel.

- Phase 4—Follow-up: In the last stage the expert together with the coordinator will monitor the performance and the deployment. The meeting set ups with the pillar coordinators and the plan to perform the audits to check that the previous phases are well deployed.

Electric predictive maintenance is an activity that is needed to be applicable in this approach followed by a component analysis. Renewable assets are mainly generation units to produce electricity, for that reason, some of the more critical component groups are precisely the electrical ones. Predictive activities in this group of components become crucial, since due to the ramp up in the plants, the components are bigger, and it is not always easy to get an outage with parts in the warehouse. This predictive should be set up to follow the phases and create a clear schedule and plan to perform all BTS, TSG and AVS activities, according to the model described in this part. It is important to develop the same strategy for the mechanical components that are more frequently used in these plans, and probably with the structural ones, but these are not so influential as the other two groups.

a) Vibration Analysis

This type of analysis is based on the vibration stages of a rotating component. The sensors that can have one two or three axis measurements, release the vibration modes sorted by frequencies. Due to the balance construction of the rotation components each frequency should have a limit and a trigger that in case of mass losses or cracks, failures etc. makes it possible to address the failure early to not provoke a catastrophic fault, reducing the outage downtime [14-19].

The triggers, alerts and alarms have a severity level that is a function of the drive power, that is related to the mass, torque, and angular speed. With these charts it is possible to create an initial model to measure and check but should be fine-tuned along time with experience and good data management.

Vibration Analysis is based on the measuring points. Following ISO 10.816-6 and ISO 8528-9 standards, it is possible to make a classification of mechanical components. It is also possible to use electrical components and instead of using the vibration modes, using the harmonics from the power train waves, is a little bit cheaper but improved data sets and experience information is needed. There is a classification for the drives and the generators in a plant that belongs to group 3 of the ISO 10.816-6. In the table the vibration levels are 18 mm/s, root mean square (RMS), but as mentioned, this is only the start point of the study, we should keep measuring to check for trends, instead of points in order to see how close the acceleration values are to the trigger limits in order to calculate the time to stop and make an inspection to confirm the failure or to plan a replacement, retrofit or repair activity.

Taking all these measurements and making the comparison with the limit levels we may address a big percentage of problems that can be checked by this kind of analysis. Some of the activities could be to align the drive train, to exchange bearings, to exchange pinions and gears, if the damage is not contained, to exchange the main shafts, medium or high-speed ones, or refurbish any of these parts. The critical problems may require an exchange of the drive train and plan the outage, with enough time to not stop the unit until the spare part is in the plant. Then the action is the coupling replacement, if a kind of reliability analysis was done at a component level, then probably we may choose a more reliable component, to remove the root cause.

b) Analysis of Lubricating Oil

Following the IEC 61400/1 we should extract oil samples every 6 months in every GU. This allows us to create a data base with more than 20.000 units around the world, with the chemical analysis to each oil sample, and with trends from more than 20 years. This Database allow us to create some trends and best practices base on the results, performing updates in the condemned rates, for oil, or limits in some metal particles or water to perform corrective actions, in order to increase the life of the component.

c) Thermography

The images that capture the temperature range in a system or in a component, show a color ranking, this inspection method can detect the variations or hot spots of the heat surface. This cause can be the current intensity, a hot fluid condition, or directly the heat in some parts due to the tribology. This technique can be applied to all groups of components and systems in which temperature is an explicative variable of the performance model. In the case of this study, we can apply it to all our component groups and systems.

This technique could be applicable as well to hydraulic pipes, or cooling systems to see if there is a blockage in the conductions.

d) Isolation Resistance Test

This is an electrical test performed in all the electrical components that have isolators, to prevent leakage currents and so on. This test periodicity should be defined and will help to detect possible aging effects due to thermal or site conditions, salinity etc. in the generation unit.

e) Polarization Index Test

This test shows the evolution between the IR test performed in different periods of time. The Polarization Index (PI) can be used to evaluate the performance of a rotating electrical machine. The test calculates the measurement of the resistance in the winds of an electrical device. This analysis gives some valuable information regarding the performance, dirt, salt, dust or the degradation in the conductors, compared to the measurement in the warranty period or in the fabrication data. It is possible to use as a safety measurement to check how far an electrical device is to its braking point.

f) Dielectric Absorption Ratio Test

The Dielectric Absorption test is a complementary analysis that can be used together with the insulation resistance test. This type of test, instead of a spot measurement is a time period one, using electrical injection over 10 minutes in order to measure the behavior, hysteresis etc. Due to the time application, the insulation will be polarized, and this gives a value information of the dynamic performance of the electrical component.

An extension of the insulation resistance test where instead of a spot test, the testing device is applied to the insulation for up to 10 minutes. The device when applied in the insulation system produce three types of current flow:

- Leakage current; this is a flow current that is resistive, and it is measured by the IR tester. If this current is low, the insulation system condition is high, and applies the other way around.
- Capacitive charging current: this is a flow current due to applying DC voltage to a capacitance, this test drew a high current at the beginning but then dropped very quickly, as soon as the capacitor was loaded with charge. Timeframe is around 1 second.
- Dielectric absorption current; this is a flow current that will draw the insulation system putting the dipole aligned applying a field. Timeframe is around 10 minutes.

g) Development of Thermal Signature model for the GU diagnosis

Finally using the Energy Utility Company data base and the data coming from the SCADA system regarding the status of the component, temperature, pressure, density, etc., we will develop the model to use the thermal signature or the relation between the temperature and the other status signals from the different parts of the GU in order to check for variances and make a proper diagnosis of each. Having more than 50 million data points regarding these signals and 4 million activity reports we will demonstrate that we are able to prove with more than 99% confidence level that any temperature variation is a condition for the wellness of the component. Due to this relation, we develop a proceeding to test nano-additives in the cooling liquid of the electrical components in order to increase the cooling capability without making any investment [12]

2.3 DATABASE FOR THE STUDY

For the study we used a database that hosts 50.000 MW around the world with more than 100 tags per unit, and with a frequency of 10 minutes, so we got close to 100 Million data points per year. Then we added the reliability data like the vibration analysis online performed on a monthly basis. The oil analysis, that is included, every 6 months for the units. Finally, we developed a digital report submission that reflects every task performed in the GU, planned or unplanned, to all of this, getting 5 million reports per year. With this data, we created several paths to investigate the relations. For example, the frequency to change or repair a component. In order to generate the Weibull distribution of each component failure (exchange). This created a frequency for failures that we estimate with the Relisoft software. These charts show us the situation if we do nothing to improve the life component. In order to correct it, we created the real frequency of failures and compared them with the Weibull distribution from the software in order to adapt our strategy. The singularities of this mechanism will be explained the mathematical tools.

We include in the annexes some examples generated of the Weibull's per failure to confirm the Fault Tree Analysis, and the Failure and Effect Mode Analysis in the IEC standards.

To use this data-base output we should create a group to coordinate all the reports, events, and the use of the different software to release the failure frequencies and all the variable relations among them, as well as the activities performed in the GU. The coordinators of Managers of the Entity (ME), Managers of the Asset in our case Generation Units (MA), Predictive Maintenance (PM) and Environment Supervisors (ES) should consider the following list:

- Form the working groups to complete the operational flow in order to do it with clearance and candid feedbacks, to detect the risks, equipment and priorities to be identified for all of them.
- Structural, electrical and mechanical components should get a unique identification with the nominal and actual load curves.
- Develop the listed criteria to analyze and identify the load losses in the performance.
- Use the PDCA (Plan-Do-Check-Action) cycle, create fishbone, and any other methods to detect, investigate and eliminate load losses.
- The working group should prepare the action plan with owners, people responsible, a list of activities, progress and time limits.
- Deploy the action plan and make a comparison with the results before and after.
- Complete the transitory operational standard to be used in each component group by the operators.
- Evaluate the performance of the component groups, using the indicators, objectives and targets, described in the definition. The information from the operational reports should be distributed among all the stakeholders.
- Avoid data misalignment or distortion. The operational reports should be evaluated continually by all the stakeholders before and after.

- Check the indicators that rule the operations by the operators in order to detect any distortions.
- Follow the operation standards in order to make comparisons and corrections by the stakeholders.
- Monitor in a continuous way the operations by the operators and use the requirements and the specifications to take the described actions.

In order to develop and perform the maintenance pillar in an autonomous way, the group should include management, supervision personnel and operation personnel. This list of things should be considered:

- Clearance and tolerance, the operation personnel should have the proper training to detect and identify anything out of the range in the group of components and labeled according to instructions received in training.
- The generation plants, units and all the areas involved should have a procedure to set the order and the cleanness levels to avoid any dirty areas, or lack of hygiene.
- Deploy the 5S [32,41]
    - Sort-(Seir)i: Take out from the work area any non-needed item.
    - Set In Order-(Seiton): Locate each needed item in its own location.
    - Shine-(Seiso): Keep the workplace with high level of cleanness.
    - Standardize-(Seiketsu): Deploy the best practices in the workplace as a standard.
    - Sustain-(Shitsuke): Maintain the needed levels all the time.
- After labeling the group components and the work area, a control plan is needed to define the problem and the actions together with the areas involved in each deviation
- The operation personal will revise the conditions for the component groups and mark with colors, nameplates etc.
- The labeling activity should be addressed with a time period report to check how many labels were placed and how many were removed in the period defined as a controlled one.
- All the above activities must be carried out correctly, to begin identifying hard-to-reach places, eliminating sources of dirt and drafting the provisional standards for cleaning, lubrication, inspection, safety and the environment.
- Make the autonomous maintenance pillar in a structured way in order to be presented in the plants to the stakeholders.
- Define how the deviations should be detected and determinate and train the stakeholders in the labeling process.
- Define and train how to deploy the cleaning process following the actions established by the labeling control.
- Deploy the label process, informing using the KPI (key performance indicator) and the tags in use.
- Remove the labels using the removing process.
- Use the KPI to indicate the number of labels removed and perform the audit to be sure the program reaches the target.

The Planned Maintenance Pillar:

- Develop and complete the checklist for the priority activities, including the list of questions for the involved areas.

- Evaluate and classify the component groups by letters, according to the importance of each component in the operation for the plant.
- Manage the stock in accordance with the letter codes, developing the reorder points for the material following urgency and importance.
- Plan inspections on all the component groups and catalog all the equipment, to be performed by the operation department.
- Review the component groups in order to meet the maintenance standards described by the OEM (original equipment manufacturer).
- Define an action plan to develop and perform any repair, maintenance, or inspection activity with the classification of the letter codes, in order to establish a prioritization.
- Develop the year plan tool for the planned activities (BTS and TSG) and the weekly scheduled tool for the unplanned activities (TSG) to all component groups.
- Use the KPI to indicate in the report the mean time between failures or the mean time to repair (MTBF, MTTR). Develop the critical analysis using this KPI to set targets and work against objectives.

The main conclusions were, if we increased the MTBF and reduced the MTTR we will get more time the plant operating in a year, this means more energy output and less cost of operation. The increased planned activities versus the unplanned ones also make a huge impact on the operative cost; due to it not being necessary to have a large amount of personnel to cover the activities.

To make a better assessment and use the reports to analyze how the results evolve, the total productive maintenance concepts (TPM) is used as well as the predictive maintenance process. The use of these two concepts in a smart way makes the component groups and systems increase the MTBF significantly and reduce the MTTR. In our case, in the wind technology of the entity, this reduction reaches 50% yearly impact.

In the work we have done, we use the MTBF (mean time between Failures) for all component groups and for all the systems under the study. We set up a baseline for all groups and systems but different for any of the five technologies under the study. Start the process and measure the values in a continuous way monthly, checking that after two years the increasing operating hours were very high in the percentage rate was mentioned.

The mean time to repair or to return (MTTR) is a measurement for each reparable item that we are using for each structural, mechanical, electrical component group and for each electric, electronic, mechanic and hydraulic system. MTTR time for repair is a measure on the basis of reparable item maintenance and calculated in the four systems and tree component classification. It shows the mean time required to repair or to return a component or system failure. The calculation also includes automatic resets, the local resets and the remote resets.

Based on the information extracted from the data of each generation power plant, it is possible to identify the causes of generation unit shutdowns and classified and addressed for each component group or system. The solution of a problem in the real situation of the entity is verifiable. With this, it is possible to simulate a plan of what would happen if presenting profits with the low-scope generation plans and develop a case model that helps the RAMS decide the decision suitable for each generation plan. This could be measured on the basis of the information of the case study, which, over time and simulation, presented a high number of occurrences of corrective actions for a component group or system.

Therefore, as soon as the problems or the failures in a component group or in a system was acknowledged, the entity section proposed a deployment of the system described, first the predictive diagnosis and second a total maintenance program. When the program generates success in a group of components, it could be interesting to move the same model to another group of components as well as to the different factions of the company.

The model based on reliability is a process that tries to understand the performance of a component and is able to predict the outputs before the system is set up. In the renewable asset management, we create our own reliability model, that will be applicable mainly for Operation and Maintenance, but will have some deliverables and outputs for lifetime extension and the design for reliability phase. There are various types of analysis to realize the availability of a system; Fault Tree Analysis (FTA) and Reliability Block Diagrams (RBD) are the most commonly used for this activity. This analysis can be performed at a group component, system or extended to the all the parts. The model is fed by several sources such as tests, former experience in the operations of the component, historical data, handbooks that could come from the same industry or from others with some equivalences. Despite the source, the prediction should be used for the component in its own use, same context and same function, to not add noise to the reliability calculation. The predictions are used to make a choice so different alternatives should be presented:

- Physics based approach, which uses the theory and the knowledge in fracture mechanics, load and fatigue, propagation theory of failures, corrosion or degradation etc.
- Model based approach, which uses the knowledge and empirics to create predictions that are based on the component types and systems and the stress applied in operation performance.

As has been explained; the reliability is the probability that a renewable asset or generation unit performs its function in time and condition as specified in the product requirements document. This definition can be extended to parts, components, and systems.

This definition includes some important points:

1. Reliability is defined over the design function of the system or the component. But if all the systems that include the generation unit or the renewable asset fails but does not perform the action that was design for counts against the reliability of the system.
2. Reliability is specified for a time, period, timeframe. This means that it is not infinite in time, the systems are designed to be used in cycles or years, or any other time measurement. An example in the renewable asset is the IEC 61400/1 that defines the design life of an asset, for example 20 years.
3. Reliability enclosed to the stated operation. It is not possible to design without restrictions or limit conditions.

To use reliability concepts some key parameter indicators, need to be specified. Some of the most common are the mean time between failures (MTBF), and mean time to repair or to return (MTTR). It is possible to compile both and classify them at system or component level, to set a trigger base on a time period, for example how many hours a system is out due to a failure in a year. It is possible as well to use percentages or lost production factor (LPF) or the efficiency concept to address them. These KPIs allow the analyst to approach the problems using statistical data and focus on alarms or triggers that are more important or get more impact.

In our case, this test or inspections should be performed at component reception, during the warranty period and before the end of warranty, a massive component inspection. The test performed to get the more reliable renewable asset, should be performed in different steps. It is different to test a complex system or a simple one. The statistical approach is the same, it is necessary to take type 1 and type 2 errors, check the sample size, and time test to put the limit to the test, in order to minimize the errors in the acceptance. The confidence level that we established is a very important indicator and has a paramount role in the test for reliability. This indicator increased when the period of the test increased, as well as the number of components or systems samples with the same characteristics increased. The plan test for the reliability should be designed to achieve the number for a group of components or systems with ceteris paribus conditions in a period in order to be able to show the test results and take the decision to deploy the program, if the case is relevant for the entity management. The plan should address the different risk levels to all the stakeholders. The target for reliability, confidence level, risk level for each stakeholder and at a system and component group, influences the test plan. The stakeholders should have an agreement in plan fulfillment and how the program should be tested. A very important side of the test for reliability is the definition of failure. Even though obvious, it needed to be fair, and very specific to get the ceteris paribus conditions. In the five technologies we are studying, the weather, operating hours and the resource are aspects that should be considering. Getting values that reflect the reality of each renewable asset is important to apply the correct reliability program. It is also very important that all the stakeholders have the same sensitivity to the results to get a fair accomplishment, to address which is a success scored by component and system and which is a failure in the deployment.

During the phase in which the requirements are developed, the reliability group develops and deploys a strategy with the renewable assets' management. The test strategy makes deals between the needs of the entity which wants the highest amount of information extracted from the data, and constraints such as cost, schedule, and available resources. Test plans and procedures are developed for each reliability test, and results are documented. These results should be comprehensive and engaging to the rest of group reports such as quality reports, engineering and construction acceptance tests, operation and maintenance records etc.

Reliability tests could be a requirement to accept an assembled component or system for a GU, some examples are in the IEC 61400 series, for blades, gearboxes etc., and IEEE for generator and transformer testing. All these standards are listed in the annexes and bibliography. The reliability and maintainability KPIs defined in this document are based on the following general diagram (figure 2.4):

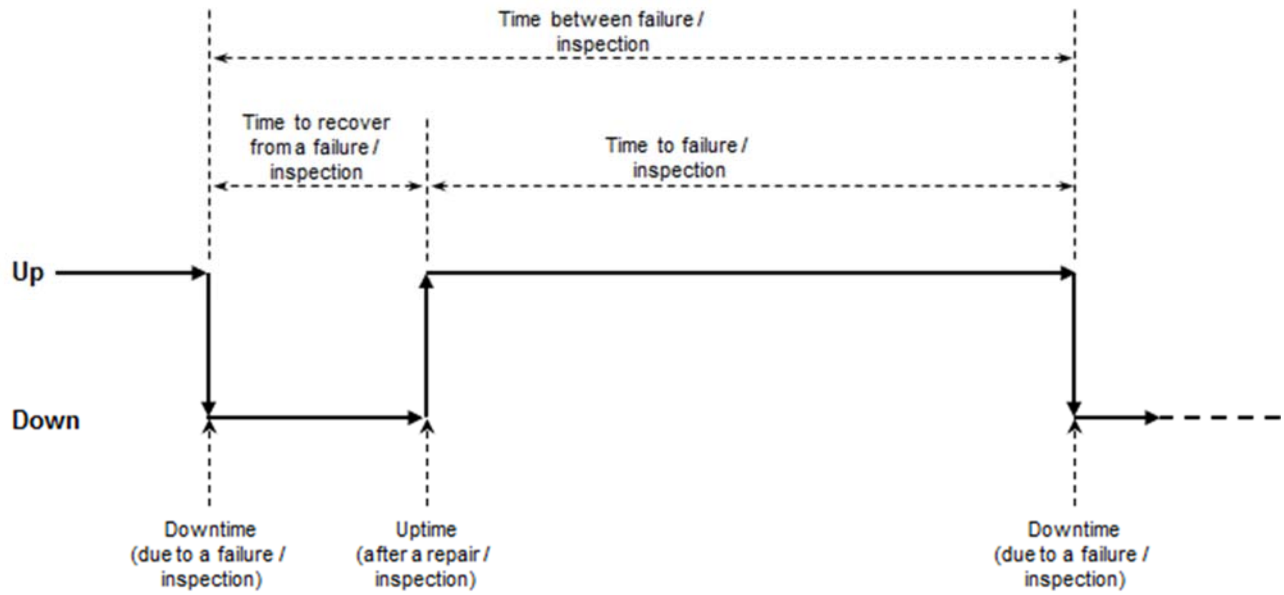


Figure 2.4. Medium time between failures

Further details on the definition and calculation rules are in the following paragraphs.

Mean time between failures (MTBF): It is the mean time between the start of downtime due to a failure and the following one, in a given time interval.

$$\frac{\sum(Time\ between\ failure)}{Number\ of\ failures} \quad \text{Equation 2.1}$$

Mean Time Between Inspections (MTBI): It is the mean time elapsed between the start of downtime due to a planned maintenance/inspection and the following one, in a given time interval.

$$\frac{\sum(Time\ between\ inspection)}{Number\ of\ inspections} \quad \text{Equation 2.2}$$

Mean Time to Recover from Failure (MTTRF): It is the mean time elapsed to return to operation after a failure, in each time interval.

$$\frac{\sum(Time\ to\ recover\ from\ a\ failure)}{Number\ of\ failure} \quad \text{Equation 2.3}$$

Mean Time to Recover from Inspection (MTTRI): It is the mean time elapsed to return to operation after a downtime due to a planned maintenance/inspection, in each time interval.

$$\frac{\sum(Time\ to\ recover\ from\ a\ inspection)}{Number\ of\ inspection} \quad \text{Equation 2.4}$$

a) Reliability Test/Check requirements

The requirements for a reliability test need to be defined or estimated. They could be a function of failure probability or modes of failures and FMEA requirements. It is necessary to define the level of confidence that is required to pass the test or not. It is very difficult to balance well the test with the cost and the confidence level. For that reason, the approach followed here, a mix of reports is generated that will set up some values to be inserted in the model, and via Monte Carlo simulation or real time data fine-tune the model outputs to reach the desired confidence level.

One branch of the engineering is used to design test programs that are balanced in order to not increase design cost or reduce the level of quality. Confidence level of 99% in a MTBF of 10.000 hours could be a trigger or a reliability requirement. In renewable assets the resource is frequently used as a measurement in equivalent hours and the availability of the asset in time or in resource impact, like wind speed, solar radiation, or water flows.

b) Accelerated Test for Renewable Assets

The purpose of high acceleration load test (HALT) and similar tests is to generate a failure in a bench test but in a shorter period than in the field with the aim to simulate the life of the renewable asset or component in days. Objectives to be achieved are:

- Realize hidden failures or design gaps before use
- Simulate the life in the bench test from the accelerated test.

A high accelerated load test can be described in the listed lines:

- The clear definition of test scope and objectives.

- Compile product requirements and information.
- Stress or weak points identification.
- Address stress limits and triggers
- Perform the HALT test and retrieve the data to get the information.

To address the life stress or loads there are several models that can be used:

- Temperature–humidity model [42]
- Temperature non-thermal model [43]
- Eyring model [44]
- Arrhenius model [45]
- Inverse power law model [46]

Operation and maintenance activities be they preventive (all the activities that can be uploaded in a yearly plan from the original equipment manufacturer manuals or own generated manuals), predictive (all activities that after a RCM and data collection can be predicted to avoid failure) or corrective (activities that are not possible to plan, and are basically the primary focus of the RCM system) performed on a system or a component can effectively improve the reliability of the GU.

In this description single component group or system reliability is considered a constraint, and single component group or system, minimum unit time maintenance OPEX as objective function to obtain optimal maintenance cycle and maintenance times and stoppage reductions. Following the theory to repair a component group or system, it must meet certain conditions to confirm the statistical model. At the end, an OPEX cost baseline and deviation limits should be set to build a probabilistic function with the maintenance factors as variables. This equation should be solved both theoretically and practically with data to build a robust model and transfer to other technologies or component groups /systems being able to display the model and correct with the data. The example analysis shows that the model can effectively save the total maintenance cost.

This study has some reference significance for the maintenance department to make the operation maintenance plan with the preventive maintenance plan tool (Boxed Task Strategy BTS Plan Tool) and the corrective schedule with the corrective scheduling tool (Trouble Shooting Guide TSG Schedule Tool). Finally, with the predictive approach, and all plan and scheduled tools, be able to predict the advance services for system or component (Advanced Services AVS). The aim of this renewable assets management system is to optimize the tasks that we need to perform in a GU, optimize means, reduce, eliminate, improve, or be able to plan in order to reduce or eliminate unplanned events.

The widespread use of renewable energy is becoming increasingly important in all countries, and now due to the COVID 19, this attention is even greater. The installed base is high year by year. The GU is an important part of the renewable power system, is a complex system and should perform over a long period. The environment in which it should perform is not perfect, and due to the characteristics of the field sometimes it is difficult to install and repair. The fine-tuned maintenance plans and schedules using the tools already mentioned to operate (BTS/TSG/AVS) will improve the reliability of the generation unit but also reduce the OPEX cost to being on the baseline with minimal deviations.

The optimization of System / Component maintenance strategy is done by simulation. The Markov Chain and Monte Carlo Simulation was used to study the maintenance decision of the component of the GU, but it can be applicable to all mechanical systems in the Renewable GU. The model that calculates component groups and systems failures is used to optimize maintenance plans and schedules, converting the un-plan into plan, and heavily reducing the

OPEX cost to fit the baselines. Sometimes we tend to solve the problem at a component group or system, and in reality, we should solve all the GU and even at plant level.

The GU is composed of key parts, such as the Drive Train, as part of the Mechanical Components and Mechanic System. These will be studied as well as Electronic, Electric and Hydraulic, and finally all the Safety components as an independent part to include the BTS/TSG/AVS tools approach.

The drive train one of the component groups in our classification and can have parts of all four systems described in this work. There is a correlation between components of multi-component system and signals, parameters, reports historical data etc. This will be the base of our algorithm to develop the BTS and TSG Tools. Convert the un-plan into plan activity is a key driver to reduce cost, in the case studied more than 50% with a very small increase in OPEX cost and people resources. The FTA/FMEA/FMECA analysis was also performed in this document following the ISO/IEC/IEEE standards. We propose an opportunistic maintenance model based on reliability of GU in this document. The model makes an optimization of the total OPEX cost using the reliability as a maintenance based on information and both theoretical and practical studies. The optimization variables to obtain the minimum maintenance and lost production cost will be described in another chapter [47].

We presented a model based on state-opportunity maintenance, as well as the practical data coming from the entity's data base for renewable asset management in this document. The Algorithm model is based on the system state indicator, as well as signals, parameters, reports etc. This model can also take decisions if the triggers of a group component or system exceed the real baselined ones, and an overhaul strategy could be applied.

Based on the model of GU requirements in renewable asset management for a component group or system, the work done is listed as follows:

- In a first stage the distribution for each component group or system, reflects its life probability and is obtained using the information from the historical data, and creating Weibull distributions. Using the statistical and historical approach, it is possible to set some life limits and baselines, which after being applicable should correct the Weibull every year or in the period of time that established.
- In a second stage, maintenance strategy is defined based on reliability. Targets, triggers thresholds for component groups and systems, together with the OPEX cost associated for each activity and the tentative LCoE are calculated together with the LPF and the estimated cost loses in production.
- In a third stage, we used our algorithm-based model in order to get the optimization of the component group and system performance, using the cost for the losses and for the repair as a trigger to apply each different option and compare it with the actual model, and correct any deviation in the trial period. Afterward we generated the Yearly plan in the BTS Tool, and the Weekly Schedule in the TSG Tool. AVS is described because of TSG scheduling tool, due to it being a special case that implies component change or repair or overhauled, for that reason we did not develop a tool to predict AVS, basically because it is included in the TSG and BTS tools.

2.4 BTS/TSG/AVS MAINTENANCE STRATEGY FOR A GU

The maintenance methods of the GU derived from the renewable asset management system are three different kinds:

- TSG or corrective actions that are not possible to plan.
- AVS or corrective actions that are possible to plan, like inspections and major component exchanges, up tower repairs etc.
- BTS or Preventive actions that are planned, and should be updated with the maintenance records, historical data, and the output of the algorithm-based model. The GU is composed of a list of group components and systems such as mechanical, structural and electrical, or electronic, electric, mechanic and hydraulic systems that allow the component groups to perform their actions. Safety is another system involved. Despite being the most important, the actions involved in that system are only checks and certifications. The reliability function of component and or system from the GU decreases with lifetime. The model of maintenance based on opportunity for GU based on reliability follows this description: if the component group and system reliability reach the trigger of a component (BTS), preventive maintenance is carried out. This opportunity can be used to perform corrective checks in the other parts of the unit in advance (TSG), so as to improve the reliability of the unit reporting the status of everything by digital app and reduce the loss of downtime and the cost of maintenance. And finally, if it is necessary to change or repair a component, we will use AVS.

a) Algorithm Model Hypothesis

To make the study simpler for the model we built the algorithm based on the assumptions described in the following list:

- every group component and system of the GU is new in the initial time or a depth revision should be performed to reset to factory set point and correct any deviation to be as sure as possible that it can perform as if it were new, this is very important for the assumption of the Weibull distribution.
- If an unexpected failure occurred in the generation unit, this problem should be solved as described in point number one of this list, in order to generate a distribution with the correct related time.
- The GU is based on the unstop performance and the failures taken into account are those that affect a group component or system and cause GU stoppage.

b) Analysis on the cost of opportunity maintenance for Generation Unit

During recent years we are experiencing a revolution in the business world when it comes to improving decision making through the use of Big Data and Data Mining. When talking about big data, data set combinations and sized data based with a huge complexity is displayed that makes it very difficult to manage or process to let the information being analyzed using former technologies. The Big Data concept also encompasses the infrastructures, technologies and services that have been created to be able to manage this large amount of information.

