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Failure analyses of onshore wind farms based on experimental data

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Abstract. In the case of the integration of renewable energy sources, the use of several sources of energy simultaneously especially, photovoltaic and wind, are recommended. The computation of Life Cycle Cost (LCC) is considered as the best way to assess the impact on the environment and economy. The Life Cycle Cost of a wind turbine can be divided into six parts: design, development, manufacturing, installation, operation and decommissioning. This paper is a contribution to assessing the costs of operating a wind farm of 2MW representing the stochastic part in the calculation of the LCC. A database of 5 years functioning of about 200 wind turbines spread over 30 farms has been used to give a first estimation of the LCC of each turbine and define the variation of MTBF and MTTR. In this study, we make a focus on the most important parts of a wind turbine and propose a global schema of maintainability of wind turbines.

Keywords: Renewable energy, failure analysis wind farms wind turbine, maintenance, life cycle cost (LCC)

1 Introduction

Renewable energy and especially the wind and photovoltaic electricity are considered as the best alternative to the fossil fuels sources of energy. Wind energy is expected to become the major source of energy due to its several advantages [1]. Wind turbines have known a lot of evolution in the last decade and become biggest and more complex. The new generation of wind turbines are subject to several requirements such as the low footprint, the low life cycle cost and the remanufacturing constraints. At the same time, the profitability of a wind farm is depending of the cost of the acquisition of turbines, the cost of installation, the cost of exploitation and maintenance, and finely the cost of operations related to the end-use [2]. The cost of manufacturing of turbine is relatively easy to estimate, because of the duration of manufacturing process which is not very long, and the deterministic behavior of the system. However, the cost of exploitation and maintenance of wind farms is difficult to define because of the large number of stochastic parameters such as: the weather conditions the experience of the maintenance agents and the degradation of turbines. Add to that, the period of Operation and Maintenance (O&M) is very long (up to 20 years)[3].

Several researchers were interested to the estimation of the cost of O&M cost of wins farms. Recently [4] have developed a cost model of O&M cost based on multi-agents systems. This model is limited to the variation of the type the used maintenance, and the installation of monitoring tools. [5] presents several works interesting in the cost estimation of wind energy (Offshore or Onshore). Few of them are based on real data because of the difficulty to obtain real data from for long exploitation periods. The study conclude that the maintenance cost is the most complex to compute because of the maintenance duration

and the variability of system.

In this paper we present the results of the evaluation of the Life Cycle Cost (LCC) of 2MW wind turbine type. The presented results are conducted on a real database issue from 5 years exploitation of various wind farms including data of approximately 210 wind turbines. These results will be compared with theoretical models of predictions of failure rates. We also present a validation of computational tools such as MTBF (Mean Time Between Failures) and MTTR (Mean Time To Repair) for this type of wind turbines.

The aim of our work is to provide a decision-making tool for customers and also product suppliers in order to optimize their O&M strategy and improve their designs by evaluation of alternatives using simulation. They can try various strategies of processing, O&M and decommissioning to optimize the LCC. The estimation of the LCC can be applied to determine the costs associated with a specific activity, for example, the effects of different approaches / maintenance concepts to cover a specific part of a turbine or a farm, or to cover only a selected phase or phases of the life cycle as the processing or the maintenance. In this paper we are interested in the estimation of all the Life cycle and specifically to the maintenance and exploitation part.

The next section of this paper presents the life cycle cost of wind turbine and the distribution of costs for all the life cycle. The 3rd section focuses on the maintenance cost estimation after that, we expose some results and conclusion extracted from the real data gathered during this study.

2 Assessment of Life Cycle Cost of wind turbine

Many companies and countries generally invest in clean sustainable processes to enhance their energy performance. In this context, wind power has emerged in various forms, onshore, offshore or small installations for the large public. However, the assessment of the and the reduction of the global production cost is not obvious. Several studies have been conducted to assess the overall cost of production of this energy. This cost which is considered as the only way to assess the ecological impact of this technology [6], interests investors, manufacturers and operators.