In renewable energy stations a multitude of sensors are installed that periodically collect different types of readings, such as temperature, electrical power, etc., that are sent and stored in a central repository. These structured data, unlike the unstructured ones such as texts, videos or audio, can be stored in a relational database but their huge amount, as well as their speed of growth, forces the use of Big Data techniques for the treatment of them.

On the other hand, Data Mining consists in the process of detecting information that can be processed in sets of large amounts of data. It is the set of techniques that is used for the extraction of useful information and that are applied for later analysis in order to perform a search for Big Data codes.

Although both Big Data and Data Mining are related to the management of large amounts of data, they have different purposes: Data Mining is the set of techniques for extracting information while Big Data is the technology capable of capturing, managing and processing this data in a reasonable amount of time.

c) Architecture and data types

In our case, we use Data Mining techniques for the main KPIs shown as explicative variables. The main ones: MTBF (Mean Time Between Failure) and MTTRf (Mean Time to Return after a failure) predictions MTBI (Medium Time Between Inspections) MTTRi (Medium Time to Return after an inspection), LPF lost production factor either due to internal or external causes, IoP (Impact on profitability). Figure 2.5 shows the architecture of the system developed from the data collection by different kinds of sensors, storage in the SCADA database, analysis and selection of the prediction model and, finally, the exploitation by the user. The input data types to the prediction model are:

- Electric variables such as generated power and cosine of phi
- Environmental variables such as ambient temperature or wind speed
- Endogenous such as internal temperatures or pressure in liquids
- Breakdowns such as type of fault, affected component and repair time
- Timestamp of each of the readings

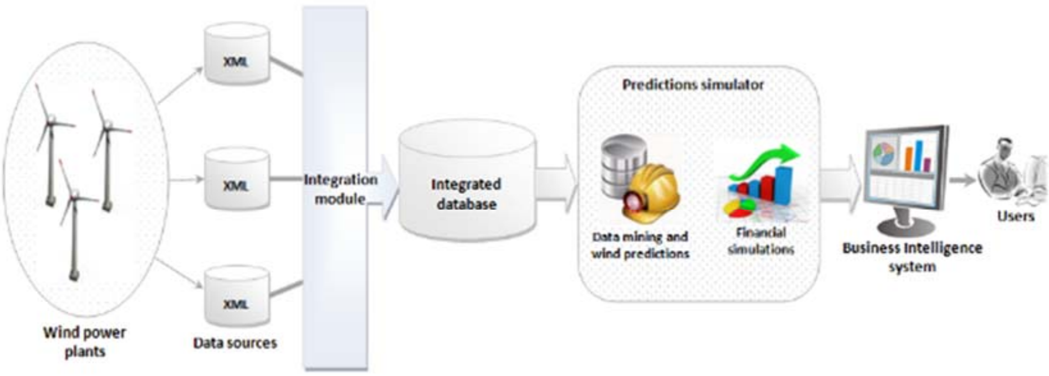


Figure 2.5. Architecture of Data Types for Database

The prediction variables of the model are (Component and Systems):

- MTBF (medium time between failures)
- MTTRf (medium time to return due to failure)
- MTBI (medium time between inspections)
- MTTRi (medium time to return due to inspection)
- IoP (impact on profitability)
- QIR (quality inspection rate)
- QPR (quality plan rate)

d) Time series and VAR model

The variables or input data have been considered a time series. A time series is a collection of observations of a variable taken sequentially and ordered in time (equalized moments of time). Time series can be defined as a particular case as stochastic processes, since a stochastic process is a sequence of random, ordered and equidistant variables chronologically referred to an observable characteristic at different times.

The objective of a time series is to study the changes in that variable with respect to time (description), and to predict its future values (prediction). Therefore, the analysis of time series presents a set of statistical techniques that allow us to extract the regularities observed in the past behavior of the variable to try to predict future behavior.

In this case, the time series is a multivariate problem because several variables have to be considered for the study, as opposed to univariate where the set of observations is about a single variable. The multivariate case studies the relationship between a variable of interest and a series of explanatory variables which influence the variable of interest. In the multivariate framework, the past of both the variable to be explained and the variables related to that variable are considered. Multivariate models of time series are a generalization of univariate models, the difference is that instead of a single variable there are n variables, and instead of a series, there are several series.

Autoregressive vector models, VAR, are one of the most commonly used models for multivariate time series analysis. The VAR models consist of a system of equations in which each one represents a linear function of the past lags of the variable and the lags of the other variables of the other series.

The general expression of a VAR model is given by:

$$y_t=f_1y_{t-1}+f_2y_{t-2}+......+f_py_{t-p}+gx_t+a_t \quad \text{Equation 2.5}$$

where y_t is the predicted variable (MTBF and MTTR), x_t is a vector of k explanatory variables (our input data), and "fi" and "g" are the vectors of coefficients to estimate, with "at" as the vector of random disturbances. This structure can be represented in a matrix form, and is easily extensible to contain a greater number of series and lags

e) Variate model methodology

Methodology for the construction of multivariate models:

- It is necessary for the time series that makes up the multivariate model to be stationary. A multivariate time series is stationary if all the time series that compose it are stationary. That is, that the statistical properties of the series are stable and do not vary over time (more specifically its mean and variance). To do this, we model and eliminate both the trend and the seasonality to achieve stationarity. Then, if when plotting the series, it is seen that it is heteroscedastic, it is not constant in variance and, therefore, does not follow a normal distribution, it is advisable to perform a logarithmic transformation to get closer to a normal distribution. If we find that the series is not stationary or having eliminated the trend and seasonality, it must be differentiated until it is achieved.
- It is necessary to identify the VAR model (p) that follows the series, where p is the length of selected delays or lags, for this the most appropriate order for the model has to be determined.

- Estimation: Equation to equation estimates the coefficients/parameters of the autoregressive terms as a univariate series by applying the MCO (Ordinary Quadratic Minimum) estimator transformed matrix-ally for a system of equations.
- Validation: At this stage, it is sought to evaluate whether the estimated model/s fit the data reasonably well and if several models were estimated to know which one is better before making use of the prediction model. Validation methods with training and test data can be used, such as cross-validation where the series is divided into training data used to estimate the model, and test data used to evaluate the prediction of the model. Using this type of techniques becomes more difficult with time series since the data is variable dependent and care must be taken when splitting up the series into training and test, recommending that training observations occur temporarily before the test. Figure 2.6 shows how the data division would be done. Finally, the residuals must be analyzed, verifying the assumption that the model errors are a purely random process (mean zero, constant variance and no serial correlation), that is, they have no dependency structure and, therefore, the residuals should not be correlated with the past, they must be independent of each other and follow a white noise process.
- Prediction: Once the best model is selected, it can be used to get the best prediction of the future values of the series from its own history. The best possible predictor that can be applied to the data will be the one that makes the least mistakes or, in statistical terms, the one that minimizes the mean square error with respect to another potential alternative predictor. When making a prediction with the model obtained, there are two types of strategies:

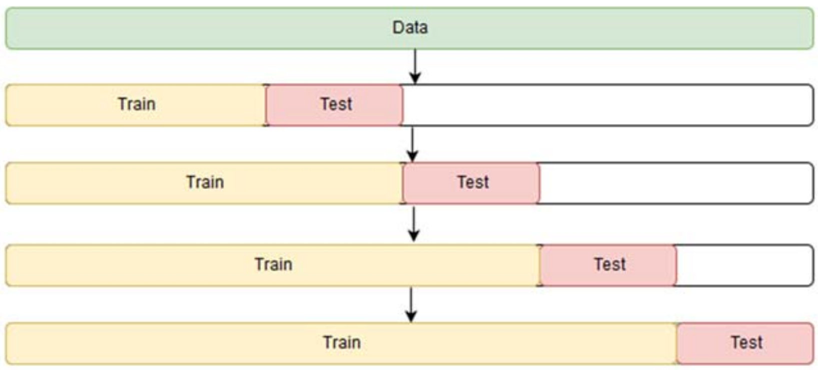


Figure 2.6. Test and Train for VAR data Model

- One-step-ahead prediction: The data that is used to predict the next instant of time and once the real next instant of time is available; this will be used instead of the predicted one for the next one-step-ahead prediction.
- Multi-step-ahead prediction: Where it is intended to predict more than one instant of the following time, for this prediction it can be used directly by predicting all the temporal values at once or iteratively by predicting the moments of time one by one using a one-step-ahead way repeated and using the predicted values to predict the following.

f) Direct Overhaul Cost

After the train test and algorithm [48-51], a cost of opportunity function will be generated with all the cost calculated, to repair, exchange etc., and all the statistical functions related to the explicative variables. They always make comparisons between the different option interventions, BTS-TSG-AVS, and the different strategies run to fail, overhaul, or maximum maintenance approach.

Assuming that the wind turbine is composed of three major component classifications and four system classification we should have a function for each that could be generated with different set points for optimal approach, meaning, extend the life for the drivetrain and all the mechanical components, but stress the electrical components due to the cost.

g) Control

The operational reliability and the OPEX cost of a generation unit, is an opportunity to build a maintenance algorithm-based model with a clear target. Increase MTBF and reduce the LCoE, including either the maintenance cost or the lack of production losses. Based on that premise the model saves from 1/3 to a 1/2, in regard the cost and could affect losses or the AEP in 5% additional output.

It is necessary to point out that this work is aimed at the establishment and solution of the opportunity maintenance model using historical data, parameters, theoretical approach and simulations. It is still relatively lacking in the accumulation of basic data. The major advantage is that while we do not have a large amount of historical data and there was a sort of Markov Chain values to run the model, and each year with all the data the model will be updated to get the target confidence level. One important value that we are providing is that we do not need a pure deterministic model failure occurrence, but only a cloud of opportunity to be solved by the available maintenance crews in the region, area or assets under the model control.

h) Inputs for the model

Listed but not limited inputs appear in the following chart. The model is valid for wind, hydro, solar and geo, we include here the site variables for wind, but those five can be substituted by the explicative ones for related technology.

Table 2.7. Model Inputs

INPUTS	VARIABLE	DESCRIPTION	UNITS
Model	*Safety_R*	Limitations on BTS due to safety restrictions	
Model	*Legal_R*	Limitations on BTS due to legal/contract restrictions	
Model	*Site_R*	Limitations on BTS due to specific site restrictions	
Model	*External_R*	External Scheduled downtime period	
Model	*Time_BTS#1*	time that one team needs for performing BTS#1 lubrication in one GU	hour
Model	*Time_BTS#2*	time that one team needs for performing BTS#2 Clearance and Adjustments in one GU	hour
Model	*Time_BTS#3*	time that one team needs for performing BTS#3 Torque and Tightening in one GU	hour

Model	*Time_BTS#4*	time that one team needs for performing BTS#4 Expert Inspection in one GU	hour
Model	*Time_BTS#5*	time that one team needs for performing BTS#5 safety in one GU	hour
Model	*BTS_Interventions*	Number of BTS interventions per year that the tool has to program. Each intervention can include 1 or more BTS activities	times
Model	*Time_TSG#1*	time that one team needs for performing TSG#1 Hydraulic in one GU	hour
Model	*Time_TSG#2*	time that one team needs for performing TS#2 Mechanic in one GU	hour
Model	*Time_TSG#3*	time that one team needs for performing TS#3 Electric in one GU	hour
Model	*Time_TSG#4*	time that one team needs for performing TS#4 Electronic in one GU	hour
Model	*Cost_BTS#1*	cost per intervention of BTS#1 Lubrication	€
Model	*Cost_BTS#2*	cost per intervention of BTS#2 Clearance and Adjustments	€
Model	*Cost_BTS#3*	cost per intervention of BTS#3 Torque and Tightening	€
Model	*Cost_BTS#4*	cost per intervention of BTS#4 Expert inspection	€
Model	*Cost_BTS#5*	cost per intervention of BTS#5 safety	€
Model	*Cost_TSG#1*	cost per intervention of TSG#1 hydraulic	€
Model	*Cost_TSG#2*	cost per intervention of TSG#2 Mechanic	€
Model	*Cost_TSG#3*	cost per intervention of TSG#3 electric	€
Model	*Cost_TSG#4*	cost per intervention of TSG#4 electronic	€
Historical	*Actual_Time_BTS#1*	Total time allocated into BTS#1 during the last 12 months. (One per each turbine)	hour
Historical	*Actual_Time_BTS#2*	Total time allocated into BTS#2 during the last 12 months. (One per each turbine)	hour
Historical	*Actual_Time_BTS#3*	Total time allocated into BTS#3 during the last 12 months. (One per each turbine)	hour
Historical	*Actual_Time_BTS#4*	Total time allocated into BTS#4 during the last 12 months. (One per each turbine)	hour
Historical	*Actual_Time_BTS#5*	Total time allocated into BTS#5 during the last 12 months. (One per each turbine)	hour
Historical	*Actual_BTS_Interventions*	Total BTS interventions during the last 12 months. Average	times
Historical	*Actual_Time_TSG#1*	Total time allocated into TSG#1 during the last 12 months. (One per each turbine)	hour

Historical	*Actual_Time_TSG#2*	Total time allocated into TSG#2 during the last 12 months. (One per each turbine)	hour
Historical	*Actual_Time_TSG#3*	Total time allocated into TSG#3 during the last 12 months. (One per each turbine)	hour
Historical	*Actual_Time_TSG#4*	Total time allocated into TSG#4 during the last 12 months. (One per each turbine)	hour
Historical	*Actual_Cost_BTS#1*	Total actual cost allocated into BTS#1 during the las 12 months	€
Historical	*Actual_Cost_BTS#2*	Total actual cost allocated into BTS#2 during the las 12 months	€
Historical	*Actual_Cost_BTS#3*	Total actual cost allocated into BTS#3 during the las 12 months	€
Historical	*Actual_Cost_BTS#4*	Total actual cost allocated into BTS#4 during the las 12 months	€
Historical	*Actual_Cost_BTS#5*	Total actual cost allocated into BTS#5 during the las 12 months	€
Historical	*Actual_Cost_TSG#1*	Total actual cost allocated into TSG#1 during the las 12 months	€
Historical	*Actual_Cost_TSG#2*	Total actual cost allocated into TSG#2 during the las 12 months	€
Historical	*Actual_Cost_TSG#3*	Total actual cost allocated into TSG#3 during the las 12 months	€
Historical	*Actual_Cost_TSG#4*	Total actual cost allocated into TSG#4 during the las 12 months	€
Kpi	*MTBI*	Average time between planned interventions (BTS)	hour
Kpi	*MTTRi*	Average time to return after a BTS intervention	hour
Kpi	*MTBF Hydraulic*	Average time between unplanned interventions (TSG Hydraulic)	hour
Kpi	*MTBF Mechanic*	Average time between unplanned interventions (TSG Mechanic)	hour
Kpi	*MTBF Electric*	Average time between unplanned interventions (TSG Electric)	hour
Kpi	*MTBF Electronic*	Average time between unplanned interventions (TSG Electronic)	hour
Kpi	*MTTRf Hydraulic*	Average time to return after an intervention (TSG Hydraulic)	hour
Kpi	*MTTRf Mechanic*	Average time to return after an intervention (TSG Mechanic)	hour
Kpi	*MTTRf Electric*	Average time to return after an intervention (TSG Electric)	hour
Kpi	*MTTRf Electronic*	Average time to return after an intervention (TSG Electronic)	hour
Kpi	*EKC*	Compose EUC parameter per plant	
Kpi	*EQR*	Enel Quality Rate	
Kpi	*EA_int*	Internal Energy Availability	%
Kpi	*EA_ext*	External Energy Availability	%

Kpi	*LPF*	Lost production	MWh
SCADA	*GU_Temperature*	Ten-minute trend of temperature in the internal part of the Nacelle	ºC
SCADA	*Mechanical_Temperature*	Ten-minute trend of temperature in the internal part of the Gearbox	ºC
SCADA	*Electrical_Temperature*	Ten-minute trend of temperature in the internal part of the Generator	ºC
SCADA	*Structural_Temperature*	Ten-minute trend of temperature in the internal part of the Converter	ºC
SCADA	*Ambient_Temperature*	Ten-minute trend of temperature in the external part of the GU	ºC
SCADA	*Wind_Speed*	Ten-minute trend of wind speed in the nacelle sensor	m/s
SCADA	*Wind_Direction*	Ten-minute trend of wind direction in the nacelle sensor	m/s
SCADA	*Active_Power*	Ten-minute trend of Active Energy Output in the Energy Meter	MW
SCADA	*Reactive_Power*	Ten-minute Reactive Energy Output in the Energy Meter	MVAR
SCADA	*T_Trigger_Mechanical*	Means that Mechanical needs an inspection	on/off
SCADA	*T_Trigger_Electrical*	Means that Electrical needs an inspection	on/off
SCADA	*T_Trigger_Structural*	Means that Structural needs an inspection	on/off
SCADA	*T_Trigger_GU*	Means that GU needs an inspection	on/off
Domain	*Resource_Distribution*	historical annual resource Weibull distribution	Distribution
Domain	*Load_Factor*	Total amount of energy per year divide in total power	hours
Domain	*Average_Temperature*	Ambient temperature distribution	º Degrees
Domain	*Average_Density*	Air Density	g/cm3
Domain	*GU_Id*	functional location at GU level	
Domain	*Turbulence Intensity*	Percentage of Turbulence, or typical deviation (sigma)	%
Domain	*Age*	years form COD	
Domain	*GU Type*	Turbine manufacturer	
Domain	*historical cost per Functional Location (Component Level)*	annual cost allocated on each FL	
Domain	*Equipment per functional location*	Model and Brand of each major component	
Domain	*Energy Price*	Energy price forecast trend	€/MWh
FMEA	*Weibull Failure Distribution Mechanical UT/DT*	Failure Distribution Mechanical	% / year

FMEA	*Weibull Failure Distribution Electrical*	Failure Distribution Electrical	% / year
FMEA	*Weibull Failure Distribution Structural*	Failure Distribution Structural	% / year
FMEA	*Repair cost per Mechanical UT*	Cost per intervention average	€
FMEA	*Repair cost per Mechanical DT*	Cost per intervention average	€
FMEA	*Repair cost per Electrical*	Cost intervention average	€
FMEA	*Repair cost per Structural*	Cost intervention average	€
Data Base	*Cost Per €/MW*	Cost per Installed MW OPEX (*)	€/MW
Data Base	*Cost Per €/MWh*	Cost per generated MWh OPEX	€/MWh
Data Base	*Impact on Profitability IoP*	Ratio between expenditures and the margin coming from energy sales	%
Data Base	*Economic Unavailability Factor EUF*	Ratio between the loss income and theoretical margin achievable	%

2.5 MATHEMATICAL HYPOTHESIS

To solve the problem, we will use several mathematical tools to monitor and adapt the data from the database, the indexes that we generate and the relations between among all these factors. Once we get all the data in the database, we will use a statistical tool to get the distribution of each set of data, or inputs, in order to understand how the factor behaves along the lifetime of the GU.

a) Normal Distribution

We will use this distribution to explain the behavior of each signal from the SCADA system of the GU. Our distributions will be the General Normal Distributions and we will extract the mean and the deviation for each signal, in order to calculate the triggers to set up alarms or alerts:

$$f(x, \mu, \sigma^2) = \frac{1}{\sigma}\varphi\left[\frac{x-\mu}{\sigma}\right] \qquad \text{Equation 2.6}$$

The μ is the average, mean or expected value for the signal, data and the σ is the standard deviation. With our database, we can build the distribution of each signal, with the sets of the two parameters μ, σ. We compared each distribution for the signals and in each generation unit, in order to be able to take limits for the alerts or alarms or address no normal behavior.

b) Pearson Correlation Coefficient

We used the Pearson correlation coefficient to check if two signals are correlated, after proving that the behavior follows a normal distribution. Comparing the signals and using this mathematical tool we are able to eliminate highly correlated signals from the input model that are highly linear dependent.

$$\rho x, y = \frac{cov(x,y)}{\sigma_x \sigma_y} \qquad \text{Equation 2.7}$$

We use this tool, either with the Excel Data Analysis sheet, or other statistical tools. We use Microsoft Power BI due to the big amount of data and in order to be able to manage the database using the minimal number of folders possible.

c) Analysis of Variance (ANOVA)

The ANOVA is a tool that commonly is used for experimental data to perform and confirm hypothesis. When an ANOVA test is performed to evaluate the null hypothesis of a sample it is assumed that the hypothesis null is true and events do not occur randomly. In order to confirm that the test reaches a certain probability the p value is needed. If the p value limit is below the probability extracted from the test, then the null hypothesis is accepted, otherwise it is rejected. ANOVA is used to study the effects of different solutions applied over the same sample of generation units. For example, the oil brand or the oil composition in the gearbox, if we accept the null hypothesis this means that the differences observed from the solutions applied are not random, or if we reject it, it means that some oils affect the component differently.

Due to the theory, the ANOVA test limits to the hypothesis are two; Type error I or false positives on a level of significance, and Type error II or false negatives. Type error II has a high dependency of the sample size.

We have several tools to perform ANOVA analysis, but we use Minitab to get the analysis of variance and some other test or coefficients. However, using the distributions we make the problem affordable, instead of using the big amount of time series data. Using this kind of software, it is impossible to manage such an amount of data points.

d) Weibull distribution for failures

We use this statistical distribution to elaborate the trends for the component failures per year. In order to monitor and compare the real values; with the trends to address if all the activities that we are performing are ok then we will reduce the failure rate, or if we are not doing it properly then we will increase the failure rate.

The function that defines the density of a Weibull random variable is:

$$f(x;\lambda,k) = \frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1} e^{-(\frac{x}{\lambda})^k} \qquad x \geq 0 \qquad \text{Equation 2.8}$$

Where, $k > 0$ is the shape parameter and $\lambda > 0$ is the scale parameter of the distribution. To generate these functions based on the data we have, we use a software program called Reliasoft (for reliability) and Weibull ++, to generate the failure frequency over the years.

e) Markov Chain Monte Carlo Metropolis-Hastings Algorithm

The Markov chain and Monte Carlo simulation methodology develop samples with variables that are continually random, and an already known density of probability that is proportional to a function. The sample is used to evaluate the area over the function. The result is a value or a variance of the value. Assembling the chains will be developed from a set of points that is chosen randomly with enough distance from one another. The stochastic processes of these chains are called walkers that move from one to another and follow an algorithm that is searching for points that contribute more to the surface in order to generate the next movement, and consequently assign high probability. The walkers assigned under the Monte Carlo methods have different theories or options, in our case we use the Markov Chain central limit theorem to estimate the error of mean values. In our case, we use the walkers as numeric values from 0 to 1 to evaluate the impact between planned tasks and variables or unplanned tasks and variables from our input model. We run the simulation and extract some relation from the factors that is applied for the next year plan. Before the year ends, we generate the next year plan with the real numbers from our report data base and simulate again the MCMC to confirm that the data from the model are correct.

We use the Metropolis-Hastings algorithm to accept the walker moves.

Let f(x) be a function that is proportional to the desired probability distribution P(x).

1. Initialization: Choose an arbitrary point Xt to be the first sample and choose an arbitrary probability density Q(x/y) that suggests a candidate for the next sample value x, given the previous sample value y. In our work, Q is assumed symmetric.
2. For each iteration *t*:
   - *Generate* a candidate x` for the next sample by picking from the distribution Q(x`/xt).
   - *Calculate* the *acceptance ratio* α=f(x`)/f(xt), which will be used to decide whether to accept or reject the candidate. Because *f* is proportional to the density of *P*, we have that $\alpha = \frac{f(x`)}{f(x_t)} = P(x`)/P(x_t)$.
   - *Accept or reject*:
     - Generate a uniform random number $\mathcal{U} \in (0,1)$.
     - If $\mathcal{U} \leq \alpha$, then *accept* the candidate by setting $x_{t+1} = x`$
     - If $\mathcal{U} > \alpha$, then *reject* the candidate and set instead $x_{t+1} = x_t$

The method that we described attempts to move around the space of a sample, accepting the moves or remaining in the place in each case following the algorithm. The ratio for acceptance σ is an indication of the probability to the new sample proposition compared with the actual sample following the same function or distribution P(x). Attempting to move a point that has higher probability than the actual point in a region with more density of P(x) the correspondence is to an σ > 1 ≥ u, then the movement will be accepted. If the attempt to move goes to a low probability region point the movement will be rejected.

We will generate Markov Chain Variables to generate a sequence of probable events in our operating units [33]; we should consider that during the first year these variables will be extracted from historical data. Along the year, random events will be generated by means of Monte-Carlo simulations to then revise each end of year the real values of the Chains, to reach the target confidence level. It is very important to remark that we do not need to place an exact data for the outputs but only a sort of opportunistic approach to be merged with the activity plan capacity. Thus, merging the demand and the capacity to accomplish this demand is valid for personnel, for components for products, for services etc.

We use the group of variables that are more explicative of the LPF output and study if we can affect those variables and how.

Two of the main contributors for the LPF that we can affect with our actions are the KPIs related to the occurrence of failures, the Medium Time between Failures (MTBF) and Medium Time to Repair (MTTRf) defined in the equations 2.1 and 2.2. Two main contributors to the LPF that are not as relevant as the related failure but were shown to have a high correlation with the above ones are the KPI related inspections, Medium Time between Inspection (MTBI) and the Medium Time to Return after an inspection (MTTRi), defined in the equations 2.3 and 2.4.

Basically, we open each KPI to the different activities that can be carried out in a planned way (inspection) or in a corrective way (failure) in order to fine-tune the tasks, times and efficiency of the repair and maintenance work of the unit with the level of quality required. At the beginning and after doing the correlation between activities and the impact on the main KPIs, we saw that there are activities that do not bring value, so we developed a Quality Inspection Plan, including the procedure, process and policy to ensure that the components, systems and assets are working properly. We used the MIL-STD mentioned in the bibliography to develop the sampling plans, the rejections and all the statistical aspects of the plan. After making sure that every asset is at the correct level of quality by performing our study with a ceteris paribus condition, we then targeted the relationship with our output target the LPF.

$$LPF = \left[\frac{Total\ Period\ Time}{MTBF} \times MTTRf\right] \times CFf + \left[\frac{Total\ Period\ Time}{MTBI} \times MTTRi\right] CFi$$

Equation 2.9

where CFf is the capacity factor when the Generation Unit fails and CFi is the capacity factor when the generation unit is inspected. The output relation whose correlation between the activities is as follows, with 90% confidence level and reflects how each activity affects the LPF and the relation among failures and inspections.

The next step was to check that all these activities are performed following the Quality process are properly reported to check at the end of the test period what the deviation from normal behavior is, and if so, improve the related activity.

The relations are basically obtained from the Energy Utility Company database, and after performing the different correlations and statistical studies by cleaning the samples we take out all the variables that are highly correlated to not directly impact our study.

These relationships are updated using machine learning algorithms and the Energy Utility Company data base. After a one-year period using the 100 million data points and the 5 million reports per year, in order to redo the annual and weekly plans at Generation Unit level.

f) Economical Key Performing Indexes

LPF (Lost Production Factor) is the measure of Energy Production available to a generation unit but not captured because of machine related technical issues of the total Possible Energy Production:

$$\text{LPF} = \frac{100\% * \text{Lost Production (kWh)}}{\text{Possible Production (kWh)}}$$ Equation 2.10

LCOE (Levelized Cost of Energy) is the measure of the average net present cost of electricity generation for a generating unit over its lifetime or a time period.

$$\text{LCOE} = \frac{\text{sum of cost over lifetime or period}}{\text{sum of electrical energy produced over lifetime}}$$ Equation 2.11

IOP (Impact on Profitability) is the measure of the total operational expenses cost, with the capital expenses to stay in business (excluding the initial capital costs) per generated unit i.e., MWh divided by the price we get for this generated unit

$$\text{IOP} = \frac{\text{OPEX/MWh+CAPEX(Stay in Bussines)/MWh}}{\text{Price per generated unit (MWh)}}$$ Equation 2.12

3. RESULTS AND DISCUSSION

In this chapter we present the results. The work hereby reported was started more than 10 years ago, trying to further control operations and reduce the LCoE (Leveraged Cost of Energy). The main drawback is the lack of knowledge about the technical parts of the components, the specifications, drawings and so on. They all make it very difficult to understand the behavior, and the reality which shows very high LPF and very low MTBF, which makes the GU spend a lot of time stopped due to failures along the years. After some period studying aero derivative turbines that have the same technology as aircraft engines, we realized that all the activities are planned. In this GU, the operational services, maintenance, and inspections are displayed in a plan that covers the lifetime of the unit. They cannot afford to have any unplanned stops due to a risk to safety. Then, we started thinking what the main features are that grant absolute control of the technology. Having the generation unit already installed and running, we should warrant the quality in the activities made in the assets. We developed a Quality plan based on Military Standards to assure everything is properly managed. This plan took some years to be deployed, but it provides an enormous amount of information regarding knowledge we have of the activities and the technical specifications of each component group, together with systems of the GU. After comparing the results, we saw that some components have the same behavior no matter the technology, and we have the same challenges. By making this effort and applying the lean six-sigma approach we develop the algorithm-based renewable assets management system [49]. This methodology is based on the study of all the movements, inefficiencies and excess of documentation. After doing that, we sorted the different challenges and classified the different MUDA (waste in Japanese) and evaluated them to attack the problem from different perspectives. The main problem stems from the lack of proper maintenance and operation manual. Some other main problems come from activities that have specific value, i.e., visual checks. Therefore, a huge number of actions have no direct evidence or proof being done. At this moment we understood that the GU has some standards that should be fulfilled, so we took the IEC 61400/1 Design Requirements for Wind Turbines and checked all the aspects to understand how these turbines are then designed and which conditions should be compliant in order to obtain the type certificate. It is possible to do the same exercise for Hydro, Solar and Geothermal plants. The main result is by using the detection improve the manuals, procedures and operations. Based on the results obtained and after having assured the ceteris paribus condition for the activities performed in the GU, we started to write our own manuals, to get the same certification that the Original Equipment Manufacturer (OEM) has. After getting the certification in compliance with IEC and ISO standards for each technology, we started with the deployment to achieve the main goal, which is to reduce unplanned activities from 80% to 10%.

3.1 CONVERT THE UNPLANNED INTO PLANNED

To address this Challenge, we should have done first the quality deployment, the maintenance manuals, and the digital reports established to get as much as information as possible from the assets. We have three main different stoppages in the GU, which we classified as inspection/planned intervention, corrective intervention that could also be planned or unplanned. As explained in the introduction and methodology chapters, we have sorted these three interventions as Box Tasks Strategy (BTS) that were, using the six-sigma lean concepts and describing the activities grouped in boxes with common factors, knowledge, documents, tools, consumables and fungibles. For example, the box called lubrication, contains all the activities to grease all the unit, allowing this box to perform alone, or in conjunction with the rest. To each box we address a task time, tools, and knowledge/documentation for the operational crews. This work was done for all the BTS boxes. The corrective intervention that at that moment is not possible to plan, we called Trouble Shouting Guides (TSG) to follow the same nomenclature described in the IEC standard. The same classification is done, but this time by systems, and we have a unique box of tasks for electronic systems. We developed the list of activities we need to understand why a GU is stopped by electronic failure, and every time the personnel who repair take, as we describe, the tools, knowledge and checks they need to perform for each activity and submit a digital report to assure that the box is performed in properly. Finally, we have the corrective actions that can be planned, which we called Advanced Services (AVS) and are basically the component exchanges or additional inspections or actions that come from the study of the signals, predictions, or diagnostics. Some examples are Gearbox exchanges or up-tower repairs, which after our system integration we are able to plan, and a portable condition monitoring measurement required by some variation in component health. As mentioned, we detected them by checking the sigma of some signals, which could be temperatures, vibrations, pressure etc. These activities have a very low impact in stoppages, but very high in operational expenditures (OPEX) due to component cost, or the inspection method required. We should keep out of alpha errors, Type I errors and false positives. Checking the behavior of all these interventions and trying to extrapolate the results using the mathematical tools we described in the methodology, we are able to create two different tools to increase the plans. The BTS Scheduled Tool (figures 3.1 and 3.2), which uses task time concept, resource prediction, and operational personnel, finds the best opportunity window to perform BTS boxes, losing the least LPF possible.

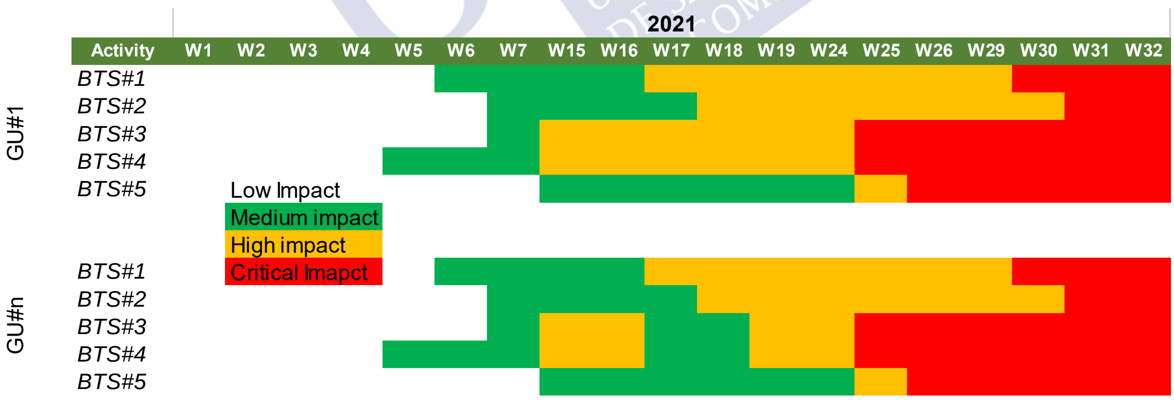


Figure 3.1. BTS Opportunity per week

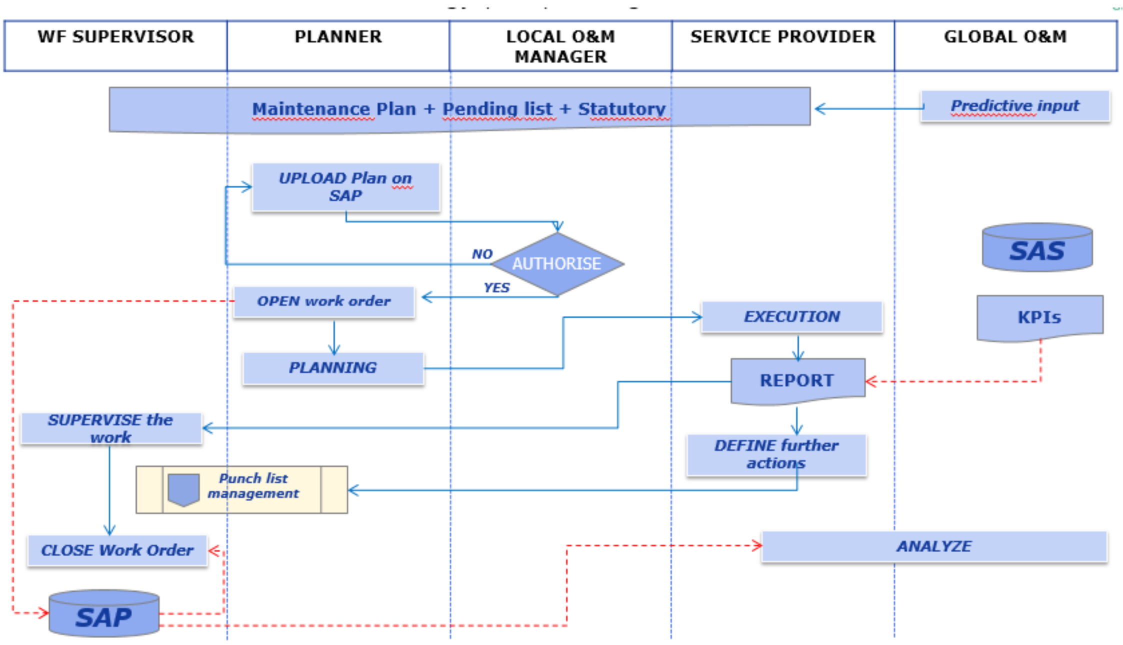


Figure 3.2. BTS Process Map

The TSG Schedule tool has a different concept. We made many simulations using different mathematical approaches and found that we do not have the capability to predict the occurrence of an event in a timeframe of hours. We checked with convolutions of distributions per variables and made systematic MCMC simulations to conclude that if we want to predict by hours, we must increase type I (α error, false positives) and type II (β error, positive errors) errors dramatically. The solution was in the operations since we do not have the capability to get a response time of hours in the personnel. After some checks, we understood the plans made by week to address efficiency. So, together with these conditions the TSG tool (figures 3.3 and 3.4) was released with a 90% confidence level that can plan interventions for the four systems in a weekly manner. This meant a huge advantage, together with the correlations we proposed after those years of study, in order to detect any sigma variation in the conditions showing if the work was performed well, and the machine performed better after the interventions.

activity	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
TSG#1	8	6	5	10	15	6	1	3	8	8	10	12	15	10	15
TSG#2	3	11	0	3	0	14	15	10	11	2	6	7	4	12	0
TSG#3	0	2	11	0	6	1	3	14	3	5	15	8	4	1	1
TSG#4	6	0	15	2	2	4	11	8	9	11	10	15	4	4	7

Low
Medium
High

Figure 3.3. TSG Schedule Impact probability per week

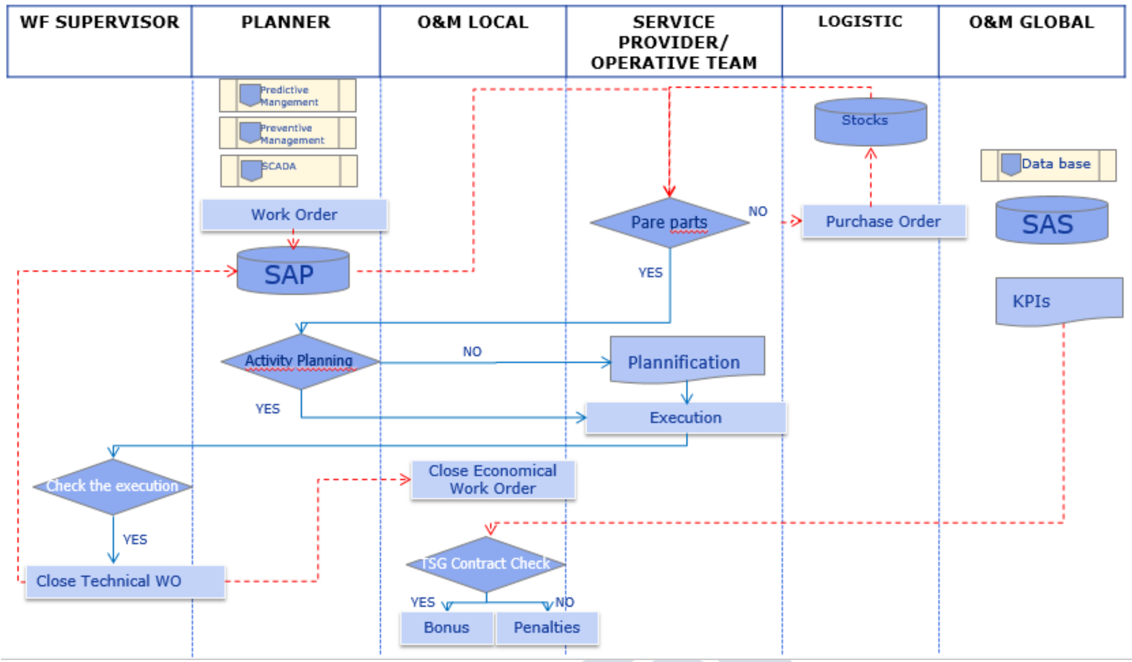


Figure 3.4. TSG Schedule Process Map

The Advanced Services are mainly all the corrections that involved a component exchange, and of any inspection. In order to assure that we are performing our operation and maintenance activities well, we created a Weibull distribution of failures with the equation 2.8 from the methodology and using the Reliasoft software to set up a baseline of how many actions per component we will perform. With this, we calculated the OPEX baseline and worked to reduce the real component failure compared with the Table 3.1 from the Weibull output. We measured the delta reduction as our capability to operate better than the baseline.

Table 3.1 AVS Weibull distribution of failures per year.

Failure Type	Component	Eta (Yr)	Beta	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10
Major Repair	Blades	129.25	1.25	0.002	0.005	0.009	0.013	0.017	0.021	0.026	0.031	0.036	0.041
Major Repair	Blades	272.55	1.24	0.001	0.002	0.004	0.005	0.007	0.009	0.011	0.013	0.015	0.017
Major Repair	Blades	469.06	1.06	0.001	0.003	0.005	0.006	0.008	0.010	0.012	0.013	0.015	0.017

Major Repair	Blades	19.03	1.94	0.003	0.013	0.027	0.048	0.073	0.103	0.137	0.175	0.217	0.262
Major Repair	Converter	17.65	0.90	0.075	0.141	0.203	0.264	0.324	0.383	0.441	0.499	0.556	0.612
Major Repair	Converter	11.76	1.26	0.045	0.106	0.176	0.250	0.328	0.409	0.492	0.577	0.663	0.750
Major Repair	Converter	25.14	0.82	0.072	0.128	0.178	0.226	0.273	0.318	0.362	0.405	0.447	0.489
Major Repair	Converter	21.99	0.84	0.074	0.133	0.188	0.241	0.291	0.341	0.390	0.438	0.485	0.531
Major Repair	Converter	17.02	1.71	0.008	0.025	0.051	0.082	0.119	0.161	0.206	0.256	0.309	0.364
Major Repair	Converter	14.87	1.21	0.038	0.087	0.141	0.199	0.260	0.322	0.386	0.451	0.517	0.584
Major Repair	Gearbox	9.36	2.06	0.010	0.041	0.093	0.164	0.251	0.351	0.462	0.579	0.701	0.825
Major Repair	Gearbox	42.39	1.17	0.013	0.028	0.045	0.063	0.082	0.101	0.121	0.141	0.162	0.183
Major Repair	Gearbox	25.68	1.45	0.009	0.025	0.044	0.067	0.092	0.119	0.148	0.178	0.210	0.243
Major Repair	Gearbox	7.42	2.52	0.006	0.036	0.098	0.194	0.320	0.469	0.631	0.797	0.959	1.116

Major Repair	Generator	20.03	0.97	0.055	0.107	0.159	0.210	0.261	0.312	0.362	0.412	0.462	0.512
Lurking Failure	Main Bearing	12.95	2.65	0.001	0.007	0.020	0.043	0.077	0.123	0.180	0.249	0.327	0.413
Lurking Failure	Main Bearing	5.58	2.65	0.010	0.064	0.178	0.350	0.562	0.786	1.002	1.206	1.401	1.598
Major Repair	Main Bearing	10.60	2.65	0.002	0.012	0.035	0.073	0.129	0.202	0.290	0.392	0.504	0.620
Major Repair	Main Bearing	11.06	2.65	0.002	0.011	0.031	0.065	0.116	0.182	0.263	0.357	0.461	0.572
Major Repair	Pitch Card	41.22	0.62	0.100	0.155	0.201	0.242	0.280	0.316	0.349	0.382	0.413	0.443

To make all the reports available to all the O&M team and all the activities mentioned and suitable for the automatic ex post analysis, the report templates are standardized and have to be available on digital support.

To ensure the proper storing of templates contained in the reports and to be compliant with the guideline provided at a global level, the local O&M team will organize a dedicated meeting after the signing of each Global Service or Basic Service main contract. Taking part in the meeting are:

- Local O&M key people
- Local DH
- Global PdM
- Global DH

During the meeting, the following deliverables must be reached:

- Report template of each maintenance activity type
- Definition agreement on digital tools and repository to be used for the report process and storage
- Referent people at local and global level
- Agreement about new report template (if any)

The reports to be used worldwide in all the Wind Farm within Entity are shown in the annexes to this thesis

Report's framework cannot be changed. Any changes will affect the automatic processing of the data included in the reports created at global level.

In case of a specific request from the service provider about a change in the template of the report to be provided, local O&M can evaluate a different template activating a specific request according to this work.

The detailed descriptions of the report templates are described in any technical specification. Not all service providers were able to embed the report template included in the annexes into the processes.

It is possible to accept alternative proposals for specific cases. To allow the use of a different report template, the service provider must communicate their proposal just after the contract sign. Local O&M oversees the proposal gathering a first alignment according GPG requirements. In any case, any report purchased by third parties service providers or GPG technicians must have the following template:

- Tractability Manual
- Renewable Asset
- Reference Number of WTG
- Starting day / time
- End day / time
- Generation Unit production (KWh)
- 1 picture before the maintenance activity showing the status of the equipment
- 1 picture after the maintenance activity showing the evidence of the activity performed

Corrective maintenance reports must include the following data in addition to the previous information:

- Main Trigger Factor
- Secondary Trigger factor
- TSG Task Description

After the first check by local O&M about the report template proposed, the specific report template and relevant storing process will be addressed and authorized during the meeting between local O&M, global O&M and DH described in this work. The list of acronyms is in Table 3.2. The process for allowing the use of a new report template is described in figure 3.5.

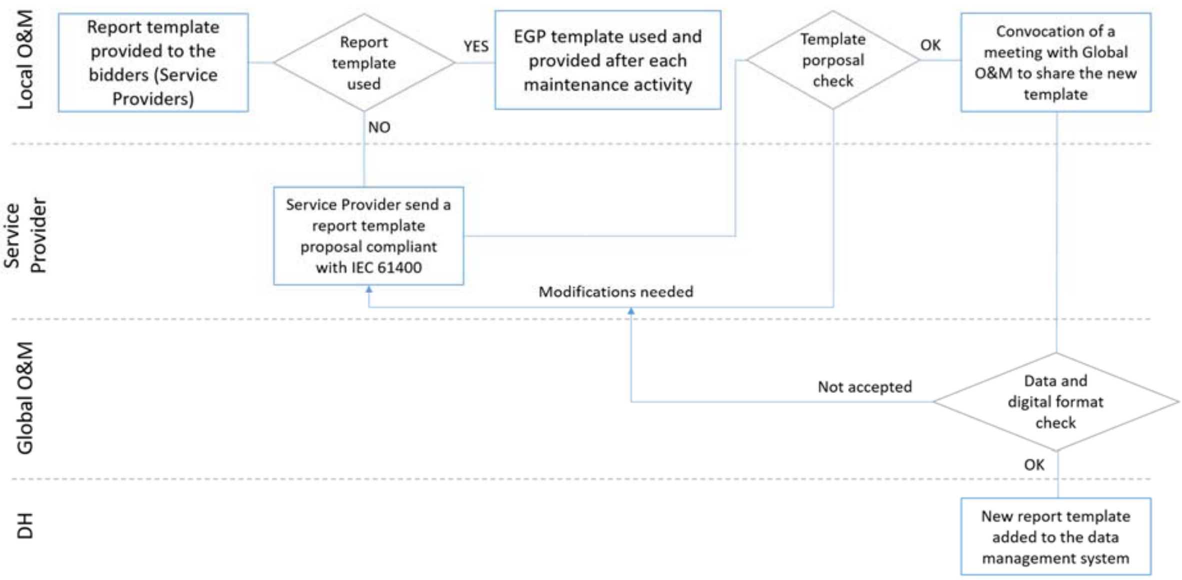


Figure 3.5. Reporting process Map

Table 3.2. Acronyms and Description

Acronym and Key words	Description
Area/Country O&M	Unit responsible for plants operation and maintenance within an Area/Country
BoP	Balance of Plants, meaning the main structural components of a Wind Farm (e.g. Roads, Substation, MV Interconnection)
SCADA	Supervisory control and data acquisition (SCADA)
Equipment	Main structuring components of the WF (e.g. BoP, WTGs)
GPG	Global Power Generation Business Line
KPI	Key Performance Indicator
MoM	Minute of Meeting
MTBF	Mean Time Between Failure
MttRf	Mean Time to Return Failure
O&M	Operation & Maintenance
Plant Supervisor	GRE Area/Country O&M Responsible for specific Wind Farm(s)
PdM	Predictive Maintenance
OPCR	Operations Process Country Responsible, i.e., the O&M person responsible for quality process at Country Level
OPR	Operations Process Rating
SPV	Special Purpose Vehicle, legal entity/company created to fulfill specific or temporary objectives
O&M Wind Global	O&M Wind Global unit
O&M Wind Local	O&M Wind organization at Country level
TSG	Troubleshooting guide related to corrective maintenance
BTS	Box Task Strategy related to preventive maintenance
GP	Generation Plant
GU	Generation Unit
DH	Digital Hub

Using these tree tools, we are able to predict the activities and reduce the existing 80% unplanned and 20% planned to 10% unplanned and 90% planned. That was the main target of our study. We should say that this was a long run of years, and we are still in the deployment face. Recently we got the latest results in the pilot test in the plants, and we are now moving to deploy massively in the EUC fleet. For the specific case of the Wind Technology, we were able to get already the benefits of the increased plan. Still need some more time, but this feature helps EUC to be more aggressive in the Renewable plant deployment, we were able to get a patent for this methodology focus on Wind technology, and with this work, we are applying for a patent to all the technologies involved.

3.2 DEVELOPMENT OF A CLASSIFICATION METHOD FOR THE ALARMS, EVENTS AND STOPPAGES

To be able to reduce the number of causes and effects that for this study, we should make a classification of events, this classification allows us developing procedures and process to address each cause, making each intervention more efficient. Regarding the use of the database and the activities, we understand that we have four different system integration in the Generation Units, Electric, Electronic, Hydraulic and Mechanic. These systems are common for the four technologies we target and connects the components to allow them run in a proper way. For the component groups, we classified them, on the different component configuration was extracted from the database and grouped in Structural, Electrical, and Mechanical.

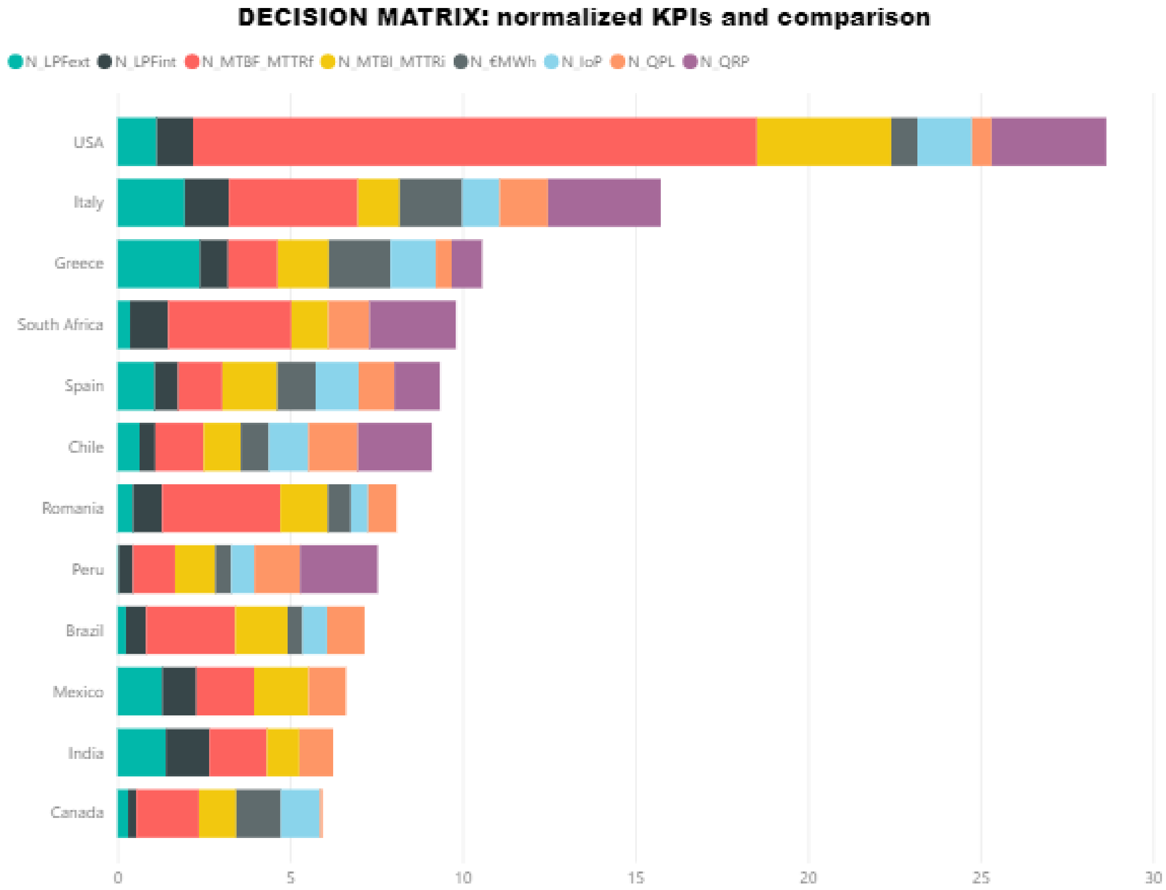


Figure 3.6. Component Based Strategy Decision Matrix (EUC Matrix for Decision)

After checking the results from the Decision Matrix (figure 3.6), it was clear that we should reduce the number of causes in order to address each FMEA properly. We used the IEC standard for Fault Tree Analysis and the Failure Mode and Effect analysis to measure the impacts of each, and display a plan to re-classify all the alarms and events using the SAP tree codes that we have available (figure 3.7).

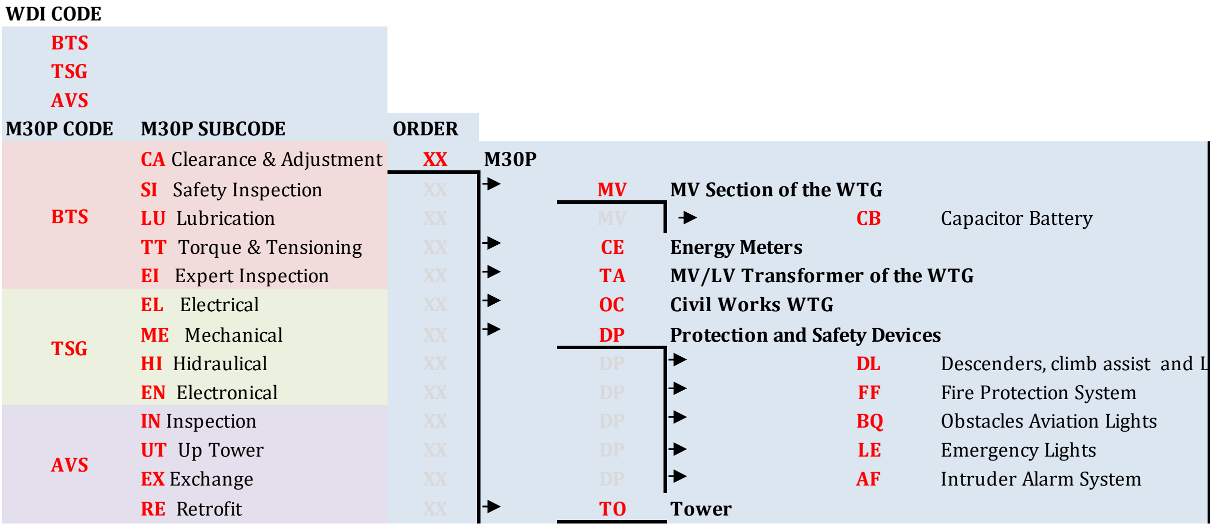


Figure 3.7. SAP tree codes and description EUC codes established per component in SAP ERP

We developed a classification in which each alarm or event is associated to a component or subcomponent. In addition, we run MCMC to simulate if the distribution of failures associated is correct or not, after the first year we confirm the distribution, with the real occurrence displaying 90% confidence level. This could be because some events may come from different components. In order to solve this variation, we generated in parallel the same approach but this time by systems (figure 3.8).

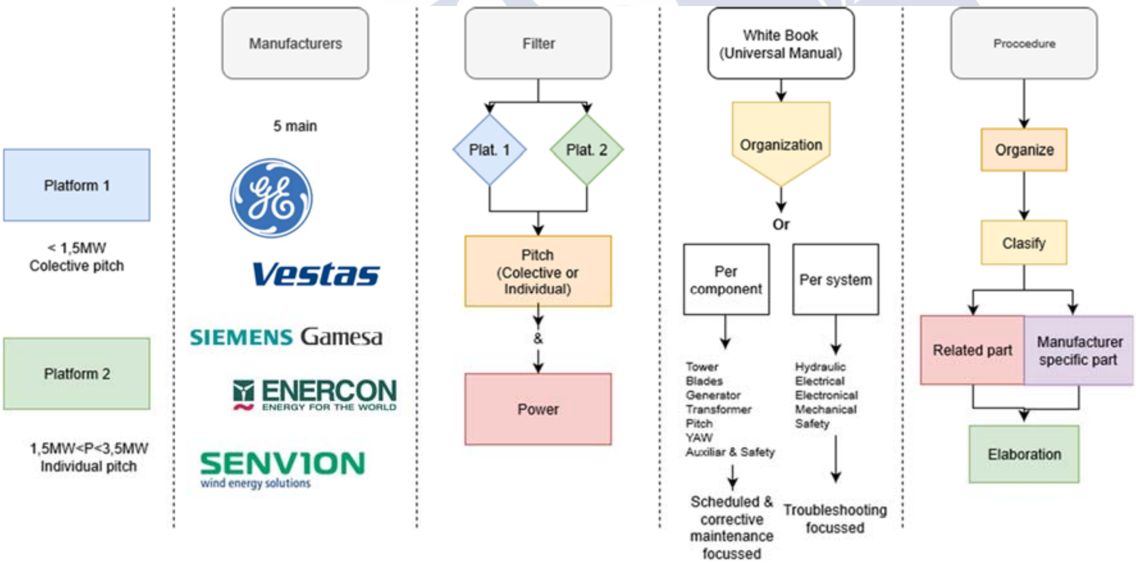


Figure 3.8. Event Classification Process Map for Systems and Components.

After the classification, we have the 50.000 MW database with 100 million data points per year, and 5 million digital reports, addressing data to confirm the causes of each event allowing performing the FTA and FMEA in a more suitable way and reaching 90% confidence level.

3.3 Modeling the LPF for the Renewable Assets Management System

We use for our model the Loss Production Factor (LPF) as an output, and after all the steps we were able to address which variables are more explicative arriving to an expression that give us a 98% of explanation for the output (Table 3.3).

Table 3.3. LPF Regression and ANOVA summary.

Regression Statistics	
Multiple Correlation Factor	0.99
R^2 R-Squared	0.98
R^2 Adjusted	0.97
Typical Error	0.00
Observations	5000

ANOVA					
Degrees of Freedom		Square sum	Square average	F	Critical value for F
Regression	11	1.16E-02	1.05E-03	82.9	2.26E-11
Residuals	15	1.91E-04	1.27E-05		
Total	5000	1.18E-02			

The next step is to sort the explicative variables in a list that are have more variance to develop and action planned on them. This classification is very important as, for example, one highly explicative variable is the resource for power energy, but in renewables we are not allowed to control the resource we receive, only in special cases like hydro plants. In the rest of the technologies we apply, we are not able to. After applying the statistical methods, linear correlations and regression, we set up the targets (figure 3.9) that we should apply for all the sets of the KPIs, Medium Time between Failures (MTBF) per system and component group, the Medium Time to return after a failure (MTTRf) per system and component group. And the same for the Medium Time between Inspections (MTBI) for the Box Task Strategy (BTS), Trouble Shooting Guides (TSG) and Advanced Services (AVS).

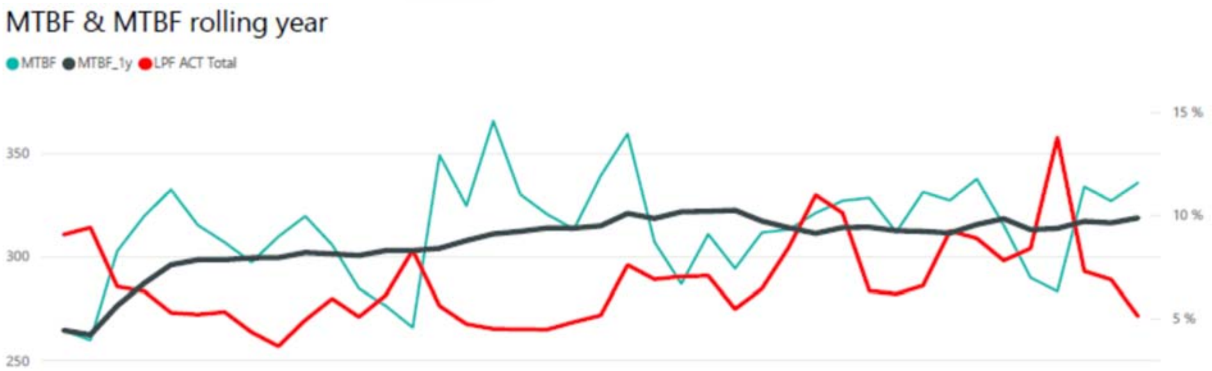


Figure 3.9. MTBF & MTTRf & LPF Results rolling year (EUC database).

By using the decision matrix reported in Table 3.4., we are able now to concentrate on these two sets of KPIs that give us the total number of hours a GU is stopped by year due to failure or due to inspection.

Table 3.4. Decision matrix table

LPF ext	LPF int	MTBF	MTTRf	MTBI	MTTRi	€/MWh	IoP	QPL	QRP	DECISION
1	0	0	0	0	0	0	0	0	0	Revise domain conditions limits for plants per site.
0	1	0	0	0	0	0	0	0	0	Revise Plan and Schedules to confront with capacity factor.
0	0	1	0	0	0	0	0	0	0	Deploy TSG Strategy.
0	0	0	1	0	0	0	0	0	0	DMAIC Services Provider.
0	0	0	0	1	0	0	0	0	0	Revise Maintenance Plan and Schedule.
0	0	0	0	0	1	0	0	0	0	M30P Process Recommendations.
0	0	0	0	0	0	1	0	0	0	Contract Control Revision and Category Management.
0	0	0	0	0	0	0	1	0	0	Cost Revision.
0	0	0	0	0	0	0	0	1	0	Beta Meeting Strategy.
0	0	0	0	0	0	0	0	0	1	Services Provider Deployment Control.

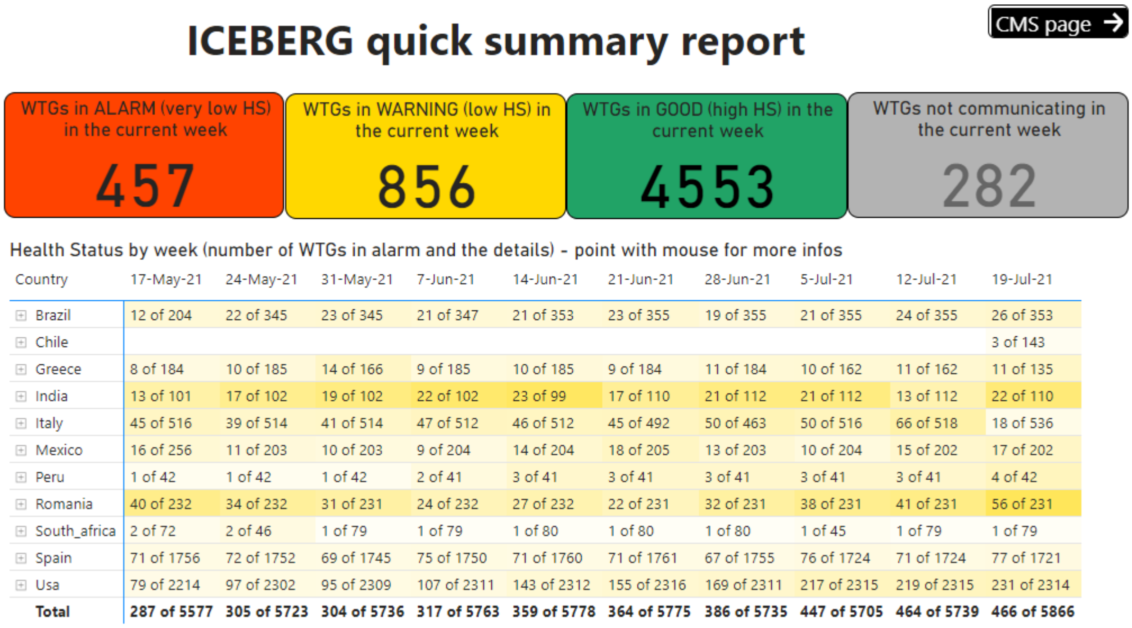
3.4 DEVELOPING THE RELATION BETWEEN EXPLICATIVE VARIABLES

We used all the mathematical analysis described in the methodology to address the relations between the different explicative variables, activities etc. The result of this analysis lets us know which parameters are more explicative, and more important to try to control. These are described in the above target. The first relations that we extracted were exactly those that explain the behavior and the interaction between BTS and TSG. For that, we use the 10 million digital reports, and the impact in the component and system health after performing an activity. We launched the MCMC using the Metropolis-Hastings algorithm that is described in the Crystal Ball software in order to formally calculate the correlation between TSG and BTS at 90% confidence level and the results are shown in table 3.5.

Table 3.5. Relation between the TSG and BTS activities (EUC database)

	TSG			
BTS	**Hydraulic**	**Mechanic**	**Electric**	**Electronic**
Clearance & Adjustment	0.20	0.20	0.30	0.30
Safety Inspection	0.25	0.25	0.25	0.25
Lubrication	0.40	0.40	0.10	0.10
Torque & Tensioning	0.30	0.60	0.05	0.05
Expert Inspection	0.35	0.55	0.05	0.05

These relations allow us to calibrate the tree tools, to configure the theoretical probability of failure per week and address the operation plan on a yearly basis. These factors are confirmed at the end of every year, after checking the digital reports to see if the factors may vary for the next season. There is some tolerance that prevents us from predicting more than 90% for the moment. Probably it is because there are some variables that we still need to study further or add to our calculations. The most important variable that we are studying to correct is temperature, as shown in figure 3.10.



ICEBERG quick summary report

CMS page

WTGs in ALARM (very low HS) in the current week	WTGs in WARNING (low HS) in the current week	WTGs in GOOD (high HS) in the current week	WTGs not communicating in the current week
457	856	4553	282

Health Status by week (number of WTGs in alarm and the details) - point with mouse for more infos

Country	17-May-21	24-May-21	31-May-21	7-Jun-21	14-Jun-21	21-Jun-21	28-Jun-21	5-Jul-21	12-Jul-21	19-Jul-21
Brazil	12 of 204	22 of 345	23 of 345	21 of 347	21 of 353	23 of 355	19 of 355	21 of 355	24 of 355	26 of 353
Chile										3 of 143
Greece	8 of 184	10 of 185	14 of 166	9 of 185	10 of 185	9 of 184	11 of 184	10 of 162	11 of 162	11 of 135
India	13 of 101	17 of 102	19 of 102	22 of 102	23 of 99	17 of 110	21 of 112	21 of 112	13 of 112	22 of 110
Italy	45 of 516	39 of 514	41 of 514	47 of 512	46 of 512	45 of 492	50 of 463	50 of 516	66 of 518	18 of 536
Mexico	16 of 256	11 of 203	10 of 203	9 of 204	14 of 204	18 of 205	13 of 203	10 of 204	15 of 202	17 of 202
Peru	1 of 42	1 of 42	1 of 42	2 of 41	3 of 41	3 of 41	3 of 41	3 of 41	3 of 41	4 of 42
Romania	40 of 232	34 of 232	31 of 231	24 of 232	27 of 232	22 of 231	32 of 231	38 of 231	41 of 231	56 of 231
South_africa	2 of 72	2 of 46	1 of 79	1 of 79	1 of 80	1 of 80	1 of 80	1 of 45	1 of 79	1 of 79
Spain	71 of 1756	72 of 1752	69 of 1745	75 of 1750	71 of 1760	71 of 1761	67 of 1755	76 of 1724	71 of 1724	77 of 1721
Usa	79 of 2214	97 of 2302	95 of 2309	107 of 2311	143 of 2312	155 of 2316	169 of 2311	217 of 2315	219 of 2315	231 of 2314
Total	**287 of 5577**	**305 of 5723**	**304 of 5736**	**317 of 5763**	**359 of 5778**	**364 of 5775**	**386 of 5735**	**447 of 5705**	**464 of 5739**	**466 of 5866**

Figure 3.10. Results for the prediction versus the reality for TSG Tool (EUC).

Some additional results were the relations between the BTS activities and their impact on the key variables we get from each Generation Unit (Table 3.6).

Table 3.6. Relation between BTS activities and the key signals from GU (EUC database)

	BTS Correlation			
Key Variables	**CL&AD**	**LUB**	**TO&TE**	**ESP INS**
Resource Mean	0.10	0.40	0.40	0.10
Resource Variation	0.10	0.40	0.40	0.10
Active Power	0.10	0.40	0.40	0.10
Reactive Power	0.10	0.40	0.40	0.10
Resource Distribution	0.10	0.40	0.40	0.10
Load Factor	0.25	0.25	0.25	0.25
Average Temperature	0.40	0.40	0.10	0.10
Average Density	0.10	0.40	0.40	0.10
Turbulence Intensity	0.10	0.40	0.40	0.10
Age	0.10	0.10	0.30	0.50

The same chart was developed as well for the Trouble shooting Guide (TSG) activities (Table 3.7.). All these relations are crucial to evaluate the Lifetime Extension, for example, or to see if it is possible to boost the GU under certain conditions.

Table 3.7. Relation between TSG activities and the key signals from GU (EUC database)

	TSG Correlation			
Key Variables	**Hydraulic**	**Mechanic**	**Electric**	**Electronic**
Resource Mean	0.30	0.30	0.30	0.10
Resource Variation	0.25	0.25	0.25	0.25
Active Power	0.30	0.30	0.30	0.10
Reactive Power	0.10	0.10	0.40	0.40
Resource Distribution	0.30	0.30	0.30	0.10
Load Factor	0.30	0.30	0.30	0.10
Average Temperature	0.20	0.20	0.30	0.30
Average Density	0.40	0.40	0.10	0.10
Turbulence Intensity	0.40	0.40	0.10	0.10
Age	0.20	0.30	0.30	0.20

3.5 DEVELOPMENT THE THERMAL SIGNATURE MODEL FOR THE GU DIAGNOSIS

As was shown in the previous results, we are not able to reach 100 % of plan activities because we face a huge challenge with the relations between the signals and the event causes. No relation perfectly matches, so we assume that due to the way we approach the problem, trying to reduce the Fault Tree Analysis and make it simple and suitable for the four technologies under the scope, we reduce the capability to reach the full target. As we will present in the conclusions, it is difficult to manage large fleet and fine-tune each asset as if it were unique. During these years of study, checking the database and reading technical papers, we found that the most critical signal to improve operations is the temperature of the components. We checked and developed the normal distribution with the average and the sigma deviation for each case. In order to be able to extract some relations described in the table 3.8, we used the Microsoft Power BI and the SAS software.

Table 3.8. Relation between TSG activities and Temperature (EUC database).

	TSG			
Thermal Signature	**Hydraulic**	**Mechanic**	**Electric**	**Electronic**
Unit Temperature	**0.25**	**0.25**	**0.25**	**0.25**
Mechanical Temperature	**0.40**	**0.40**	**0.10**	**0.10**
Electrical Temperature	**0.10**	**0.20**	**0.60**	**0.10**
Structural Temperature	**0.10**	**0.10**	**0.20**	**0.60**
Transformer Temperature	**0.00**	**0.00**	**0.60**	**0.40**
Ambient Temperature	**0.25**	**0.25**	**0.25**	**0.25**

This relation is very important to be able to check the TSG schedule tool, and supervise the activities performed in the GU. To check if the quality of the operations and the checks described in the TSGs are performing well, or if we should take decisions after the year plan. This was described in an organizational procedure that describes the roles and responsibilities of Organizational Units and other internal/external actors within a given process. The process described herein refers to the new O&M blades' strategy for the entire EUC's fleet.

The overall process for the development of uniform Operation and Maintenance guidelines is divided into four different phases to successfully capture the site specifics and experience. Starting with Phase I, the goal is to define the sample procedures that need to be followed and define the skeleton of the guidelines. The second phase refers to the development of specific Operation and Maintenance action recommendations by creating "ad hoc" guidelines according to the defined components and system severities, i.e., the O&M templates. Finally, both the third and fourth phases of the process relate to the implementation of site-specific observations. In terms of the former, the O&M work procedures are applied by the local technical teams. In terms of the latter, all the work implementation observations are used to improve and revise the guidelines.

However, the current results document was focused on all phases to be applicable. Nonetheless, the overall methodology has been compiled by taking into consideration all phases and will be implemented.

The process we followed to write the operative instruction, appears in the listed activities.

Activity 1: Mapping out the different Site-specific Operation and Maintenance procedures.

- Each site has different Operation and Maintenance procedures due to the different characteristics (e.g., different legislation, operational conditions etc.). Therefore, it is vital to know each site's particularities, as these may affect the implementation of the suggested O&M actions.

Activity 2: The person responsible for O&M (on site level) should pick the appropriate template, as this is obtained from the selection matrix.

Activity 3: The component and system status of the assets is established via analysis of performed inspections:

- Using the latest full assessment inspections (end-of-warranty, take-over, planned full inspections) if those are less than a year old and cover the listed hotspots according to the individual blades' templates.
- Alternatively, a new bench-line inspection is performed following the inspection plan in the work instruction.

Activity 4: Site-specific priorities and O&M cost factors. According to the base line inspection, the site-specific priorities can also be identified to order the O&M actions (as these are defined in the respective templates) to be prioritized according to the site's needs.

Activity 5: The person responsible for O&M should approve the selected procedure as this is defined by the selected template in the Entity CCM organization. The CCM organization shall advise the official O&M maintenance manuals regarding component and system affected.

Activity 6: The Site organizes and aligns all the work instructions and procedures as well as the inspection and repair campaigns according to the approved template. Planning and scheduling process: ET shall verify that the local organization has all the needed procedures to plan and tackle all the maintenance activities based on work orders. This process shall cover both long term pacifications (annual base) and short-term modifications (Daily and weekly). The process shall include a simple way to modify the maintenance plan based on the predictive-maintenance outcomes, pending tasks, and safety requirements.

Activity 7: The Site will report all the activities and the outcomes of each inspection campaign in the reporting system. The reporting methodology should follow some specific norms according to the current guidelines and in accordance with EUC's policies to achieve data consistency and better O&M cost monitoring and prioritization.

Activity 8: After being registered to EUC's reporting system, each inspection campaign's outcome should be evaluated, and respective actions should be planned.

Activity 9: Update the work procedures prescribed in the templates, according to the field observations and site particularities (Figure 3.11).

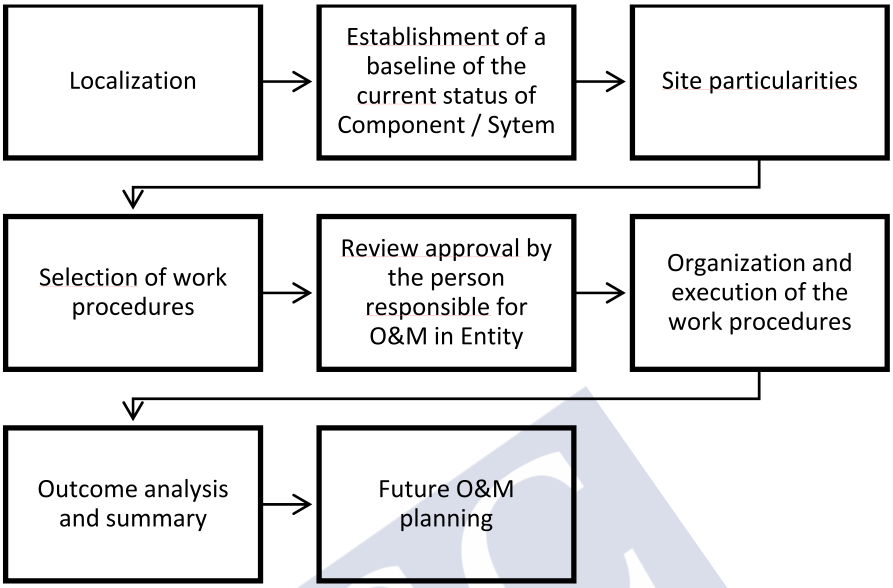


Figure 3.11: Overview of the overall process methodology.

Based on the description of the previous activities, a flowchart for developing the O&M guidelines

The purpose of this document is to establish a clear process and a comprehensive list of activities for the correct management of reporting after any maintenance activity on a Generation plant [51].

The reporting process described below refers to the following maintenance activities:

- Planned maintenance activities on Wind Turbines (BTS, AVS)
- Unplanned maintenance activities on Wind Turbines (TSG)

The reporting of all the activities should be done following the generic reports template that will be realized in the form of Annex. Each report should be accountable for all the tasks, either planned or unplanned, with evidence before and after the performed activity. The Reports should be uploaded in the entity system that was already defined and following the process instructions included in this document.

This operating instruction shall be implemented and applied as far as possible within global renewable energies business lines and in compliance with any applicable laws, regulations, and governance rules, including any stock exchange and unbundling-relevant provisions, which in any case prevail over the provisions contained in this document.

4. CONCLUSIONS AND FUTURE ACTIVITIES

In this chapter, we will present the conclusions of the work performed along the last years. In addition, we include some suggestions for future activities to continue the reported work.

1. Convert the Unplanned into Planned

For the main target "Converting the unplanned into planned", we were able to reduce the unplanned activities in the renewable plants by 70%, with a high impact in the leveraged cost of energy (LCoE), and effectively apply the ISO 55000 in the four technologies we have in scope. Probably if we took more variables and specified the model for each, the target 100 % could be theoretically reached but in practice we are not able to intervened in to short time of on the GU. This action could imply increasing the cost in personnel, to have many people available to act or, have the O&M crews in the plant, all the time.

2. Developing a classification method for alarms, events and stoppages

Regarding the target "Developing a classification method for alarms, events and stoppages", we may consider it fully achieved. Probably it is fair to address other classification methods but all of them should fit into the organization that is performing the assets management. This task probably it is easy if we enter in the business by the first time, but having in mind that we developed for a century-aged company, we should fulfill some internal considerations, use the already proposed systems and software that are in application.

3. Modeling the LPF for the Renewable Assets Management System

Regarding the target "Modeling the LPF for the Renewable Assets Management System", we consider we were able to reach the target, it is possible to set up other outputs like MTBF, LCoE, or IoP etc. This "Y" target may be change depending if the organization are for example a capital found or an independent power producer. In our case we apply for a utility with presence in several countries and different types of energy. Taking into account that was set up as a company target together with other additional KPIs, we consider that was the right one.

4. Developing the relation between explicative variables

Regarding the target "Developing the relation between explicative variables", which is very linked to the "Y" we stablished that using LPF as a main output, so we reached objectives with this work, however additional relations should be tested if the "Y" is different from ours. Probably we could increase the robustness of the relation results and the confident level, as soon as we can make more frequent the data coming from the GU and use more properly neuronal nets, and machine learning techniques.

5. Developing the thermal signature model for the GU diagnosis

Regarding the target, "Developing the Thermal Signature model for the GU diagnosis". We have realistically fulfilled this objective reached for this target. For future works, we should increase the number of signals received from the GU, and the time frequency (10 minutes data), with this we can capture more than trends including the peaks and other anomaly behaviors to address the new technologies available in this moment. In our opinion, for the installed fleet we can increase the cooling capacity by using nano-additives in the cooling fluids, without any capital expense perform. Other way to investigate is if we are able to reduce the temperature in the electrical components, by using these new cooling liquids, we can transfer this new gap to avoid the de-rating by temperatures or increase the amount of power output.

5. BIBLIOGRAPHY

A) MIL-STD STANDARDS:

MIL-HDBK-61A(SE): Configuration Management Guidance
MIL-HDBK-108 Sampling Procedures and Tables for Life and Reliability Testing
MIL-HDBK-108(1): Notice 1
MIL-HDBK-189C: Reliability Growth Management
MIL-HDBK-217F Reliability Prediction of Electronic Equipment - Notice F
MIL-HDBK-251 Reliability/Design Thermal Applications.
MIL-HDBK-338B Electronic Reliability Design Handbook - Revision
MIL-HDBK-338B (1): Notice 1 (
MIL-HDBK-344A Environmental Stress Screening (ESS) of Electronic Equipment
MIL-HDBK-344A(1): Notice 1 (1 page, 17 KB)
MIL-HDBK-470ª Designing and Developing Maintainable Products and Systems
MIL-HDBK-470A(1): Notice 1 (
MIL-STD-471A Maintainability Verification/Demo/Evaluation - Revision A
MIL-HDBK-472 Maintainability Prediction (176 pages, 5.85 MB). Notice 1
MIL-STD-690D Failure Rate Sampling Plans and Procedures - Revision D
MIL-STD-721C Definition of Terms for Reliability and Maintenance - Revision C
MIL-STD-750E Test Methods for Semiconductor Devices - Revision E
MIL-STD-750F: With Change 1 (21 pages, 205 KB).
MIL-STD-756B Reliability Modeling and Prediction - Revision B
MIL-HDBK-781A Handbook for Reliability Test Methods Revision A
MIL-STD-781D Reliability Testing for Engineering Development Revision D
MIL-STD-785B Reliability Program for Sys. Equip. Develop. and Prod. – Rev. B
MIL-STD-790F Established Reliability and High Reliability Qualified Products
MIL-STD-882C System Safety Program Requirements
MIL-STD-882D System Safety
MIL-STD-882E System Safety
MIL-STD-883J Test Method Standard Microcircuits
MIL-STD-1543B Reliability Program Requirements for Space and Launch Vehicles - Revision B
MIL-STD-1629A Procedures for Performing a Failure Mode Effects and Criticality Analysis - Revision A
MIL-STD-2074 Failure Classification for Reliability Testing
MIL-STD-2155 Failure Reporting, Analysis and Corrective Action Systems
MIL-STD-2164 Environmental Stress Screening Process for Electronic Equipment
MIL-HDBK-2164A Environmental Stress Screening Process for Electronic Equipment - Revision A
MIL-STD-2173 Reliability Centered Maintenance Requirements for Naval Aircraft, Weapons Systems and Support Equipment (265 pages, 10.8 MB) Notice 2
MIL-STD-3034 Reliability-Centered Maintenance (RCM) Process

MIL-P-24534A Planned Maintenance System: Development of Maintenance Requirement Cards, Maintenance Index Pages, and Associated Documentation

MIL-PRF-19500P with Amendment 2 Performance Specification: Semiconductor Devices, General Specification For

B) IFRS STANDARDS:

IFRS 1 First-time Adoption of International Financial Reporting Standards
IFRS 2 Share-based Payment
IFRS 3 Business Combinations
IFRS 4 Insurance Contracts
IFRS 5 Non-current Assets Held for Sale and Discontinued Operations
IFRS 6 Exploration for and Evaluation of Mineral Resources
IFRS 7 Financial Instruments: Disclosures
IFRS 8 Operating Segments
IFRS 9 Financial Instruments
IFRS 10 Consolidated Financial Statements
IFRS 11 Joint Arrangements
IFRS 12 Disclosure of Interests in Other Entities
IFRS 13 Fair Value Measurement
IFRS 14 Regulatory Deferral Accounts
IFRS 15 Revenue from Contracts with Customers
IFRS 16 Leases
IFRS 17 Insurance Contracts
IAS 1 Presentation of Financial Statements
IAS 2 Inventories
IAS 7 Statement of Cash Flows
IAS 8 Accounting Policies, Changes in Accounting Estimates and Errors
IAS 10 Events after the Reporting Period
IAS 11 Construction Contracts
IAS 12 Income Taxes
IAS 16 Property, Plant and Equipment
IAS 17 Leases
IAS 18 Revenue
IAS 19 Employee Benefits
IAS 20 Accounting for Government Grants and Disclosure of Government Assistance
IAS 21 The Effects of Changes in Foreign Exchange Rates
IAS 23 Borrowing Costs
IAS 24 Related Party Disclosures
IAS 26 Accounting and Reporting by Retirement Benefit Plans
IAS 27 Separate Financial Statements
IAS 28 Investments in Associates and Joint Ventures
IAS 29 Financial Reporting in Hyperinflationary Economies
IAS 32 Financial Instruments: Presentation
IAS 33 Earnings per Share
IAS 34 Interim Financial Reporting
IAS 36 Impairment of Assets
IAS 37 Provisions, Contingent Liabilities and Contingent Assets

IAS 38 Intangible Assets
IAS 39 Financial Instruments: Recognition and Measurement
IAS 40 Investment Property
IAS 41 Agriculture

C) IEC STANDARDS:

IEC 60027 Letter symbols to be used in electrical technology.
IEC 60028 International standard of resistance for copper.
IEC 60034 Rotating electrical machinery.
IEC 60038 IEC Standard Voltages.
IEC 60041 Field acceptance tests to determine the hydraulic performance of hydraulic turbines, storage pumps and pump-turbines.
IEC 60044 Instrument transformers.
IEC 60050 International Electro Technical Vocabulary.
IEC 60060 High-voltage test techniques.
IEC 60068 Environmental Testing.
IEC 60071 Insulation Co-ordination.
IEC 60076 Power transformers.
IEC 60085 Electrical insulation.
IEC 60086 Primary batteries.
IEC 60119 The Electrical Performance of Semiconductor Rectifiers (Metal Rectifiers).
IEC 60137 Bushings for alternating voltages above 1000V.
IEC 60146 Semiconductor Converters.
IEC 60183 Guide to the selection of high voltage cables.
IEC 60193 Hydraulic turbines, storage pumps and pump-turbines - Model acceptance tests.
IEC 60204 Safety of machinery - Electrical equipment of machines.
IEC 60245 Rubber-Insulated Cables.
IEC 60255 Electrical Relays.
IEC 60270 High-Voltage Test Techniques – Partial Discharge Measurements.
IEC 60273 Characteristics of indoor and outdoor post insulators for systems with nominal voltages greater than 1000V.
IEC 60298 high voltage switchgear in metallic enclosure.
IEC 60308 Hydraulic turbines - Testing of control systems.
IEC 60331 Tests for Electric Cables under Fire Conditions.
IEC 60417 Graphical symbols for use on equipment.
IEC 60439 Low voltage switchgear and control gear assemblies.
IEC 60445 Basic and safety principles for man-machine interface.
IEC 60446 Wiring colors.
IEC 60457 Method of sampling insulating liquids.
IEC 60502 Power cables with extruded insulation and their accessories for rated voltages from 1kV up to 30kV.
IEC 60519 Safety in installations for electro heating and electromagnetic processing.
IEC 60529 Degrees of protection provided by enclosures (IP Code).
IEC 60545 Guide for commissioning, operation and maintenance of hydraulic turbines.
IEC 60609 Hydraulic turbines, storage pumps and pump-turbines - Cavitation pitting evaluation - Part 1: Evaluation in reaction turbines, storage pumps and pump-turbines - Part 2: Evaluation in Pelton turbines.

IEC 60617 Graphical symbols for diagrams.

IEC 60694 Common Specifications for High-Voltage Switchgear and Control Gear Standards.

IEC 60721 Classification of environmental conditions.

IEC 60726 Dry type power transformers.

IEC 60812 International Standard on Fault Mode and Effects Analysis.

IEC 60815 Selection and dimensioning of high-voltage insulators intended for use in polluted conditions.

IEC 60825 Laser safety.

IEC 60826 Design criteria of overhead transmission lines.

IEC 60865-1 Short Circuit Current: Calculation of Effects. Results.

IEC 60947 Standards for low-voltage switchgear and control gear.

IEC 60950 Safety of information technology equipment.

IEC 60994 Guide for field measurement of vibrations and pulsations in hydraulic machines (turbines, storage pumps and pump-turbines).

IEC 61000 Electromagnetic compatibility (EMC).

IEC 61025 Fault tree analysis.

IEC 61116 Electromechanical equipment guide for small hydroelectric installations.

IEC 61131 Programmable Logic Controllers.

IEC 61164 Reliability growth – Statistical test and estimation methods.

IEC 61194 Characteristic parameters of stand-alone photovoltaic (PV) systems.

IEC 61238 Compression

IEC 61277 Terrestrial photovoltaic (PV) power generating systems – General and guide.

IEC 61280 Field testing method for measuring single mode fiber optic cable.

IEC 61968 Application integration at electric utilities – System interfaces for distribution management.

IEC 61970 Application integration at electric utilities – Energy management system application program interface (EMS-API)

IEC 62006 Hydraulic machines - Acceptance tests of small hydroelectric installations

IEC 62040 Uninterruptible power systems.

IEC 62041 EMC requirements for power transformers, power supplies, reactors and similar products

IEC 61286 Character set with electro technical symbols

IEC 61334 Distribution automation using distribution line carrier systems - a standard for low-speed reliable power line communications by electricity meters, water meters and SCADA.

IEC 61345 UV test for photovoltaic (PV) modules

IEC 61346 Industrial systems, installations and equipment and industrial products – Structuring principles and reference designations.

IEC 61355 Classification and designation of documents for plants, systems and equipment.

IEC 61362 Guide to specification of hydraulic turbine control systems

IEC 61364 Nomenclature for hydroelectric power plant machinery

IEC 61366 Hydraulic turbines, storage pumps and pump-turbines - Tendering Documents.

IEC 61378 Converter Transformers.

IEC 61400 Wind turbines.

IEC 61439 Low-Voltage switchgear and control gear assemblies.

IEC 61467 Insulators for overhead lines - Insulator strings and sets for lines with a nominal voltage greater than 1 000 V - AC power arc tests.

IEC 61499 Function blocks.

IEC 61508 Functional safety of electrical/electronic/programmable electronic safety-related systems.

IEC 61511 Functional safety – safety instrumented systems for the process industry sector.

IEC 61513 Functional safety – safety instrumented systems for the Nuclear Industries.

IEC 61523 Delay and Power Calculation Standards.

IEC 61523-1 Delay and power calculation standards - Part 1: Integrated circuit delay and power calculation systems.

IEC 61523-3 Delay and power calculation standards - Part 3: Standard Delay Format (SDF) for the electronic design process.

IEC 61537 Cable management – Cable tray systems and cable ladder systems.

IEC 61557 Equipment for measuring electrical safety in low-voltage distribution systems.

IEC 61558 Safety of power transformers, power supplies, reactors and similar products.

IEC 61643 Surge protective devices connected to low-voltage power distribution systems.

IEC 61646 Thin-film terrestrial photovoltaic (PV) modules – Design qualification and type approval.

IEC 61690 Electronic design interchange format, EDIF.

IEC 61701 Salt mist corrosion testing of photovoltaic (PV) modules.

IEC 61724 Photovoltaic system performance monitoring – Guidelines for measurement.

IEC 61727 Photovoltaic (PV) systems – Characteristics of the utility interface.

IEC 61730 Photovoltaic modules.

IEC 61800 Adjustable speed electrical power drive systems.

IEC 61803 Determination of power losses in high-voltage direct current (HVDC) converter stations.

IEC 61829 Crystalline silicon photovoltaic (PV) array – On-site measurement of I-V characteristics.

D) IEEE STANDARDS:

IEEE Application Guide for Surge Protection of Electric Generating Plants.

IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines.

IEEE Recommended Practice for Determining the Electric Power Station Ground Potential Rise and Induced Voltage from a Power Fault.

IEEE Recommended Practice for Determining the Electric Power Station Ground Potential Rise and Induced Voltage from a Power Fault.

IEEE Standard for Electric Penetration Assemblies in Containment Structures for Nuclear Power Generating Stations.

IEEE Standard for Electric Penetration Assemblies in Containment Structures for Nuclear Power Generating Stations.

IEEE Standard Nomenclature for Generating Station Electric Power Systems.

IEEE Standard Environmental and Testing Requirements for Communications Networking Devices Installed in Electric Power Substations.

IEEE Standard Criteria for Class IE Electric Systems for Nuclear Power Generating Stations.

IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces.

IEEE Standard Environmental and Testing Requirements for Communications Networking Devices in Electric Power Substations

IEEE Standard Environmental and Testing Requirements for Communications Networking Devices Installed in Electric Power Substations

IEEE Standard Environmental and Testing Requirements for Communications Networking Devices Installed in Electric Power Substations.

IEEE Standard Environmental and Testing Requirements for Communications Networking Devices in Electric Power Substations Amendment 1: Add Requirements for Altitude and Altitude De-rating Factors

IEEE Standard for Electric Power Systems Communications -- Distributed Network Protocol (DNP3).

IEEE Standard Test Procedures for Electric Energy Storage Equipment and Systems for Electric Power Systems Applications.

IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines.

IEEE/IEC International Standard for High-voltage switchgear and control gear -- Part 37-013: Alternating-current generator circuit-breakers.

IEEE/IEC International Standard for high-voltage switchgear and control gear - Part 37-013: Alternating current generator circuit-breakers: Corrigendum 1.

IEEE/IEC Draft International Standard for High-Voltage Switchgear and control gear -- Part 37-013: Alternating-Current Generator Circuit-Breakers.

IEEE Standard for AC High-Voltage Generator Circuit Breakers Rated on a Symmetrical Current Basis..

IEEE Guide for Synchronous Generator Modeling Practices and Applications in Power System Stability.

IEEE Standard for Salient-Pole 50 Hz and 60 Hz Synchronous Generators and Generator/Motors for Hydraulic Turbine Applications Rated 5 MVA and Above.

IEEE Guide for Synchronous Generator Modeling Practices and Parameter Verification with Applications in Power System Stability Analyses..

IEEE Guide for Synchronous Generator Modeling Practices in Stability Analyses.

IEEE Guide for AC Generator Protection.

IEEE Guide for the Application of Neutral Grounding in Electrical Utility Systems, Part II - Grounding of Synchronous Generator Systems.

IEEE Guide for the Application of Neutral Grounding in Electrical Utility Systems, Part II--Synchronous Generator Systems.

IEEE Guide for the Application of Neutral Grounding in Electrical Utility Systems, Part III - Generator Auxiliary Systems.

IEEE Guide for the Application of Neutral Grounding in Electrical Utility Systems, Part III -Generator Auxiliary Systems.

IEEE Guide for Operation and Maintenance of Hydro-Generators.

IEEE Standard for AC High Voltage Generator Circuit Breakers Rated on a Symmetrical Current Basis - Amendment 1: Supplement for Use with Generators Rated 10-100 MVA.

IEEE Guide for Generator Ground Protection.

IEEE Recommended Practice for Establishing Liquid-Filled and Dry-Type Power and Distribution Transformer Capability When Supplying Non-Sinusoidal Load Currents.

IEEE Recommended Practice for Establishing Transformer Capability When Supplying Non-Sinusoidal Load Currents

IEEE Recommended Practice for Establishing Liquid Immersed and Dry-Type Power and Distribution Transformer Capability when Supplying Non sinusoidal Load Currents

IEEE Guide for Establishing Power Transformer Capability while under Geomagnetic Disturbances.

IEEE Guide for Transformers Directly Connected to Generators.

IEEE Guide for Grounding of Instrument Transformer Secondary Circuits and Cases.

IEEE Standard for High Accuracy Instrument Transformers.

IEEE Standard Requirements for Liquid-Immersed Distribution Substation Transformers.

IEEE Guide for Establishing Power Transformer Capability while under Geomagnetic Disturbances - Corrigendum 1

IEEE Guide for the Detection and Determination of Generated Gases in Oil-Immersed Transformers and Their Relation to the Serviceability of the Equipment.

IEEE Standard for Requirements for Distribution Transformer Tank Pressure Coordination.

IEEE Guide to Describe the Occurrence and Mitigation of Switching Transients Induced by Transformers, Switching Device, and System Interaction.

IEEE Guide to Describe the Occurrence and Mitigation of Switching Transients Induced by Transformers, Switching Device, and System Interaction.

IEE Proposed Guide for Transformer Impulse Tests.

IEEE Standard for Test Methods and Performance of Low-Voltage (1000 Vrms. or Less) Surge Protective Devices Used on Secondary Distribution Systems (Between the Transformer Low-Voltage Terminals and the Line Side of the Service Equipment)

IEEE Guide for the Application of Low-Voltage (1000 Vrms. or Less) Surge Protective Devices Used on Secondary Distribution Systems (Between the Transformer Low-Voltage Terminals and the Line Side of the Service Equipment).

IEEE Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers.

IEEE Guide for Application of Transformer Connections in Three-Phase Distribution Systems.

IEEE Guide for Transformer Through-Fault-Current Duration.

IEEE Guide for the Evaluation of the Reliability of HVDC Converter Stations.

IEEE Guide for Commissioning High-Voltage Direct-Current (HVDC) Converter Stations and Associated Transmission Systems.

IEEE General Requirements and Test Code for Oil Immersed HVDC Converter Transformers

IEEE Guide for Technology of Unified Power Flow Controller Using Modular Multilevel Converter - Part 1: Functions.

IEEE Recommended Practice for Determination of Power Losses in High-Voltage Direct-Current (HVDC) Converter Stations.

IEEE Standard Practices and Requirements for Thermistor Converters for Motor Drives Part 1- Converters for DC Motor Armature Supplies.

IEEE Standard for Terminology and Test Methods of Digital-to-Analog Converter Devices.

IEEE Standard for Terminology and Test Methods for Analog-to-Digital Converters.

IEEE Recommended Practice: Test Procedure for Utility-Interconnected Static Power Converters.

IEEE Guide for Self-Commutated Converters.

E) ISO Standards

ISO 9001 Quality Management.

ISO 12100 Safety of Machinery Design
ISO 13857 Safety of Machinery Operation
ISO 14001 Environmental Management.
ISO 20121 Sustainability Management.
ISO 26000 Social Responsibility Management.
ISO 27001 Information Technology.
ISO 31000 Risk Management
ISO 50001 Energy Management
ISO 55000 Assets Management.

F) REFERENCES

[1] "Renewables 2017 global status report", REN 21 Network, 2017, https://www.ren21.net/gsr-2017/

[2] "Renewable Energy Statistics 2017". International Renewable Energy Agency (IRENA), 2017, https://irena.org/publications/2017/Jul/Renewable-Energy-Statistics-2017

[3] "World Energy Outlook 2019" International Energy Agency (IEA), 2019, https://www.iea.org/reports/world-energy-outlook-2019

[4] "Renewables 2020 global status report", 2020, REN 21 Network, https://www.ren21.net/gsr-2020/

[5] Ioannou A., Angus, A., Brennan, F. "Parametric CAPEX, OPEX, and LCOE expressions for offshore wind farms based on global deployment parameters" *Energy Sources, Part B: Economics, Planning, and Policy*, vol. 13, no. 5, pp. 281–290, 2018, doi: 10.1080/15567249.2018.1461150

[6] "Hydropwer Status Report 2017," International Hydropower Association IHA, 2017, https://www.hydropower.org/

[7] Mandley S. J., Daioglou V., Junginger H. M., van Vuuren D. P., Wicke B. "EU bioenergy development to 2050" *Renewable and Sustainable Energy Reviews*, vol. 127, 109858, 2020, doi: 10.1016/j.rser.2020.109858

[8] Matzenberger J., Kranzl L., Tromborg E., Junginger M., Daioglou V., Sheng C., Keramidas G.K. "Future perspectives of international bioenergy trade" *Renewable and Sustainable Energy Reviews* Vol. 43, pp. 926-941, 2015, https://doi.org/10.1016/j.rser.2014.10.106.

[9] Hubbard P. G., Xu J., Zhang S., Dejong M., Luo L., Soga K., Papa C., Zulberti C., Malara D., Fugazzotto F., Garcia Lopez, F., Minto C. "Dynamic Structural Behavior Monitoring and Damage Detection of a Model Wind Turbine Tower using Rayleigh-Based Distributed Fiber-Optic Strain Sensing" *Journal of Civil Structural Health Monitoring*, (under review).

[10] Blanco Silva F. "El triángulo de la gestion energética en la empresa y administración pública", Ed. Instituto Iberoamericano de Ingenieros de la Energía. 2018.

[11] Wiser R., Bolinger M., Lantz E. "Assessing wind power operating costs in the United States: Results from a survey of wind industry experts" *Renewable Energy Focus*, vol. 30, pp. 46-57, 2019, doi: 10.1016/j.ref.2019.05.003.

[12] García F., Argenio F., Asensio J., Varela, L. M. Lugo L., Fernández J. "Analysis of the Thermal Signature of Wind-turbine Generators: implications for their main Operative Parameters and future application of nanofluids" *NANOUPTAKE COST ACTION (CA 15119) Working Group Meeting*, Naples, Italy, 28th – 29th May 2018

[13] Alba Perez J., Anselmi A., Asensio Marquez J., Ayra V., Cabrera Escribano E., Garcia Lopez F., Governanti A., La Pegna L., Lopez Zubiri I., Moset Hernandez A., Onofrj F., Paoli

S., Sideris G., Vidal Rodriguez J., Argenio F. "Método per la definizione e pianificacione parametrizzata di interventi di manutenzione Sistema di gestione manutenzione/M30P" (Italy, 102017000129875), Societa Italiana Brevetti accepted January, 30, 2020, https://www.sib.it/en/.

[14] Weijtjens W., Verbelen T., Capello E., Devriendt C. "Vibration based structural health monitoring of the substructures of five offshore wind turbines" *Procedia Engineering,* vol. 199, pp. 2294-2299, 2017, doi: 10.1016/j.proeng.2017.09.187.

[15] Kim W., Yi J.-H., Kim J.-T., Park J.-H. "Vibration-based Structural Health Assessment of a Wind Turbine Tower Using a Wind Turbine Model" *Procedia Engineering*, vol. 188, pp. 333-339, 2017, doi: 10.1016/j.proeng.2017.04.492.

[16] Nguyen C.-U., Huynh T.-C., Kim J.-T. "Vibration-based damage detection in wind turbine towers using artificial neural networks" *Structural Monitoring and Maintenance,* vol. 5 no. 4, pp. 507-519, 2018, doi: 10.12989/smm.2018.5.4.507.

[17] Qiu B., Lu Y., Sun L., Qu X., Xue Y., Tong F. "Research on the damage prediction method of offshore wind turbine tower structure based on improved neural network" *Measurement,* vol. 151, 2020, 107141, doi: 10.1016/j.measurement.2019.107141.

[18] Ciang C.C., Lee J.-R., Bang H.-J. "Structural health monitoring for a wind turbine system: a review of damage detection methods" Measurement Science and Technology vol. 19, no. 12, 122001, 2008, doi: 10.1088/0957-0233/19/12/122001.

[19] Oliveira G., Magalhaes F., Cunha A., Caetano E. "Vibration-based damage detection in a wind turbine using 1 year of data" *Structural Control and Health Monitoring* vol. 25, no.11, e2238, 2018, doi: 10.1002/stc.2238.

[20] Avendano-Valencia L.D., Fassois S.D. "Natural vibration response based damage detection for an operating wind turbine via Random Coefficient Linear Parameter Varying AR modelling" *Journal of Physics: Conference Series* vol. 628, pp. 24-26, 012073, 2015, doi: 10.1088/1742-6596/628/1/012073.

[21] Xianlong H., Tianli S. "A New Identification Method for Bolt Looseness in Wind Turbine Towers" *Shock and Vibration* 6056181, 2019, doi: 10.1155/2019/6056181.

[22] Nguyen C.T., Huynh T.-C., Yi J.-H., Kim J.-T. "Hybrid bolt-loosening detection in wind turbine tower structures by vibration and impedance responses" *Wind and Structures An International Journal* vol. 24, no. 4, pp. 385-403, 2017, doi: 10.12989/was.2017.24.4.385.

[23] Benedetti M., Fontanari V., Zonta D. "Structural health monitoring of wind towers: remote damage detection using strain sensors" *Smart Materials and Structures* vol. 20, no. 5, 055009, 2011, doi: 10.1088/0964-1726/20/5/055009.

[24] Bang H.-J., Kim H.-I., Lee K.-S. "Measurement of strain and bending deflection of a wind turbine tower using arrayed FBG sensors" *International Journal of Precision Engineering and Manufacturing* vol. 13, pp. 2121-2126, 2012, doi: 10.1007/s12541-012-0281-2.

[25] Soga K., Luo L. "Distributed fiber optics sensors for civil engineering infrastructure sensing" *Journal of Structural Integrity and Maintenance* vol. 3, pp. 1-21, 2018, doi: 10.1080/24705314.2018.1426138.

[26] Masoudi A., Newson T.P. "Contributed Review: Distributed optical fibre dynamic strain sensing" *Review of Scientific Instruments* vol. 87, pp. 011501, 2016, doi: 10.1063/1.4939482.

[27] Samiec, D. "Optical Metrology: Distributed fibre-optic temperature and strain measurement with extremely high spatial resolution" *Photonik International* pp. 10-13, 2012.

[28] Hubbard P. G., Xu J., Zhang S., Dejong M., Luo L., Soga K., Papa C., Zulberti C., Malara D., Fugazzotto F., Garcia Lopez, F., Minto C. "Dynamic structural health monitoring of a model wind turbine tower using distributed acoustic sensing (DAS)" *Journal of Civil Structural Health Monitoring,* vol. 11, pp. 833–849, 2021, doi: 10.1007/s13349-021-00483-y.

[29] Holcomb, C. M., Bitmead R. R. "Gas Turbine Analytics Using Archival Data Sets" *ASME Turbo Expo 2015: Turbine Technical Conference and Exposition*, June 15–19, 2015, Montreal, Quebec, Canada, 2015.
[30] Holcomb, C. M., de Callafon R. A., Bitmead R. E. "Closed Loop Nonlinear System Identification Applied to Gas Turbine Analytics", *ASME Turbo Expo 2014: Turbine Technical Conference and Exposition*, June 16–20, 2014, Düsseldorf, Germany, 2014.
[31] Zhu C., Chen S., Song C., Liu H., Bai H., Ma F. "Dynamic analysis of a megawatt wind turbine drive train" *Journal of Mechanical Science and Technology*, vol. 29, no. 5, pp. 1913–1919, 2015, doi: 10.1007/s12206-015-0413-6.
[32] Mazlan A. H., An T. H., Halim A. R. b. A., Abidin M. F. Z., Aziz A., Ridzwan M. "5S concept and usage" *Conference on Language, Education, Engineering and Technology* vol. 1, pp. 5–7, 2-3 September, 2015.
[33] Stroeer A. and, Veitch J. "Bayesian approach to the study of white dwarf binaries in LISA data: The application of a reversible jump Markov chain Monte Carlo method" *Physical Review D*, vol. 80, no. 6, 064032, 2009, doi: 10.1103/PhysRevD.80.064032.
[34] Duan F. "Wind Energy Cost Analysis CoE for offshore Wind and LCOE financial modeling" Bachelor Thesis, Helsinki Metropolia University of Applied Sciences, pp. 3–41, 2017.
[35] Yanlin W., Haijun Z. "Data Asset Value Assessment Literature Review and Prospect" *Journal of Physics: Conference Series*, vol. 1550, no. 3, 032133, 2020, doi: 10.1088/1742-6596/1550/3/032133.
[36] "Assets Definition", Technical Internal Procedure, Enel Green Power, pp. 1–6, 2011.
[37] "Key performance indicators: definition and reporting", Technical Internal Procedure, Enel Green Power; pp. 1–6, 2011.
[38] "Activities_of_Wind_Predictive_Maintenance." Technical Operative Internal Operative Instruction 293. 2019.
[39] "Organizacional Procedure for Asset Management" N 58, Enel Green Power, pp. 1–22, 2011.
[40] Blaabjerg F., Zhou D., Sangwongwanich A., Wang H. "Design for reliability in renewable energy systems" *2017 International Symposium on Power Electronics (Ee)*, 2017, pp. 1-6, doi: 10.1109/PEE.2017.8171658.
[41] Veres C., Marian L., Moica S., Al-Akel K. "Case study concerning 5S method impact in an automotive company", Procedia Manufacturing,vol. 22, pp. 900-905, 2018, https://doi.org/10.1016/j.promfg.2018.03.127
[42] Onaifo F., Akpofure A. "Effect of Temperature, humidity and irradiance on solar power generation" *Journal of Engineering Studies and Research* vol. 26, no. 4, pp. 112-118, 2020.
[43] Yagi, M., Leblanc, F., Chaufray, J. Y., Modolo R., Hess, S., Gonzalez-Galindo, F. "Three dimensional exosphere model: multispecies thermal and non-thermal model" *EPSC-DPS Joint Meeting 2011*, p.812, October 2-7 2011, Nantes, France, http://meetings.copernicus.org/epsc-dps2011
[44] Long D. R., Conca L., Sotta P. "Dynamics in glassy polymers: The Eyring model revisited" *Physical Review Materials* vol. 2, 105601, 2018, doi: 10.1103/PhysRevMaterials.2.105601.
[45] Meilikhov, E.Z., Farzetdinova, R.M. "Bistable perception of ambiguous images: simple Arrhenius model" *Cognitive Neurodynamics* vol. 13, pp. 613–621, 2019, doi: 10.1007/s11571-019-09554-9.
[46] Devlin P., Kepner J., Luo A., Meger E. "Hybrid Power-Law Models of Network Traffic" *2021 IEEE International Parallel and Distributed Processing Symposium Workshops*, pp. 280-287, 2021, doi: 10.1109/IPDPSW52791.2021.00051.

[47] Hongbo Li, Pei Li, Nannan Gao, Lin Niu, Yanyan Zhang, Yongbin Bao, Wenqi Xu. "Opportunistic Maintenance Model for Wind Turbine Based on Reliability Constraint", *IOP Conference Series: Materials Science and Engineering* Vol. 366, 366, 012026, 2018, doi: 10.1088/1757-899X/366/1/012026.
[48] “Wind operation process” Nº 96, Enel Green Power, pp. 1–8, 2011.
[49] Vivekananthamoorthy N., Sankar S. "Lean Six Sigma" KCG College of Technology, Chennai India. 2014, ISBN 978-953-307-370-5.
[50] F. Venturini, “Subject : Operating Management Subject : Operating Management,” no. 132, pp. 1–9, 2014.
[51] “Organizational Procedure for Operating Management" Nº 146, Enel Green Power, pp. 1–32, 2014.

RESUMO

As enerxías renovábeis están producidas por recursos naturais, que están a ser renovados continuamente nun factor de escala humano, son tamén chamadas enerxías de superficie, e son especialmente abundantes en certas rexións. Imos a centrarnos basicamente neste traballo en catro tipos, que serán a xeración hidráulica, a xeración solar, a eólica e a xeotérmica, que basicamente teñen moito impacto tamén en Galicia.

Baseado no reporte REN21´s do 2017 as enerxías renovábeis contribuíron case no 20% do consumo total da humanidade, e en case o 25% na xeración de enerxía. Este consumo de enerxía e debido o impacto da pandemia do COVID en 2020, está a sufrir cambios moi importantes balanceándose doutro xeito entre os consumos domésticos e industriais. Debido as protocolos asinados pola maioría dos países, e agora os plans de reactivación económica trala saída da crisis, unha gran parte de países están a planear inverter nun cambio de modelo enerxético desconectándose case completamente ou adiantando os plans de desconexión das enerxías de subsolo ou fósiles.

A nivel nacional non menos de 30 países xa teñen contribucións de enerxía renovable que superan o 20 % da súa cantidade total. Os mercados nacionais de enerxías renovábeis están a ser proxectados para continuar cun crecemento moi alto na década que estamos, e en moitos casos xa se teñen conseguido compromisos de total independencia, de empresas e algúns países para o ano 2025. Hoxe en dia por exemplo Islandia e Noruega xeran a súa enerxía de xeito totalmente renovable, como temos dito moitos países teñen ese plan para o futuro próximo. Mais de 50 países o redor do mundo teñen mais do 50% da súa xeración enerxética con base renovable.

Como comentabamos anteriormente, co a crise derivada da pandemia do COVID do 2020 a situación mudou de xeito tan forte, que foron moitas as empresas produtoras de enerxía que xa planearon o horizonte 2025 nos seus obxectivos. Entre elas encontrase Enel Green Power, que é a empresa que vou a usar como exemplo e da que vou usar a súa base de dados.

O horizonte fixado para EU-27 e do 2030. Compre resaltar que as enerxías renovables están concentradas nun numero moi grande de países convertendo ou democratizando a xeración de enerxía, dado que os recursos son ilimitados e sen custo.

O gran crecemento e implantación deste tipo de enerxías así como o incremento da súa eficiencia resulta nunha moi significante seguridade enerxética, redución dos efectos do cambio climático e beneficios económicos moi sustancias, especialmente para aqueles países moi dependentes das enerxías fósiles. Os informes realizados xa reflexan unha gran aceptación sobre todo das enerxías eólicas e solares.

Moitos proxectos de produción de enerxía teñen que ser de gran capacidade, polas economías de escala e outros factores, mentres que as enerxías renovábeis permiten a implantación local a calquera tipo de escala, dende xeración distribuída ou domestica a grandes plantas de produción para consumos industriais. Como este tipo de enerxías ademais poden ser aplicadas con unha electrificación, teñen benéficos adicionais dado que pode ser convertida en calor, ou en enerxía mecánica con unha grande eficiencia, sendo totalmente limpa no seu punto de consumo. Adicionalmente a enerxía renovable e moito mais eficiente que a fósil, polo seus ciclos de conversión facendo que se precisen moitos menos recursos primarios. A rápida adhesión, das enerxías renovables e da súa eficiencia, coa diversificación tecnolóxica e co alcance da mesma a case calquera estado fai que a seguridade e beneficios económicos sexan dous factores moi importantes a hora de planear un cambio de paradigma enerxético, en moitos países. A redución da polución pode ter implicacións moi fondas na mellora da saúde, e eficiencia nos sistemas de saúde dos países, e finalmente son tecnicamente inesgotables, polo que se poden planear futuros escenarios de uso.

O cambio climático, e as alarmas xeradas o respecto, a afección de fenómenos meteorolóxicos así como as mortes debidas a polución, xunto cos custos deste tipo de enerxía e a tecnoloxía na que se

desenrola, fan que todos os países podan adoptalas de xeito positivo, sen atender a razóns xeopolíticas ou dependencias de terceiros países que son moi inestables.

As novas regulacións e políticas están axudando as empresas que actúan de xeito positivo contra cambio climático sobre poñerse as crisis financeiras e agora tamén a crise do COVID moito mellor que outros sectores. No 2019 a Axencia internacional de enerxía renovable estableceu que temos que crecer seis veces mais rápido si queremos limitar o incremento de temperatura por debaixo dos 2 º C neste século, si o comparamos coas tendencias de crecemento que tiñamos antes da revolución industrial.

No 2014 saíu a norma ISO 55.000, a súa serie que incluía tamén os sistemas de xestión de activos. Esta norma converteuse nunha importante maneira de entender como deben ser xestionados os activos. E moi importante debido o cambio da normativa económica, sobre todo o referente os criterios de valoración de activos. Esta norma fixa os criterios de xeito estándar para os reportes financeiros, o valor dos activos etc. Facendo mais intercambiable as contas entre as rexións, países ou continentes. A importancia da enerxía renovable e dos seus activos e a súa localización fai moi relevante a maneira de xestionar as plantas de xeración por moitas causas. Na maioría dos países este tipo de activos están clasificados como de utilidade pública, polo tanto deben seguir unhas regras, e debido o interese estratéxico, deben garantir a información para poder ser financiados, ou tidos en conta nos mercados financeiros, ademais de poder comprarse así como ser quen de facilitar a información os inversores, accionistas e demais grupos de interese.

Debido os obxectivos fixados nos horizontes H2020 e H2050, a importancia dos activos renovábeis foron cada vez mais grandes, e chegouse a establecer un libro branco mundial para cumprir co protocolo de Kyoto e o mais recente protocolo de París. Esta situación incrementou o interese amosado polas compañías ou grupos de elas, para entrar no sector da enerxía e en concreto no sector das renovábeis.

Estes factores fan moi importante o xeito de xestionar os activos e a información que debe ser aportada. Algúns parámetros que son chave son por exemplo o coste medio de enerxía (LCOE), os custos de inversión tecnolóxica (CAPEX) ou os custes de operación (OPEX). A clasificación de utilidade pública fai que o custo da enerxía renovable entre nos índices de consumo, e nos cálculos dos prezos e demais relacións de factores que son presentados polos países, como parámetros de inversión ou actividade económica. O reto e o de optimizar o custo para eliminar as incertezas de creación de prezo. As grandes empresas de xeración de enerxía como Enel Green Power, debido a migración das enerxías de subsolo as enerxías de superficie ou renovábeis e a súa proxección internacional fan moi importante a optimización do custo para seren competitivos en calquera pais ou mercado.

Debido a grande importancia da mestura enerxética, e logo de ver que as enerxías renovábeis, o recurso non é fixo, polo tanto debese ter unha potencia instalada moito maior, para poder cubrir as demandas do mercado. Todo isto fai moi importante que sexamos capaces de ter as unidades de xeración dispoñibles a maior cantidade de tempo cando o recurso e dispoñible. Temos que ter en conta que en case todos os países debemos ser capaces de predicir a cantidade de enerxía que enviamos o sistema cada hora, e con predicións bastante exactas en horizontes semanais.

Os activos renovábeis teñen actualmente só un 20 % de actividades planadas e un 80% non planeadas. Esta situación fai que sexa un reto reducir os custos, a menos que sexamos capaces de reverter ese factor. O plan que estamos a propor neste traballo e alcanzar o 90% de perdición ou de actividades planeadas. O noso principal obxectivo e probar que o factor de perdida de produción, e unha variable resultado, na que podemos actuar. Deste xeito propoñemos que variables podemos escoller como explicativas do LPF, e que relacións teñen entre elas para optimizar a produción e a predición da mesma e así facer mais eficiente as unidades de xeración.

E moi importante, ser capaces de amosar estas relacións para tentar de sacar un bo rendemento, e tratar de convencer os grupos de interese de que as renovábeis ademais de eficientes, sostibles etc., son tamén fontes baratas de xeración.

Os fundamentos da xestión de instalacións de enerxía renovable e os sistemas de soporte que nos estamos a explicar, cando están integrados no mais amplo cadro de goberno e na xestión dos riscos do operador, poden contribuír con beneficios moi tanxibles e oportunidades, dado que a xestión de activos renovábeis traslada ós obxectivos da organización na toma de decisións, plans e actividades usando sempre o risco como variable de medición. A xestión de activos renovables permite o operador valorar as actividades a realizar nos activos e vinculalas o seus obxectivos, mentres se equilibran os factores financeiros, medioambientais e de costes sociais. Todas estas vantaxes tamén son incrementadas pola calidade e a responsabilidade social corporativa que ven integrada na norma que estamos a usar como guía.

A intención desta disertación e a de xuntar todos os últimos conceptos de Xestión de activos, que veñen das diferentes normas tanto ISO como IEC, e enfocalos nas enerxías renovábeis e mais en concreto nos activos de xeración de enerxía. Logo de varios anos de crecemento na construción sobre todo de parques eólicos e plantas solares, e logo de ver que a cantidade de instalacións actuais así como o envolvemento das directivas europeas, protocolos de nacións unidas con referencia o cambio climático, economía sostible, Sustentabilidade enerxética, e tempo de poñer o foco nesta clase de activos, para ver como se poden xestionar de maneira efectiva e optimizada. Todo isto vense de acelerar moito coa situación acaecida a nivel mundial co impacto da COVID. Vendo a situación actual e a proxección no futuro, e tempo de deixar as estratexias a curto prazo para tratar de mellorar os riscos na xestión de activos, descritos na ISO 31000, e poñer en práctica estratexias de longo recorrido, para traer un horizonte que converta a mestura de fontes enerxéticas actual nun futuro completamente sostible e renovable.

Usarei a análise estatística de eventos e sinais, alarmas e información sobre as mesmas etc. que ven recollida a traveso do Sistema de adquisición de dados do activo renovable, así como o os dados do Sistema de vixilancia da condición dos compoñentes, tanto a nivel compoñente como a nivel sub compoñente, así como dados históricos, reportes dixitais recibidos das actividades de operación e manutención que se realizan no activo. O sistema de vixilancia da condición usa os dados para determinar os comportamento dun sistema dun compoñente ou dunha planta, detectar si hai algún tipo de degradación, estimar a vida remanente do compoñente ou identificar as posibles fallas. Os métodos de vixilancia poden ser dende a inspección física directa con diferentes sensores ou o uso de modelos de comportamento simulado que permiten entender o comportamento do activo, tanto a nivel compoñente como sistema como planta.

Para as máquinas mais modernas e en especial para as plantas de Enerxía renovable, os dados históricos gardados na operación, representan unha parte inexplorada con un gran potencial para o exercicio que nos ocupa. A vixilancia intelixente da condición das plantas e a detección precoz dos fallos e necesaria nos sistemas modernos para previr a operación insegura dos mesmos, que a fin é unha directriz que recae sobre os operadores dos sistemas segundo as normas IEC. Esta maneira de facer diagnose, permite xestionar a manutención programada de tal xeito que poda suprimir o risco de accidentes e de fallas nos equipos. O coste de interrupción do funcionamento dun activo, e deste xeito mais alto que o custo da execución das actividades de predición. De feito e moi revelador ver como a maioría dos fabricantes teñen desenvolvido os seus propios sistemas de diagnose remota para seguir sendo competitivos.

Tamén e moi importante a capacidade para predicir a vida remanente do activo, así como a súa capacidade para consumir esa reserva en función de diferentes escenarios. Así tamén a duración de cada compoñente de xeito individual, para evitar os faios catastróficos e as paradas longas. Para elo vamos a ver as relacións entre os diferentes parámetros que recibimos dos sistemas de dados, e usaremos algunhas ferramentas matemáticas bastante comúns para ver como inflúen esas variables, e tratar de conseguir un modelo que explique por exemplo o funcionamento da unida de xeración ou as perdas de produción etc. Neste traballo fixaremos como variable de saída Y o factor de perda de produción (LPF polas súas siglas en inglés), e trataremos de construír un modelo que explique esa factor, usando todas as variables que recibimos. Tendo en conta que temos unha grande variedade de sinais, vamos a usar mecanismos matemáticos para reducilas a un número que podamos manexar. Temos que ter en conta que a base de dados ca que estamos a traballar ten mais de 50.000 MW de activos das catro tecnoloxías que temos como obxectivo (Hidráulica, Eólica, Solar, Xeotérmica), recibe mais de 100 millóns de datos temporais, que se gravan cada 10 minutos, e o redor de 5 millóns de reportes dixitais. Debido a que estamos a usar series de datos cno unha frecuencia de tempo determinada, fixamos o nivel de confianza limite de cada resultado no 90%. Para o caso que nos ocupa seremos capaces de alcanzar os nosos obxectivos dado que o que buscamos e ser quen de planificar as actividades, e capturar tendencias de comportamento nos compoñentes ou nos sistemas. Para outro tipo de traballo que daría a captura dos casos mais específicos que son mais difíciles de prever.

Todo isto levounos a fixar para esas catro tecnoloxías, unha clasificación de compoñentes e sistemas, que faga que o modelo de comportamento se poda replicar para cada caso. Así mesmo seremos quen de demostrar que as variables nas que mais podemos centrarnos para acadar a predición do LPF, son o tempo medio entre fallos (MTBF) e o tempo de retorno despois de fallo (MTTRf), que seremos quen de dividir o seu impacto nos catro sistemas que integran as unidades que serían, hidráulico, mecánico, eléctrico, electrónico. É pola outra banda o tempo medio entre inspeccións e o tempo de retorno despois de inspección, (MTBI) e (MTTRi) respectivamente, e a súa aplicación nos grupos de compoñentes que eliximos como mínimo común, neste caso serían compoñentes estruturais, mecánicos, e eléctricos respectivamente.

Neste traballo seremos quen de demostrar tamén que a variable temperatura de cada compoñente e de cada sistema e unha fonte excepcional de información, revelándose como un factor a ter en conta tanto para predicir os fallos como para ver a capacidade remanente de produción ou comportamento de cada compoñente, especialmente os vinculados a parte mecánica, que reflectirían o rozamento, a falta de engraxe etc. e os vinculados a parte eléctrica que amosarían as perdas por efecto joule ou pola lei de Ohm.

Imos a explicar a metodoloxía matemática que usaremos para conseguir, os distintos obxectivos, así usaremos as distribucións estatísticas Normal e de Weibull. A primeira delas usarémola para confirmar o comportamento de cada sinal que se recibe, e valorar coas diferentes probas de normalidade si os fenómenos que se describen seguen efectivamente esa distribución dun xeito aceptable para os nosos niveis de confianza. Faremos para elo provas de normalidade, coeficientes de Pearson, e compararemos distribucións é as súas varianzas usando análises das mesmas ANOVA, coeficientes de correlación lineal, e regresións. Para as taxas de fallo temos que usar outro tipo de distribución estatística, temos o problema de que a cantidade de datos que dispoñemos por reparación de compoñente e moi limitada, e por iso, facemos unha serie de asuncións o respecto, a primeira é que un compoñente ten unha taxa de fallo determinada e cando rompe, substituímolo por outro similar, ou reparámolo de xeito que as taxas temporais empezan a contar de cero novamente. Para o calculo destas taxas usamos un programa que se chama Reliaplus, que se usa moito no campo da fiabilidade. No caso que nos ocupa, o que facemos e xerar as distribucións de weibull de cada compoñente ou grupo dos mesmos, e poñémolas como obxectivo de fiabilidade. E vamos introducindo melloras nas actividades para ser quen de reducir esas taxas e volvelas a calcular cada ano, e así ir afinando os obxectivos de reparación e substitución de compoñentes.

Usando esta metodoloxía seremos quen de demostrar que o noso modelo ten un 90% confianza para predicir o LPF. Con esta capacidade abordaremos o primeiro dos nosos retos, e de xeito o mais importante, que é converter o nivel de predición de actividades por fallo ou por inspección nos activos temos hoxe, que sería do 20%, nunha capacidade de predición total do 90%. Deixando só o 10% de eventos non predicibles. Este incremento tería un impacto moi forte nas variables económicas como o LPF e o impacto sobre beneficio (IoP). Cada vez é mais importante ter un control sobre os activos renovables, para ser quen de demostrar que son unha tecnoloxía de confianza para o futuro, e poder completar a mestura enerxética ata reducir a aportación das enerxías fósiles a cero, canto antes. Co impacto da pandemia do COVID, e o estar cambiando os escenarios de consumo, este tipo de obxectivo global está a acelerarse, a por exemplo moitas empresas xeradoras xa adiantaron a súa desconexión das enerxías de subsolo para 2025, como é o caso de Enel Green Power.

Unha vez establecido o modelo tomando como saída o LPF, e momento de ver nas catro tecnoloxías as relaciones entre as diferentes variables. Como xa explicamos usaremos a relación coa temperatura, e mediremos todos os cambios e todas as combinacións de actividades que somos quen de facer, para explicar os cambios de temperatura, nos compoñentes. Para elo, usaremos as cadeas de Markov e simulación de Monte Carlo, usando o algoritmo de Metropolís-Hastings. Con esta metodoloxía calcularemos os "andadores" entre as diferentes actividades mantemento ou de reparación que temos seleccionado como únicas, e fixaremos una distribución de probabilidade, que co andar do modelo confirmará nos ou non, ata acabar coas iteracións. Usaremos estas relacións para crear dúas ferramentas de planificación, una para facer os planes de mantemento do activo, e outra para ser quen de planificar a probabilidade de ocorrencia de fallo de cada sistema.

Cando empezamos co noso modelo, pretendiamos predicir con unha certeza moi alta os fallos en cada sistema a nivel unidade de xeración. Pero vimos nas simulacións que canto mais nos queriamos acercar á predición mais lonxe nos quedabamos por aumentar os fallos tipo I e II, sobre todo os de falsos positivos. Logo fomos quen de ver, que no hipotético caso de predicir os fallos en horas, non éramos quen de enviar a xente de operacións nun tempo tan corto. Deste xeito corriximos o modelo e fixamos as predicións a nivel rexión e semanal. Deste xeito somos capaces de ter o nivel de confianza que buscamos, e predicir o comportamento do LPF tal como estabamos a fixar nos obxectivos.

ANNEXES

ANNEX A: APLICATION OF THE ISO 55000 ASSET MANAGEMENT SYSTEM

a. TERMS AND DEFINITIONS

For the purposes of this work, the following terms and definitions apply. Those names are found in the IEC-IEEE-IFRS-ISO-IEEE-IFRS standards and in any other industrial standard related Renewable Assets.

1) General terms

1. Audit

Systematic, independent and documented process for obtaining evidence and evaluating it objectively to determine the extent to which the evaluation criteria are fulfilled. All process and procedures can be audited, and in this document, we suggest auditing at least the Safety Process, Quality Process, Environmental Process, Operation, and Maintenance Process. For that propose we will use some statistical standards such as the MIL-STD series.

Note 1 to entry: An audit can be an internal audit (first party) or an external audit (second party or third party), and it can be a combined or integrated audit (combining two or more disciplines).

Note 2, to entry: “Audit evidence” and “audit criteria” are defined in ISO 19011.

2. Capability

Renewable Asset Management measure of capacity and the ability of an entity system, person or organization to achieve its objectives

Note 1 to entry: Renewable Asset management capabilities include processes, resources, competences and technologies to enable the effective and efficient development and delivery of Renewable Asset Management Plans and asset life activities, and their continual improvement.

3. Competence

Ability to apply knowledge and skills to achieve intended results. In our case is all reflect the renewable energy surfaces, and its technical specifications. The physics bases, of any energy, as well as all the concepts and theory, which could explain behaviors, performance, financial investments, quality, safety etc.

4. Conformity

Fulfilment of a requirement. In our case, will be all the product required and services required specifications, to operate and maintained the renewable assets in the optimal performance or within the optimized Key Performance Indicators.

5. Continual improvement

Recurring activity to enhance performance. Renewable assets Management system, has a sort of Key Performance Indicators and Continual improvement, will act mainly as a comparison between time conditions. The improvement will consider any kind of positive impact in the KPIs along a specific period.

6. Documented information

Information required be controlling and maintaining by an organization and the medium on which it is contained. The Renewable Assets Management System should have a database, in which it is possible to upload and maintained any kind of report, documented process, procedure, policy etc., and every correction that should be made along the period of control. In this document it is described, all the reports that should be maintained, together with all the systems that should be used and the information that its needed to extract from SCADA, ERP Statistics etc.

Note 1 to entry: Documented information can be in any format and media and from any source, hence in this document we defined some best practice for reports, systems, and formats.

Note 2 to entry: Documented information can refer to:

- The Renewable Assets Management System, including related processes, procedures and policies;
- Information created in order for the organization to operate (documentation);
- Evidence reports of results achieved (e.g. records, key performance indicators).

7. Effectiveness

Extent to which planned activities are realized and planned results achieved. In the Renewable Assets Management System, after the generation of the Plan Tool and the Schedule Tool, the effectiveness is calculated with the measurement of the deviation, to the original plan and schedule, in time, in quality, in safety and in economic figures.

8. Incident

Unplanned event or occurrence resulting in damage or other loss, that does not affect any people, but only assets or aspects of the assets.

9. Monitoring

Determining the status of a system, a process a procedure or an activity. In the Renewable Assets Management System, was considered monitoring, all the systems, programs, software, to keep under control any key parameter index, any signal, alarm, event coming from SCADA, ERP, CMS, or whatever mechanism, that allow that propose.

Note 1 to entry: To determine the status, there may be a need to check, supervise or critically observe.

Note 2 to entry: For the purposes of Renewable Asset Management, monitoring may also refer to determining the status of an asset. This is typically referred to as "condition monitoring" or "performance monitoring".

10. Measurement

Process to determine a value, based on the technical specifications of the Standards, Process and or procedures, described in this document, and providing the evidence of this value together with the limits to get the insights in order, to take the subsequent decision. All the measurements will be reflected in the reports, Safety, Quality, Environmental, Technical, or

Financial, to discuss the evidence with the people involved and describe the corrective actions, in agreement with all the stakeholders of the process.

11. Nonconformity

Non-fulfilment of a requirement described in this document, after the measurement, and checked with the limits. If the measurement exceeds the objectives, and the specifications of a process, procedure, standard of any other specified target in the document, in the beta meeting should be reflected all the deviations found and reported within the evidence reports for safety, quality, technical, financial, and environmental.

Note 1 to entry: Nonconformity can be any deviation from Renewable Asset Management System requirements, or from relevant work standards, practices, procedures, legal requirements, etc.

12. Objective

Result to be achieved in a time frame, described in the Renewable Assets Management System, that reflects the conditions to be reached in Safety, Quality, Environmental, Technical, Financial for example.

Note 1 to entry: An objective can be strategic, tactical, or operational.

Note 2 to entry: Objectives can relate to different disciplines (such as financial, health and safety, and environmental goals) and can apply at different levels (such as strategic, organization-wide, project, product, and process.

Note 3 to entry: An objective can be expressed in other ways, e.g. as an intended outcome, a purpose, an operational criterion, an asset management objective or by the use of other words with similar meaning (e.g. aim, goal, or target).

Note 4 to entry: In the context of Renewable Asset Management Systems, objectives are set by the organization, consistent with the organizational objectives and Renewable Asset Management policy, to achieve specific measurable results.

13. Organization

Person or group of people that has its own functions with responsibilities, authorities, and relationships to achieve its objectives.

Note 1 to entry: The concept of organization includes, but is not limited to, sole-trader, company, corporation, firm, enterprise, authority, partnership, charity or institution, or part or combination thereof, whether incorporated or not, public or private.

14. Organizational objective

Overarching objective that sets the context and direction for an organization’s activities

Note 1 to entry: Organizational objectives are established through the strategic level planning activities of the organization.

15. Organizational plan

Documented information that specifies the programs to achieve the organizational objectives.

16. Outsource (In-House)

Make an arrangement where an external organization performs part of an organization’s function or process.

Note 1 to entry: An external organization is outside the scope of the Renewable Assets Management System, although the outsourced function or process is within the scope if its activities influence the effectiveness of the Renewable Asset Management System.

17. Performance

A measurable result, in regard the key parameter index that enable to understand the behavior of the Renewable Assets Management System. Could be the Assets itself, or the organization, or any other part of Renewable Assets Management System.

Note 1 to entry: Performance can relate either to quantitative or qualitative findings.

Note 2 to entry: Performance can relate to the management of activities, processes, products (including services), systems or organizations.

Note 3 to entry: For the purposes of Renewable Asset Management, performance can relate to assets in their ability to fulfil requirements or objectives.

18. Policy

Intentions and direction of an organization as formally expressed by its top management.

19. Process

Set of interrelated or interacting activities, which transforms inputs into outputs.

20. Requirement

Need or expectation that is stated, generally implied or obligatory

Note 1 to entry: "Generally implied" means that it is custom or common practice for the organization and stakeholders that the need or expectation under consideration is implied.

Note 2 to entry: A specified requirement is one that is stated, for example in documented information.

21. Risk

Effect of uncertainty on objectives.

Note 1 to entry: An effect is a deviation from the expected — positive and/or negative.

Note 2 to entry: Objectives can relate to different disciplines (such as financial, health and safety, and environmental goals) and can apply at different levels (such as strategic, organization-wide, project, product, and process.

Note 3 to entry: Risk is often characterized by reference to potential "events" (as defined in ISO Guide 73:2009, 3.5.1.3 and "consequences" (as defined in ISO Guide 73:2009, 3.6.1.3), or a combination of these.

Note 4 to entry: Risk is often expressed in terms of a combination of the consequences of an event (including changes in circumstances) and the associated "likelihood" (ISO Guide 73:2009, 3.6.1.1) of occurrence.

Note 5 to entry: Uncertainty is the state, even partial, of deficiency of information related to, understanding or knowledge of, an event, its consequence, or likelihood.

[ISO Guide 73:2009, 1.1]

22. Stakeholder

Person or organization that can affect, be affected by, or perceive themselves to be affected by a decision or activity

Note 1 to entry: A "stakeholder" can also be referred to as an "interested party".

23. Top management

Person or group of people who directs and controls an organization at the highest level.

Note 1 to entry: Top management has the power to delegate authority and provide resources within the organization.

Note 2 to entry: If the scope of the Renewable Assets Management System covers only part of an organization, then top management refers to those who direct and control that part of the organization. If multiple asset management systems are employed, the systems should be designed to coordinate efforts.

2) Terms relating to Renewable Assets

1. Asset (Renewable Asset)

Item, thing or entity that has potential or actual value to an organization

Note 1 to entry: Value can be tangible or intangible, financial or non-financial, and includes consideration of risks and liabilities. It can be positive or negative at different stages of the asset life.

Note 2 to entry: Physical Renewable Assets usually refer to equipment, inventory and properties owned by the organization. Physical renewable assets are the opposite of intangible renewable assets, which are non-physical assets such as leases, brands, digital assets, use rights, licenses, intellectual property rights, reputation, or agreements.

Note 3 to entry: A grouping of assets referred to as an asset system could also be considered as an asset.

2. Asset life (Renewable Asset life)

Period from asset (3.2.1) creation to asset end-of-life could have some derivations as the standard design life, or life extension, remaining useful life.

3. Life cycle

Stages involved in the management of a Renewable Asset

Note 1 to entry: The naming and number of the stages and the activities under each stage usually vary in different renewable industry sectors, and are determined by the organization, and the standards that could be under application, such IEC 61400/1 (for Wind Energy Assets)

4. Asset portfolio

Assets that are within the scope of the Renewable Asset Management System

Note 1 to entry: A portfolio is typically established and assigned for managerial control purposes. Portfolios for physical hardware might be defined by category (e.g. plant, equipment, tools, land). Software portfolios might be defined by software publisher, or by platform (e.g. PC, server, mainframe).

Note 2 to entry: A Renewable Asset Management System can encompass multiple asset portfolios where multiple asset portfolios and Renewable Asset management systems are employed, Renewable Asset management activities should be coordinated between the portfolios and systems.

5. Asset system (Renewable Asset System)

Set of assets that interact or are interrelated.

6. Asset type

Grouping of assets having common characteristics that distinguish those assets as a group or class. In Renewable case, Hydro, Solar, Wind, Biogas, Geothermal.

EXAMPLE Physical assets, information assets, intangible assets, critical assets, enabling assets, linear assets, information and communications technology (ICT) assets, infrastructure assets, moveable assets.

7. Critical asset

Asset having potential to significantly impact on the achievement of the organization's objectives.

Note 1 to entry: Assets can be safety-critical, environment-critical, or performance-critical and can relate to legal, regulatory or statutory requirements.

Note 2 to entry: Critical assets can refer to those assets necessary to provide services to critical customers.

Note 3 to entry: Asset systems can be distinguished as being critical in a similar manner to individual assets.

3) Terms relating to Renewable Asset Management

1. Asset management (Renewable Asset Management)

Coordinated activity of an organization to realize value from assets.

Note 1 to entry: Realization of value will normally involve a balancing of costs, risks, opportunities, and performance benefits.

Note 2 to entry: Activity can also refer to the application of the elements of the asset management system.

Note 3 to entry: to entry: The term "activity" has a broad meaning and can include, for example, the approach, the planning, the plans, and their implementation.

2. Strategic Renewable Asset Management plan SRAMP

Documented information that specifies how organizational objectives are to be converted into asset management objectives, the approach for developing asset management plans, and the role of the asset management system in supporting achievement of the asset management objectives

Note 1 to entry: A strategic asset management plan is derived from the organizational plan.

Note 2 to entry: A strategic asset management plan may be contained in, or may be a subsidiary plan of, the organizational plan.

3. Renewable Asset Management Plan

Documented information that specifies the activities, resources and timescales required for an individual asset, or a grouping of assets, to achieve the organization's asset management objectives

Note 1 to entry: The grouping of assets may be by asset type, asset class, asset system or asset portfolio.

Note 2 to entry: An asset management plan is derived from the strategic asset management plan (3.3.2).

Note 3 to entry: An asset management plan may be contained in, or may be a subsidiary plan of, the strategic asset management plan.

4. Preventive action (BTS)

Action to eliminate the cause of a potential nonconformity or other undesirable potential situation. We defined as a plan activity or box task strategy; activity, use to be defined in the maintenance plans, or maintenance manuals, that can be develop by the original equipment manufacturer or other actor, like the owner of the asset.

Note 1 to entry: This definition is specific to renewable asset management activities only.

Note 2 to entry: There can be more than one cause for a potential nonconformity.

Note 3 to entry: Preventive action is taken to prevent occurrence and to preserve an asset's function, whereas corrective action is taken to prevent recurrence.

Note 4 to entry: Preventive action is normally carried out while the asset is functionally available and operable or prior to the initiation of functional failure.

Note 5 to entry: Preventive action includes the replenishment of consumables where the consumption is a functional requirement.

5. Predictive action (AVS)

Action to monitor the condition of an asset and predict the need for preventive action or corrective action. We define as an inspection type of activity, or any other action, that can prevent a future major component failure. In the RAMS, we can plan these activities and can be only inspections or remediation actions, such as on-site repairs.

Note 1 to entry: Predictive action is also commonly referred to as either "condition monitoring" or "performance monitoring".

6. Level of service

Parameters or combination of parameters, which reflect social, political, environmental, and economic outcomes that the organization delivers

Note 1 to entry: The parameters can include safety, customer satisfaction, quality, quantity, capacity, reliability, responsiveness, environmental acceptability, cost, and availability.

4) Terms relating to Renewable Assets Management system

1. Corrective action (TSG)

Action to eliminate the cause of a nonconformity and to prevent recurrence. In RAMS we called as well unplanned activities and or troubleshooting (guide) activity, that could include not only troubleshooting but as well substitution of parts, remediation on site, with the common factor that the activity cannot be include in the yearly plan, but in the week schedule.

Note 1 to entry: In the case of other undesirable outcomes, action is necessary to minimize or eliminate the causes and to reduce the impact or prevent recurrence. Such actions fall outside the concept of corrective action, in the sense of this definition.

2. Management system (Renewable)

Set of interrelated or interacting elements of an organization to establish policies and objectives and processes to achieve those objectives

Note 1 to entry: A management system can address a single discipline or several disciplines.

Note 2 to entry: The system elements include the organization's structure, roles and responsibilities, planning, operation, etc.

Note 3 to entry: The scope of a management system may include the whole of the organization, specific and identified functions of the organization, specific and identified sections of the organization, or one or more functions across a group of organizations.

3. Renewable Asset Management System (RAMS)

Management system for asset management (3.3.1) whose function is to establish the asset management policy (3.1.18) and asset management objectives

Note 1 to entry: The Renewable asset management system is a subset of asset management.

b. CONTEXT OF THE ORGANIZATION

The organization shall determine external and internal issues that are relevant to its purpose and that affect its ability to achieve the intended outcome(s) of its Renewable asset management system. In the Renewable assets, not only will be the Safety, Quality, Technical, Environmental, and financial, but circular economy and its context. All those in the countries where the plants are located, the mix together with the other energy surfaces and the geopolitical situation of the region, will affect or tentatively will affect to the organization, for that reason all the aspects above should be considered.

Renewable Asset Management objectives, included in the strategic renewable asset management plan (SAMP), shall be aligned to, and consistent with, the organizational objectives.

1) Overview

1. Renewable Asset Management System Integration

The Renewable Asset Management System forms an integrated part of the organization's management system and has a prescribed structure. It should fit in and result from:

- The organizational objectives;
- The organizational plan.

The asset management system includes:

a) the Renewable Asset Management policy.
b) the Renewable Asset Management objectives.
c) the Strategic Renewable Asset Management Plan (SRAMP);
d) the Renewable Asset Management plan which are implemented in:
    - operational planning and control;
    - supporting activities;
    - control activities;
    - Other relevant processes.

The relationship between the key elements of a Renewable Asset Management System, are described in this document together with the related clauses in ISO 55001.

The scope of an organization's Renewable asset management system and the outputs from its Renewable asset management activities should be used to set out the approach to enable the delivery of its organizational objectives.

The requirements for the scope and context of an organization's asset management system are given in ISO 55001:2014, Clause 4.

The organizational objectives provide the overarching context and direction to the organization's activities, including its renewable asset management activities. The organizational objectives are generally produced from the organization's strategic level planning activities and are documented in an organizational plan.

NOTE 1: The organizational plan can be referred to by other names, e.g. the corporate plan.

The principles by which the organization intends applying renewable asset management to achieve its organizational objectives should be set out in a renewable asset management policy. The approach to implementing these principles should be documented in a strategic renewable asset management plan (SRAMP).

NOTE 2: A strategic renewable asset management plan can be referred to by other names, e.g. an asset management strategy.

The SRAMP should document the relationship between the organizational objectives and the renewable asset management objectives and should define the framework required to achieve the renewable asset management objectives.

The links between the organizational plan and the SRAMP should be two-way and should be developed through an iterative process. For example, the organizational objectives should not be developed in isolation from the organization's renewable asset management activities. Renewable Asset capability and performance, as well as the outputs from renewable asset management activities (e.g. the renewable asset management plan(s)), are key inputs into establishing realistic and achievable organizational objectives.

2. SRAMP Develop

In developing its SRAMP, the organization should:

a) Consider the expectations and requirements of stakeholders;
b) Consider activities that could extend beyond the organization's routine planning timeframe, and which should be subject to regular review;
c) Clearly document the processes to establish its renewable asset-related decision-making criteria.

The SRAMP should be a high-level plan that contains the asset management objectives. It should be used to develop the asset management plan(s), which should set out the asset level activities. The renewable asset management plan(s) can be cascaded in large organizations or in organizations with complex renewable asset portfolios.

3. Renewable Asset Management System Scalable

All parts of the renewable asset management system should be scalable, e.g. for small organizations, the organizational plan could be a single document that includes separate sections for:

a) The organizational objectives;
b) The SRAMP;
c) The renewable asset management plan(s).

Alternatively, the organizational plan could be kept separate from the SRAMP, which could include the renewable asset management plan(s) as a sub-section, or all three plans could be kept separately. While it is necessary to distinguish between the SRAMP and the asset management plan(s), it is not a requirement of ISO 55001 to create separate documents for each.

The concept of ensuring alignment and consistency between the organizational objectives, the renewable asset management policy, the SRAMP, the renewable asset management objectives and the renewable asset management plan(s), should reinforce within the organization that asset level activities support the delivery of the organizational objectives. It is important that this alignment be communicated to ensure that stakeholders at all levels understand why asset activities and asset management activities are implemented.

2) The organization and its context

1. Renewable Assets Management System consistency

When establishing or reviewing a renewable asset management system, it is important to ensure that the approach is consistent and aligned with the external and internal contexts of the organization, since these can significantly influence the design and scope of the renewable asset management system.

2. Organization Evaluation.

Evaluating the organization's external context can include, but is not limited to, the following issues:

a) The social and cultural, political, legal, regulatory, financial, technological, economic, circular, competitive and natural environment, whether international, national, regional or local;
b) Key drivers and trends having impacts on the objectives of the organization;
c) Relationships with, and perceptions and values of, external stakeholders.

3. Organization Evaluation Requirements

Evaluating the organization's internal context can include, but is not limited to, the following issues:

a) Governance requirements;
b) Organizational structure, roles, accountabilities and authorities;
c) Policies, objectives, and the strategies that are in place to achieve them;
d) Capabilities, understood in terms of resources and knowledge (e.g. capital, time, people, systems and technologies);
e) Information systems, information flows and decision-making processes (both formal and informal);
f) Relationships with, and perceptions and values of, internal stakeholders;
g) The organization's culture;
h) Standards, guidelines and models adopted by the organization;
i) The form and extent of contractual relationships;
j) Risk management plans;
k) Renewable asset management practices and other management systems, plans, process(es) and procedure(s);
l) Integrity and performance of the assets and asset systems;
m) Feedback from the investigation of previous asset and asset system failures, incidents, accidents and emergencies;
n) Assessing the ability of the renewable asset management system to achieve the intended outcomes of the organizational objectives;
o) Feedback from previous self-assessments, internal audits, third party reviews and certification reviews.

3) Understanding the needs and expectations of the stakeholder

The organization shall determine:

- The stakeholders that are relevant to the renewable asset management system;
- The requirements and expectations of these stakeholders with respect to renewable asset management;
- The criteria for renewable asset management decision making;

- The stakeholder requirements for recording financial and non-financial information relevant to renewable asset management, and for reporting on it both internally and externally.

1. Stakeholder identification

The organization should identify and review the stakeholders that are relevant to renewable asset management and the needs and expectations of these stakeholders.

2. Internal Stakeholder

Internal stakeholders can include the following:

a) Employees within the organization;
b) Groups within the organization, i.e. functional groups (e.g. engineering, accounting, maintenance, operations, purchasing, receiving, logistics) or other groups (e.g. safety delegates);
c) Shareholders, management consortiums, owners.

3. External Stakeholder

External stakeholders can include the following:

a) Customers, users, suppliers, service providers and contractors;
b) Non-governmental organizations, including civil society organizations, consumer organizations and the media with an interest in issues related to asset management;
c) Government organizations, government agencies, regulatory authorities, and politicians at all levels of government;
d) Investors or taxpayers;
e) Local communities;
f) Those in society interested in social, financial, environmental or other forms of sustainability;
g) Financial institutions, rating agencies, and insurers;
h) Employee representatives.

4. Stakeholder Expectation

Stakeholders' needs and expectations should be documented and communicated. This may be captured in a statement of stakeholders needs within the SRAMP and should reference any mandatory requirements, as well as the expectations of different stakeholder groups. The organization should consider a means of tracking how current the information is, and the methods involved for its collection.

When engaging with stakeholders to determine their needs and expectations, the organization can use the list of contexts given in 4.1.2 to frame the discussions.

One objective of renewable asset management is to enable the organization to meet the service needs of the customers and users of its asset(s). The organization should measure the levels of service (see 6.2.1) that its renewable assets deliver, and analyze these against the requirements and expectations of its customers and users. A level of service review process can be a useful approach to understand the expectations of customers and users.

Stakeholders are likely to make judgments about the organization's renewable asset management and its renewable asset management outputs and outcomes, based on their perceptions. These can vary due to differences in values, needs, assumptions, concepts and concerns, as they relate to the issues under discussion. Since the views of stakeholders can have a significant impact on the organization's asset-related decisions, it is important that their perceptions are determined, recorded, and taken into account in the organization's decision-making process.

Understanding how renewable asset-related decisions are made is an important part of renewable asset management. The criteria for decision making are influenced by the needs of external and internal stakeholders, by the renewable asset management policy and by the risk attitude of the organization. The external and internal stakeholders' input to establishing decision-making criteria is important for setting priorities and resolving conflicting requirements. Decision-making criteria should be appropriate to the importance and complexity of the decisions being made. Decision-making criteria should be used to evaluate competing options to meet renewable asset management objectives and develop asset management plans. The criteria can be expressed in several ways, to support quantitative, semi-quantitative or qualitative decisions. The processes to establish the decision-making criteria that guide renewable asset management should be clear and documented.

The level of detail needed when reporting to stakeholders will vary from one stakeholder to another, depending on the scope of the organization's activities and on the complexity of the renewable assets being managed. The detail should only disclose proprietary information as appropriate for the stakeholders receiving the information.

Stakeholders generally need to be informed about the decisions that can affect them and might need to provide input into decisions that can have an impact on them. Failure to both communicate and consult in an appropriate way about asset management activities can in itself constitute a risk, because it could later prevent an organization from fulfilling its objectives.

It is important that the terminology used in communicating with stakeholders is consistent and aligned with other functions in the organization, and in accordance with legal requirements, where applicable.

This is particularly necessary when communicating financial information.

4) Determining the scope of the renewable asset management system

The organization shall determine the boundaries and applicability of the renewable asset management system to establish its scope. The scope shall be aligned with the SRAMP and the renewable asset management policy. When determining this scope, the organization shall consider:

- The external and internal issues.
- The requirements.
- The interaction with other management systems, if used.

The organization shall define the renewable asset portfolio covered by the scope of the renewable asset management system. The scope shall be available as documented information.

Based on the outcomes of reviews of its context and stakeholders the organization should define (or review) the boundaries of the renewable asset management system and establish its scope.

The boundaries and applicability of the asset management system should be captured in a statement of scope (which may be included in the SRAMP). It should be communicated to all relevant stakeholders, both internal and external to the organization. The detail will be influenced by the size of the organization and the scale and complexity of the asset portfolio covered by the renewable asset management system. It should clearly show what is considered inside and outside scope.

The scope should consider:

a) The renewable assets, renewable asset portfolio(s), their boundaries and interdependencies;
b) Which other organizations are involved in meeting the organization's renewable asset management system requirements (including the requirements of ISO 55001), e.g. through the outsourcing of renewable asset management activities or activities related to life cycle stages;
c) The organizational aspects, e.g. which parts or functions of the organization are involved;
d) The organization's period of responsibility (e.g. where the management of renewable assets is contracted out for a set period of time), including its residual liabilities beyond the operation or use of the renewable asset (e.g. where an organization remains accountable for risks beyond its use of an asset, such as a renewable plant asset environmental impacts; owner that retains liability for remediation plans);
e) The interactions with other parts of the organization's management system (e.g. for quality or environmental management), which can require defining the boundaries, functions, and responsibilities of each part of the management system.

5) Renewable Asset Management System

The organization shall establish, implement, maintain and continually improve a renewable asset management system, including the processes needed and their interactions, in accordance with the requirements of (IEC-IEEE-IFRS-ISO) International Standards.

The organization shall develop a SRAMP, which includes documentation of the role of the renewable asset management system in supporting achievement of the asset management objectives.

In the initial development of the renewable asset management system, the organization should outline how it will establish, implement, maintain and improve the system. An initial review of the organization's current processes against the requirements of ISO 55001 will determine the areas that need to be developed to support the functioning of a compliant renewable asset management system. The renewable asset management system should not stand-alone. A factor of successful renewable asset management is the ability to integrate asset management processes, activities and data with those of other organizational functions, e.g. quality, accounting, safety, risk and human resources. Where possible, existing business processes should be leveraged to avoid unnecessary new work and duplication of existing work and data. These interactions with the existing processes need to be clearly communicated to all involved.

Consideration should be given to how to prioritize what to develop first, as there is usually a limit on resources available. The review can guide the organization in formulating plan(s) for implementing and prioritizing improvements to its asset management system. An appropriate starting point is the establishment of an asset management policy, which often helps to provide focus for the organization and to identify its intentions. Following this, the organization should develop its SRAMP. It is important to be aware of, and to clarify, any variations in terminology between IEC-IEEE-IFRS-ISO standards and the terminology used in the organization's common practice.

Compliance with all the requirements of IEC-IEEE-IFRS-ISO should be considered as achieving only the minimum starting point for an effective renewable asset management system and should not be seen as the final goal.

ANNEX B: APPLICATION OF THE IEC 61400 IN WIND POWER PLANTS MAINTENANCE

WIND POWER PLANTS MAINTENANCE (M30P)

Goal and scope

The document aims to set out roles, responsibilities, phases and activities of the renewable power plants maintenance process within EUC portfolio. The document covers all the maintenance activities, BTS, TSG and AVS, and is the example we set up to be expand to the rest of the technologies under the scope Hydro, Solar, Geothermal.

Procedure referent

This document is developed under all the conditions displayed in the preliminary chapters, and is a fine-tune example for an EUC, that can be managed as Global Corporation. The document should be approved by the head of the Operation & Maintenance department and by the head of the Human Resources department of EUC, in order to be aligned with the Renewable Assets Management System requirements.

Organizational process allocation inside the EUC processes taxonomy

Macro-process: Electric Energy Generation
L1 Process/Reference Sub-process: Plants Maintenance
L2 Process/Reference Sub-process: Maintenance execution

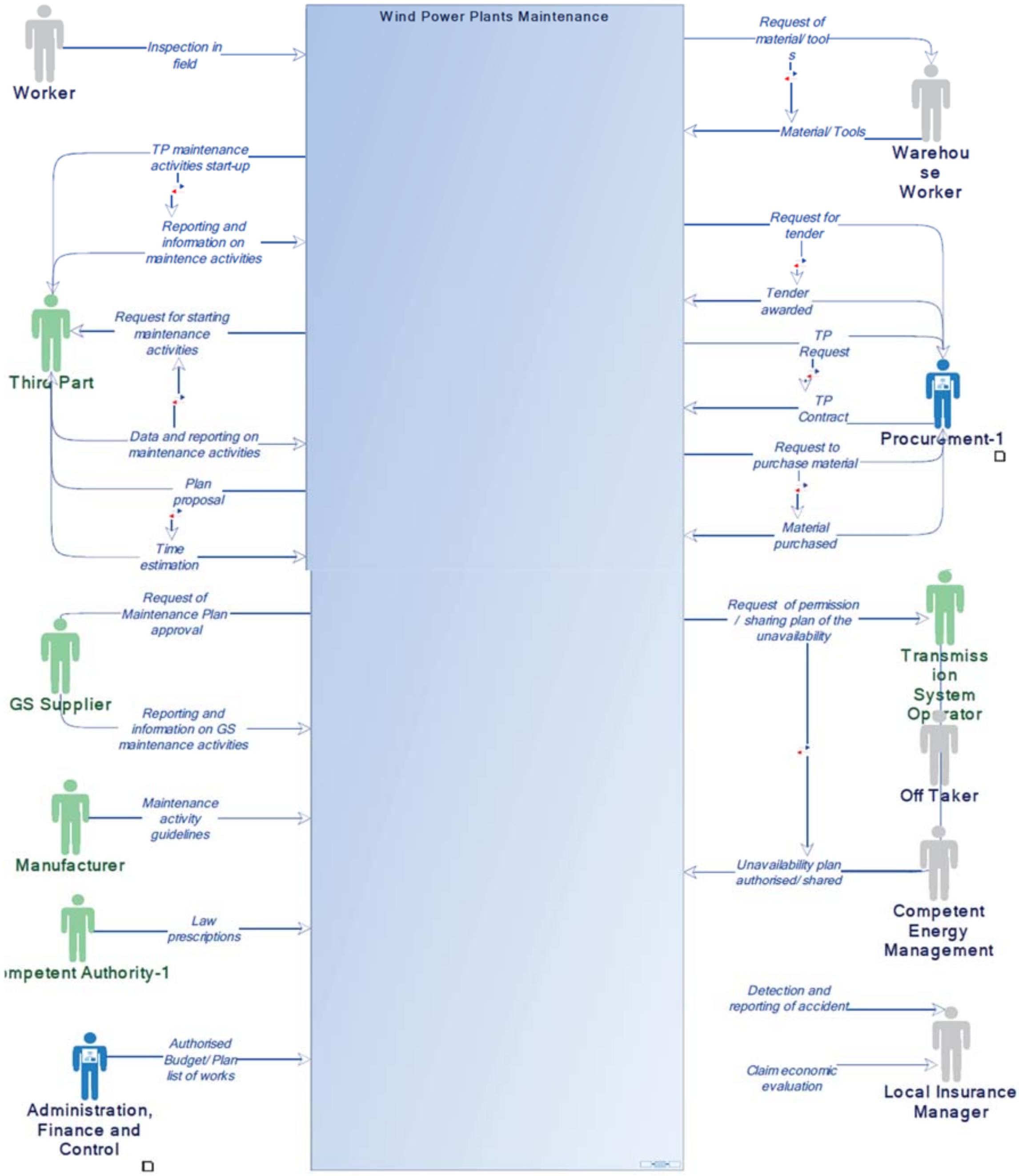
Definitions and acronyms

- Assistant/Supervisor: Person responsible for Operator activities management and planning.
- Manufacturer/Supplier: External to the EUC responsible for the implementation and commissioning, in some cases, of power plants of the EUC.
- Competent Energy Management: Unit responsible for the activities of Energy Management in a particular Area / Country in which EUC operates.
- GS Supplier: External subject to the EUC. that is responsible for Global Service Maintenance service.
- Local Insurance Manager: Person responsible for insurance contract operative management within each EUC Area
- Operation & Maintenance Area/Country: Operation & Maintenance unit within an Area/Country.
- Operator: Person responsible for maintenance activities in the field.
- Warehouse worker: Person who manages warehouse.
- Competent Planning & Control: Area/Country Planning & Control unit.
- O&M Local Manager: Head of O&M Area/Country unit
- Off Take
- Stakeholders
- Third Party
- TSG: Trouble Shooting and or corrective maintenance is a maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function.

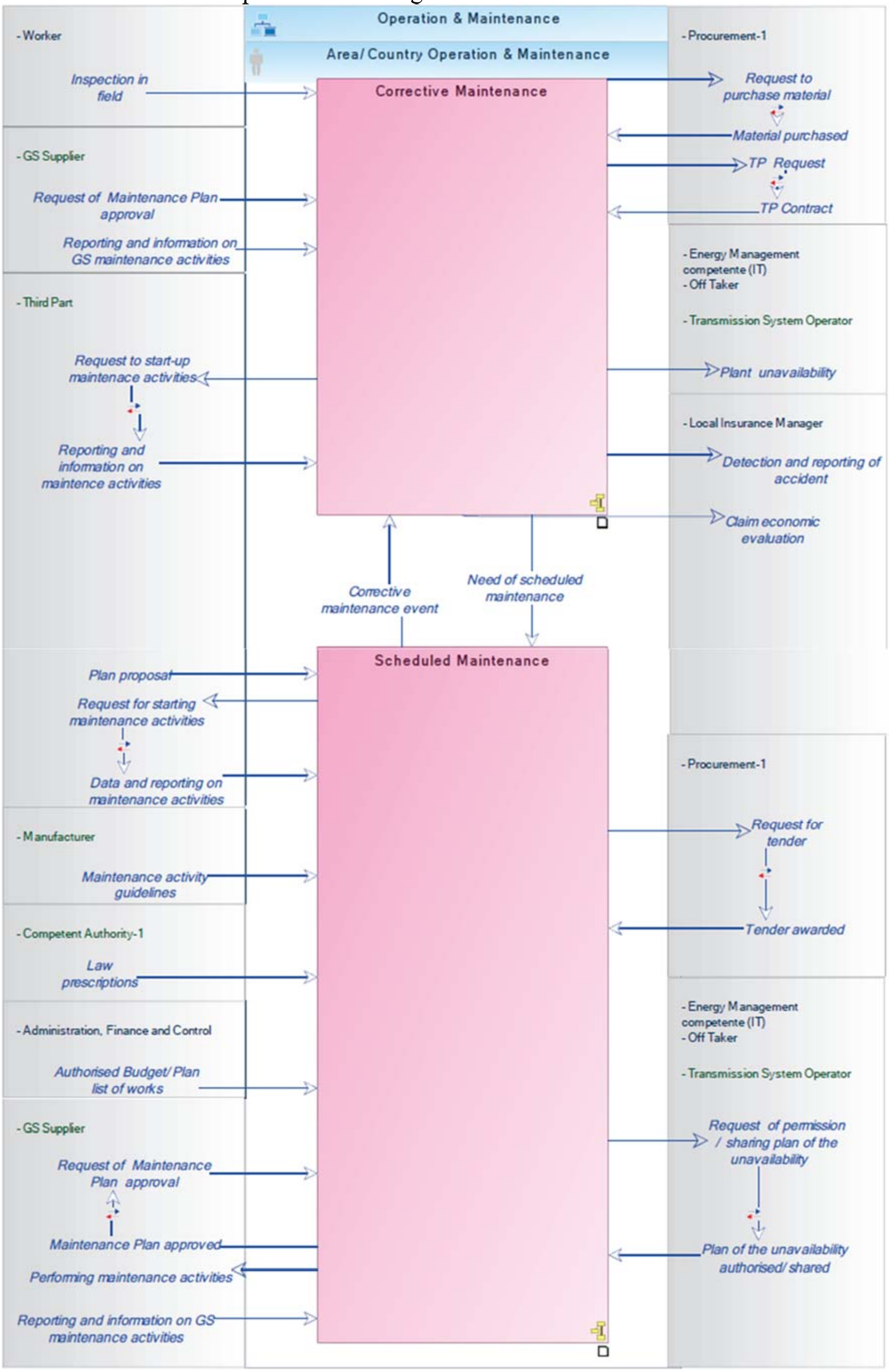
- AVS: Advance Services are the different services that can occurred in a plan way and affects the component based strategy, listed but not limited, to inspections, test, checks, component exchange, component upgrade, component repair.
- PPE: personal protective equipment.
- BTS: Boxed Task Strategy or preventive maintenance are the maintenance carried out at predetermined intervals (time) or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item, it includes all the controls made to verify equipment status BTS has the meaning of "prevent" the occurrence of the fault, in fact, if preventive action is carried out with effectiveness, the component replacing occurs when it is still functioning and therefore the fault doesn't occur (it's avoided).
- Predictive maintenance (AVS): condition based maintenance carried out following a forecast derived from repeated analysis or known characteristics and evaluation of the significant parameters of the degradation of the item. Predictive techniques help determine the condition of in-service equipment in order to predict when maintenance should be performed. Predictive maintenance activities include all the controls made to monitor vibration, heat, pressure, noise, thickness of some equipment etc. Is part of the AVS classification (component based)
- Proactive maintenance: also known as improvement maintenance, maintenance that aims to improve the value or performance of a system or part of it. The fault, in this case, does not occur because the fault cause itself has been removed.
- Scheduled maintenance: maintenance carried out in accordance with an established time schedule or established number of units of use. The schedule (maintenance plan) includes the maintenance activities suggested by the equipment manufacturer, the ones required by law, preventive and predictive activities.
- Local unit: Area/Country O&M unit.
- O&M: Operation & Maintenance department.
- Plant Management: system that enables the O&M business area to make the operational management of the power production data coming from power plants in particular, the collection, logging, management and visualization of operating data.

Process description

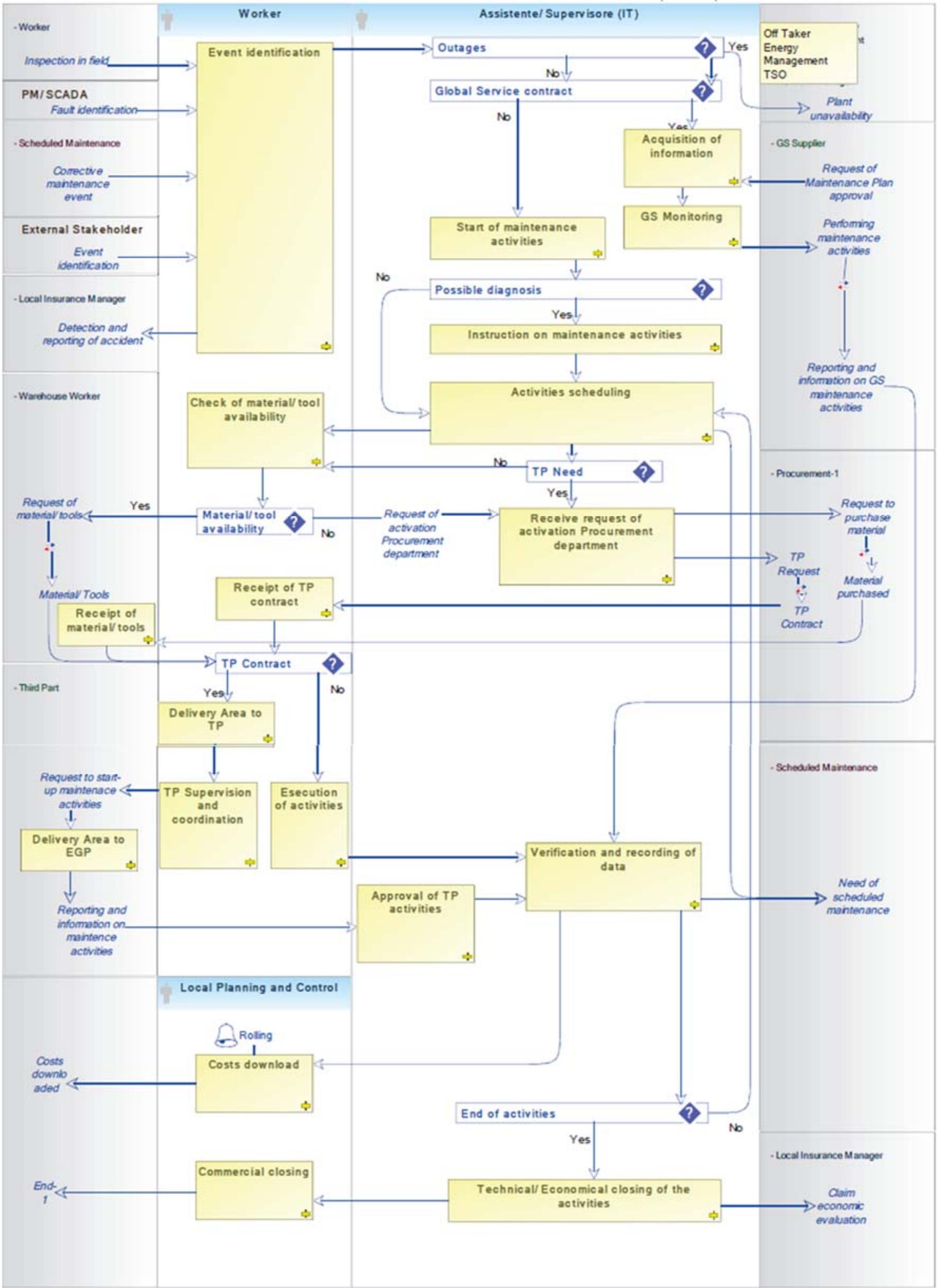
1. Component diagram



2. Implementation diagram



I. Renewable Power Plants Corrective Maintenance (TSG)



Event identification

Renewable Power Plant are subject to faults during operation, that can require corrective maintenance activities. Faults/malfunctions can be identified in different ways:

- Stakeholders (newspapers, citizens, land owners etc.) can m the EUC of an event;

- Operator can identify a fault/malfunction or a potential fault, without outage, that can be identified by supervision systems or not, during inspections or another maintenance activity (scheduled or not) which can require machinery stop to be performed. The operator must report the failure and can also propose a maintenance activity, by email, or by electronic device (i.e. tablet), if it is available.
- Local unit can be supported by a power plant supervision and control system (i.e. SCADA, Control Room etc.), if it's available, that monitors the status of power plant components and can feed a Plant Management (PM) system, if it is developed.

Control Room operators identify the fault in real time through SCADA and can m available colleagues in case an intervention out of working hours is necessary.

In case of Plant Management availability, on the basis of signal/warning, the system automatically creates an event according to the setting of the supervision system (an event isn't created for each signal/warning).

If the fault determines an outage, Local unit must communicate plant unavailability to Competent Energy Management/commercial unit, if applicable, to the TSO or to the Off taker, in case of a direct energy selling contract.

If there is a damage linked to the fault, LIM must be med.

In case of critical fault and/or fault related to the main component, the Local unit must m Renewable Assets Management Unit and O&M Coordination and Performance Improvement unit in order to optimize recovering plan (fault resolution through the case studies analysis and spare parts management).

Acquisition of information

If the Power Plant is managed in GS, the assistant/supervisor acquires information from supervision and control systems (SCADA, PM, Control Room) and is med by the manufacturer/GS provider about the activities necessary to put back in operation the power plant. At the end of activity, the provider must send to Local unit a report with the information on maintenance activities (fault, its cause, performed activities, materials etc.), in order to update them on the RAMS (ERP systems and Plant Management).

GS Monitoring

Even if during Global Service maintenance activities are managed by the provider of the service, Local unit must monitor GS in order to verify the accuracy of maintenance activities, its timing and the respect of contract rules and safety and environment prescriptions.

Start of maintenance activities

If the Power Plant is not managed in Global Service, the assistant/supervisor verifies events identified with SCADA/PM o by operator or by stakeholders and decides if the power plant needs a maintenance activity, its priority and opens the "technical object" to manage fault, as it is better described below.

During budget definition phase, Local unit must define an amount of money destined to corrective maintenance activities. For each fault with an intervention, the assistant/supervisor must verify if the amount is covered by budget. Otherwise he must require authorization for the expenditure.

For Local units with a maintenance unit, maintenance activities are managed by technical staff within this unit.

In compliance with the "Maintenance" policy, local units must use a proper accounting system for the classification and management of maintenance events (breakdowns, abnormalities, activities etc..) which allows their traceability in the proper time and technical and economic analysis.

Below four different cases are described, on the basis of the different IT systems.

The functionality of the systems mentioned below (ERP-SAP PM, tablets) will be described in detail in other epigraph.

Plant Management and ERP (ERP-SAP available)

PM system (on the basis of its setting) can automatically generate, for certain events, a maintenance event (ME); the assistant/supervisor validates the event and then the ME is opened or PM can directly open a ME (in case of certain interventions – e.g. outages). In case of maintenance activity proposed by operator (by e-mail/term sheet or tablet, if it's available) or of the information received by an external stakeholder, the assistant/supervisor defines if the event requires an intervention and, then, he opens a ME. Control Room Operator (if present) can open a ME in PM, too. The assistant/supervisor can decide, if it is adequate, to store events in PM or to start a maintenance activity also without reporting it. The ME opening in PM determines the Service Notification (AdM) opening in ERP-SAP. Therefore, the assistant/supervisor can decide immediately to open a Work Order (OdM) (this decision is related to the possibility to make a preliminary diagnosis of the event cause. It can happen that the outage can be solved with a local reset and it doesn't need a specific maintenance activity).

Plant Management available, ERP (ERP-SAP) unavailable

The ME is opened as described before; the only difference is the absence of Service Notification (AdM). In this case, ME is the repository of the technical information related to the maintenance activities.

Plant Management not available, ERP (ERP-SAP) available

If ERP-SAP is available and PM is not implemented yet, the assistant/supervisor analyses information coming from the field by supervision systems (SCADA) or by third parties and, if it is necessary, opens a service notification (AdM) and a work order (OdM) in ERP-SAP.

Plant Management and ERP(ERP-SAP) not available

If ERP-SAP and PM are not yet implemented, in coherence with the guidelines defined in "Maintenance" policy, the assistant/supervisor must record technical and economical information, related to maintenance activities, in an IT database also using an excel file, in order to guarantee the recording of the following information: item object of the fault, its reason, action, material utilized, date and hour of unavailability start and end, if applicable.

Instructions on maintenance activities

On the basis of available information, if it's possible to make a diagnosis, the assistant/supervisor gives instructions to the workers about the tools, spare parts and technical documentation to be used, including detailed in the procedure and, if PM is available, he uploads the information in the ME or in ERP-SAP, if it is available.

Activities scheduling

The assistant/supervisor quickly schedules activities in order to solve faults as soon as possible, according to their priority, and he allocates works to teams, according also to other minor maintenance activities that can be made at the same time.

If PM and tablet are available, the assistant allocates ME to the workers uploading them on the tablet system, if not, he allocates works by sheets or by e-mail.

If necessary, the assistant/supervisor avails itself of the technical support/maintenance local unit for the failure assessment, and, in case of major failures and lack of local expertise, makes use of the EUC group of experts, coordinated by the head of the Wind Competence Centre.

If the fault needs a deeper detailed schedule, the activity follows the process of scheduled maintenance (BTS)

Check of material\tool availability

The team, before going to the plant, must require tools and materials for maintenance activities to the warehouse worker, on the basis of the guidelines received by the assistant/supervisor and according to the preliminary information about the event.

If the management of spare parts is centralized, the availability is verified both at a central and at a local warehouse, according to the spare parts management O&M policy.

I'd also necessary to verify the existence of an open contract.

In order to optimize activities time and to avoid several moving due to the lack of the necessary resources in the power plant, the working team (usually 2 workers) can be supported by a mobile warehouse (equipped van) with basic parts/tools for the most common and frequent maintenance activities.

When it is possible, if the necessary material is not immediately available, local units must start up the plant also using provisional means and materials.

Purchasing request receipt and activation of Procurement department

If the item/tool is not available, neither in warehouse (local or central) nor within mobile warehouse, the warehouse worker asks activation of procurement phase for assistant/supervisor. The assistant/supervisor prepares the technical documentation necessary for the procurement phase, availing itself of the technical support/maintenance unit.

The Procurement department can be activated even if Local unit needs the support of one or more external companies, third parties (TP) to perform maintenance activities, in order to have the necessary contract.

Area and plant delivery

In case of activities to be performed both by EUC personnel and/or by third parties, the assistant/supervisor delivers the area and the plant to the personnel in charge of the activity, once authorization and TP work permissions have been verified, works have been shared, security prescription have been communicated and once possible interferences with other teams/third parties have been evaluated, according to the applicable legislation and instructions.

It can happen that a maintenance activity must be performed both by EUC personnel and by Third parties, in this case local unit performs some activities and, in parallel, deliveries the area to the third party, supervising it.

Execution of activities

In case of "in house" activities, the team, composed by EUC workers, moves to the plant in order to manage maintenance activities, always respecting policies issued by EUC Safety and Environment department. In order to track the activities and all used materials, the operators must record all the information linked to the maintenance activities, directly in the field. If PM and Tablet system are available, the operators upload information in the system.

Once done maintenance activities, the team reports to the assistant/supervisors all the related information.

TP Supervision and coordination

When external maintain the power plants, EUC personnel must monitor and coordinate the external companies, in order to verify the accuracy, times of activities, the respect of contractual rules, safety and health laws and environmental protection, according to the policies issued by EUC Safety and Environment department.

Approval of TP activities

Once TP activities have been done, the assistant/supervisor verifies them and analyses supplier report and the report drafted by EUC personnel in charge of supervising the activity (procedure for contracts operational management), if applicable, and, if it is opportune, approves it. The approval of supplier activities is the main condition in order to authorize his payment.

Verification and recording of data

The assistant/supervisor must verify the completeness and reliability of information received both from EUC team and external company (third party or GS supplier) and the he uploads them in the systems. If PM and Tablet system are available, the operators can directly download data on PM without manual transcriptions.

The assistant/supervisor validates information and then they are automatically recorded on ME (within PM), service notification (AdM) and work order (within ERP-SAP).

Regarding the correct use of technical accounting objects, the Responsible of Local unit should analyze their accuracy, underline any non-compliances and indicate corrective actions, if necessary.

If Tablet is not available, after validation, the assistant/supervisor uploads data in the systems. In this case, if PM and ERP-SAP are available it is sufficient to upload information on PM and then, from PM itself, they are automatically updated in ERP-SAP.

The data recording on ERP-SAP system determines the automatically updating of material in ERP system (ERP-SAP MM) related to logistic material management.

The assistant/supervisor can decide to start a scheduled maintenance activity, if it is necessary, on the basis of information received by the operators on the field.

The correct failures data entry in the systems (according to Maintenance Policy: the details of the component being maintained, the failure cause, the affected component, the date and time of beginning and end of the unavailability, if not present a Plant Management system, the quantification of lost energy, the costs, divided in categories of expenditure -personnel, materials, third parties, etc., a description of the solution adopted and the used spare parts) is crucial to make a periodic failures analysis, aimed at minimize accidental events in terms of impact and frequency.

Costs download

Periodically (once maintenance activity is done or not), the local planning and control unit calculates the final costs of the maintenance activity (material, times, third parties works).

If ERP (ERP-SAP) is available, the costs, uploaded in the work order, are accounted in specific accounting items (WBE, etc.) according to the accounting prescription set when the work order was opened.

For the most frequent used work orders (e.g. PMAC for corrective maintenance, PMES for operation activity PMES or PMPR for scheduled maintenance) the accounting rule is the reference cost center of the OdM technical structure code. In general, the final accounting of costs must be made in accordance with accounting principles defined by the Administration, Finance and Control department.

Technical\economical closing of the activities

When activities and scheduled work have been carried out, the assistant/supervisor closes the activities in the systems, closing the accounting object opened for it.

If ERP-SAP system is available, the assistant/supervisor closes the work order from a technical point of view that no longer allows to modify more technical information (e.g. change the equipment broken in the system or schedule new activities or materials), but it is possible to impute costs of materials, internal and external services planned before the closing.

In case of existence of PM, if the work order has been generated from the ME, the technical closing of the work order is automatic when the ME is closed. If it is necessary, it is possible to cancel the closing. Once activities have been closed, if there is a damage linked to the fault, the assistant/supervisor can deeply evaluate costs and business interruption, and the Local Insurance Manager.

Commercial closing

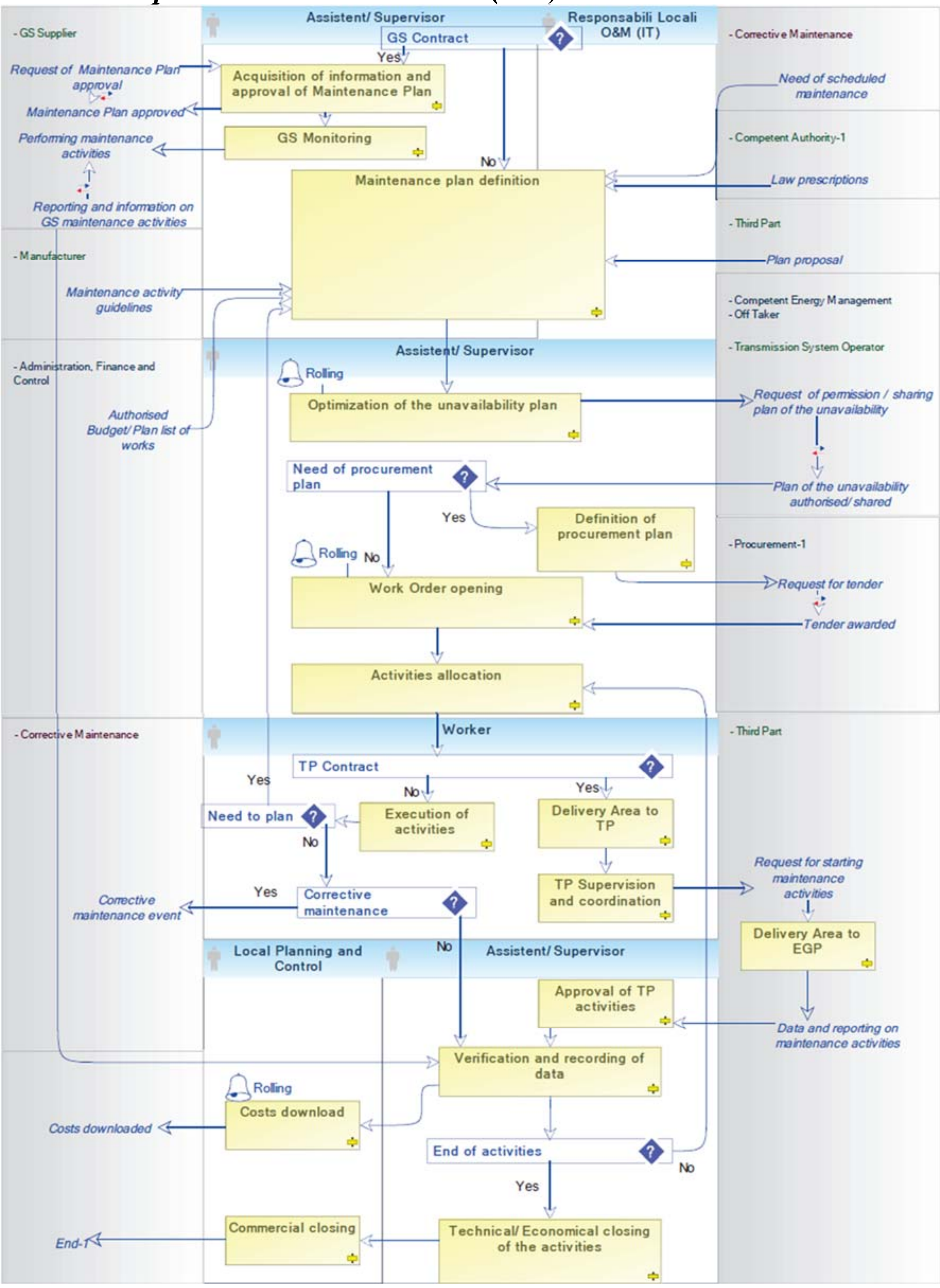
Once technical closing and costs download have been carried out, the competent Planning and Control unit can manage the commercial closing for the following cases:

- no more costs must be accounted;
- all costs have been downloaded;
- all the activities have been closed.

The commercial closing is managed directly in ERP-SAP and it is in charge of competent unit within Administration Finance and Control department every year or every six months.

The Work order technically closed that don’t receive costs for a long time, can be commercially closed, in accordance with local unit.

II. *Wind plants scheduled maintenance (BTS)*



Acquisition of information and approval of Maintenance Plan

If the plant is managed in Global Service (GS), [18] the provider is in charge of scheduled maintenance (BTS), he prepares the maintenance plan and sends it to the Local unit for approval.

At the end of the activities, the manufacturer/GS supplier must send a report to the assistant/supervisor containing all the information about maintenance activities for their uploading in the systems (ERP system and Plant Management).

For "In Service" contracts, in case of scheduled maintenance, the management of maintenance activities is the same described for global service.

GS Monitoring

Local unit personnel must monitor GS supplier in order to verify the accuracy of maintenance activities, the timing and the respect of contract rules and safety and environment prescriptions.

Maintenance Plan definition

In case of in-house activities, every year the Head of local O&M defines Maintenance Plan, that includes all scheduled activities to be done during the following year, that is to say: maintenance activities related to the manufacturer guidelines (preventive, periodic etc.), predictive maintenance, law prescriptions and other maintenance activities, that must be authorized according to the EUC Management (RAMS).

The output of this process is the list of Budget/Plan works authorized by RAM department. (Ordinary maintenance activities – OPEX, investments and extraordinary maintenance, that includes proactive maintenance, and).

Maintenance activities can be suggested also by internal or external resources, during other maintenance activities (scheduled or not) or by external stakeholders.

The Maintenance Plan is drafted also taking into account case study analysis, personnel operational experience, maintenance strategy (see "Wind Power Plants Maintenance Strategy") and the results of "Operational Efficiency" project that, based on data downloaded from SCADA, provides analysis and reporting of alarms and a comparison of the actual power with the power curve, in order to identify the components with the most frequent alarms and plan appropriate maintenance activities. Adding the Algorithm Based BTS Plan Tool, the RAMS will create and update Maintenance Plan updated per year, and using the TSG Schedule Tool, a Maintenance Schedule per week updated each month to be upload in the ERP.

The Maintenance Plan, in coherence with maintenance policy, must be uploaded on EUC dedicated systems and it must be communicated to O&M. The Plan is periodically updated (Yearly). While the Schedule Plan will be updated periodically (monthly)

Planned activities are linked to specific accounting objects that are related to costs, in ERP-SAP or in other ERP system.

When ERP-SAP is available, the activities must be managed according to:

- PMO functionality (Plant Maintenance Optimization) within PM ERP-SAP module, in order to manage in an optimal way, scheduled, preventive, predictive maintenance activities and law controls,
- WBS/WBE, NTW (PS module) linked to the management of projects/investments/extraordinary maintenance.

In general, even if ERP-SAP is not available, Local unit must respect accounting principles defined by RAM department in order to account costs of maintenance activities.

Planned activities (BTS-TSG-AVS) must be managed using a Gantt diagram (Or similar) that can assure to the assistant/supervisor a global view of the activity. The Gantt diagram can be uploaded in Plant Management, if it is available.

Optimization of the unavailability plan

The assistant/supervisor optimizes the maintenance plan (within PM, if it is available), and distinguishes activities that do not cause unavailability from activities which cause unavailability. The optimization of the maintenance plan (with unavailability) is done with the support of Competent Energy Management/commercial unit, according to the availability of resource, to the estimated information of energy value, to the rotation of spare parts, to any activities overlapping, grid constraints, other external constraints.

The plan of activities with unavailability must be authorized/shared by third competent subject (internal or external – Competent Energy Management, Off taker, TSO etc.). Once plan has been authorized, it comes into effect.

Possible changes to the plan must be authorized/shared.

Local units must send the unavailability plan to O&M, in absence of Plant Management.

Definition of procurement plan

For scheduled maintenance activities, on the basis of needs, the assistant/supervisor defines an annual procurement plan in the contract system, that includes a list of all contracts related to maintenance activities (contracts, goals and times). The plan is sent to Procurement department and to O&M, according to the principles of maintenance policy.

Work Order opening

Weekly, or according to the scheduling of activities, (for "big maintenances", with several work orders, they are opened at the same time) the assistant\supervisor must open the work order for each maintenance activity and must record all technical and economical information related to the activities. If ERP-SAP is available but PM has not been yet implemented, the assistant/supervisor opens both the work order (accounting object) and the service notification (AdM -technical object).

If both ERP-SAP and PM are available, the assistant\supervisor opens Maintenance Events (ME) for each maintenance activity; at the same time, ERP-SAP opens automatically an AdM (service notification) and a work order related to the ERP-SAP object that caused the activity.

Activities allocation

The assistant/supervisor, on the basis of priorities and of the schedule reported in Gantt program, allocates works to the team.

If tablet system is available, the assistant/supervisor assigns MEs to the operator uploading them on the tablet. On the contrary, if the tablet is not in use, he assigns works on a sheet or by email.

Execution of activities

Scheduled maintenance activities, first of all those with long outage, require a particular attention for preparing site, logistic of site, material/spare parts. The activities must be carried on with respect of policies issued by Safety & Environment department, according to the scheduled program.

The maintenance plan (with the indication of resources, material and times) must be updated during the activities and all variations and/or possible improvements must be taken into account for the next stops.

Once activities have been executed, the work team (operators) sends to the assistant/supervisor reports with all the related information.

In some cases, it could be possible that the activity must be scheduled again in order to schedule it in a different/better way or with other resources or to schedule a corrective maintenance activity.

In this case, it’s possible that the interventions priorities can be changed.

Delivery Area to TP

In case of “outsourcing” activities, once TP authorization have been verified, works have been shared, security prescription have been communicated and once possible conflicts with other team have been evaluated, EUC personnel delivers area to TP.

TP Supervision and coordination

When external companies perform maintenance activities, EUC personnel must monitor and coordinate the external companies, in order to verify the accuracy, times of activities and the respect of contractual rules and safety and health laws according to the policies issued by Safety and Environment department.

Approval of TP activities

Once TP activities have been done, the assistant/supervisor verifies them and analyses supplier reports and, if it is opportune, he approves it. The approval of supplier activities is the main condition in order to authorize payment.

Verification and recording of data

The assistant/supervisor must verify the completeness and reliability of information received both from EUC team and external company (third party or GS supplier) and the he uploads them in the systems. If PM and Tablet system are available, the operators can directly download data on PM without manual transcriptions.

The assistant/supervisor validates information and then they are automatically recorded on ME (within PM), service notification (AdM) and work order (within ERP-SAP).

Regarding the correct use of technical accounting objects, the Responsible of Local unit should analyze their accuracy, underline any non-compliances and indicate corrective actions, if necessary.

If Tablet is not available, after validation, the assistant/supervisor uploads data in the systems. In this case, if PM and ERP-SAP are available it is sufficient to upload information on PM and then, from PM itself, they are automatically updated in ERP-SAP.

The data recording on ERP-SAP system determines the automatically updating of material in ERP system (ERP-SAP MM) related to logistic material management.

Costs download

Periodically (once maintenance activity is done or not), the local planning and control unit calculates the final costs of the maintenance activity (material, times, third parties works).

If ERP-SAP is available, the costs, uploaded in the work order, are accounted in specific accounting items (WBE, etc.) according to the accounting prescription set when the work order was opened.

For the most frequent used work orders (e.g. PMAC for corrective maintenance, PMES for operation activity PMES or PMPR for scheduled maintenance) the accounting rule is the reference cost center of the OdM technical structure code. In general, the final accounting of costs must be made in accordance with accounting principles defined by the Administration, Finance and Control department.

Technical\economical closing of the activities

When activities and scheduled work have been carried out, the assistant/supervisor closes the activities in the systems, closing the accounting object opened for it.

If ERP-SAP system is available, the assistant/supervisor closes the work order from a technical point of view that no longer allows to modify more technical information (e.g. change the equipment broken in the system or schedule new activities or materials), but it is possible to impute costs of materials, internal and external services planned before the closing.

In case of existence of PM, if the work order has been generated from the ME, the technical closing of the work order is automatic when the ME is closed. If it is necessary, it's possible to cancel the closing.

Commercial closing

Once technical closing and costs download have been carried out, the competent Planning and Control unit can manage the commercial closing for the following cases:

- no more costs must be accounted;
- all costs have been downloaded;
- all the activities have been closed.

The commercial closing is managed directly in ERP-SAP and it is in charge of competent unit within Administration Finance and Control department every year or every six months.

The Work order technically closed that don't receive costs for a long time, can be commercially closed, in accordance with local unit.

ANNEX C: AUTHORIZATION AND DISCLAIMER

- Enel Green Power authorization letter
- SAS Disclaimer letter for use

USC
UNIVERSIDADE DE SANTIAGO DE COMPOSTELA

ENEL GREEN POWER
VIALE REGINA MARGHERITA, 125
00198 ROMA - ITALIA

To whom it may be concern

Roma, 22nd June 2021

SUBJECT: Doctoral Thesis of Francisco Garcia Lopez - Request for authorization to Enel Green Power

Messrs: Universidade de Santiago de Compostela,

Francisco Garcia Lopez is employed in Enel Green Power and his job concerns Energy Expert in Evolution Projects, which implies the use of databases and software provided by our company.

During his job, he performed calculations, extracted KPIs and confirmed some hypothesis. For this reason, considering the scientific relevance of the data he collected, he asked us to use them for his Doctoral Thesis OPERATIONAL EXPENDITURES MODEL FOR RENEWABLE PLANT

So, as we believe in the personal and professional growth of our employees, we allowed Mr. Francisco Garcia Lopez to use such data for his thesis, in plain respect of Enel's and third parties' IP and Industrial rights.

Kind Regards,

José Alba Pérez

Rafael Antonio González Sánchez

Firmado por 09736128K RAFAEL ANTONIO GONZALEZ (R: B61234613) el día 27/06/2021 con un certificado emitido por AC CAMERFIRMA FOR NATURAL PERSONS - 2016

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Messrs: Universidade de Santiago de Compostela,

Notwithstanding the above, SAS requested us to insert the following disclaimer in Francisco's Phd thesis:

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