One way to evaluate this cost is to use the life cycle cost method (LCC: Life Cycle Cost). The LCC of a product is the sum of the costs of dismantling this product in the design phase [7]. Therefore, it includes the design of wind, development, production, installation, operation and finally dismantling as shown in Figure 1.

It is known that the concept of expected services is more important than the product itself. The purchase price is well up to the notion of cost of ownership that takes into account the operating and maintenance costs [8]. For example, in the case of a wind turbine, the purchase price, the customer's point of view is the visible part of the "iceberg", but it will add the cost of maintenance, repairs, parts of spare parts, etc. For LCC estimation, we consider that the maintenance cost of the electronic parts is the most dominant. However, corrective maintenance of organs such as the blades can mobilize significant resources.

The concept of assessment of the life cycle cost involves a basic understanding of the life cycle of a product and the activities carried out during these phases. It is also essential to understand the relationship between these activities and the performance, security, reliability, maintainability and other product characteristics, contributing to the cost of the life cycle. This general model can be decomposed as follows:

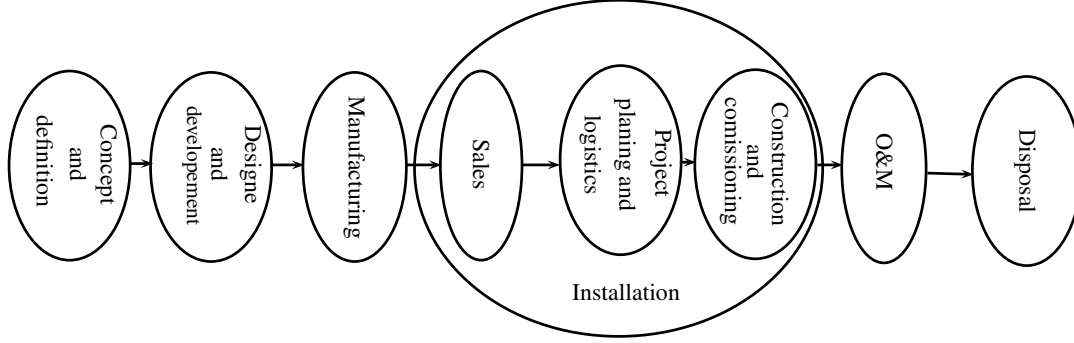


Fig. 1. Life cycle of wind turbine

$$LCC = C_{conception} + C_{development} + C_{manufacturing} + C_{installation} + C_{exploitation} + C_{endlife} \quad (1)$$

Where:

- LCC is the Life Cycle Cost
- $C_{conception}$ is the cost related to the conception and definition step
- $C_{development}$ is the cost related to the development of the turbines it includes the part of qualification and tests.
- $C_{manufacturing}$ is the cost of manufacturing of turbines it includes the cost on installation of workshops and the raw materials.
- $C_{installation}$ is the cost of sales, project planning & logistics and construction and commissioning
- $C_{exploitation}$ is the cost of exploitation, it includes the cost of O&M, advertising and distribution costs
- $C_{endlife}$ is the cost of demolition and remanufacturing

From the equation 1, it is possible to estimate the cost of purchase of a wind farm as follows:

$$LCC_{purchase} = C_{conception} + C_{development} + C_{manufacturing} + C_{installation} \quad (2)$$

Decomposition of these parts allows us to define an estimate of the distribution of the wind turbine LCC. This result is represented in Figure 2 below.

In this context, several studies have been conducted to evaluate the LCC of wind turbines installed in offshore and onshore farms [6],[9]. In a [10], authors presented a work that assesses the LCC for each part of a wind turbine, they conclude that the wind energy is the manufacturing cost in the most important and the O&M cost is not easy to estimate and it depends on the quality of management of farms and weather conditions. In [9] and especially in [6] an assessment of the impact of a 1KWh power wind farm on the environment was presented. In [9] the authors conducted an analysis of the materials used for the construction of wind turbines.

In the development phase, the machine design and the choice of materials are analysed according to the power and location. In this phase, the life cycle cost is used to estimate the overall cost of a wind turbine ownership. This phase is also concerned by sizing the major organs of the turbine such as the generator and gearbox. Generally, the prototype has a much higher cost than a machine mass produced

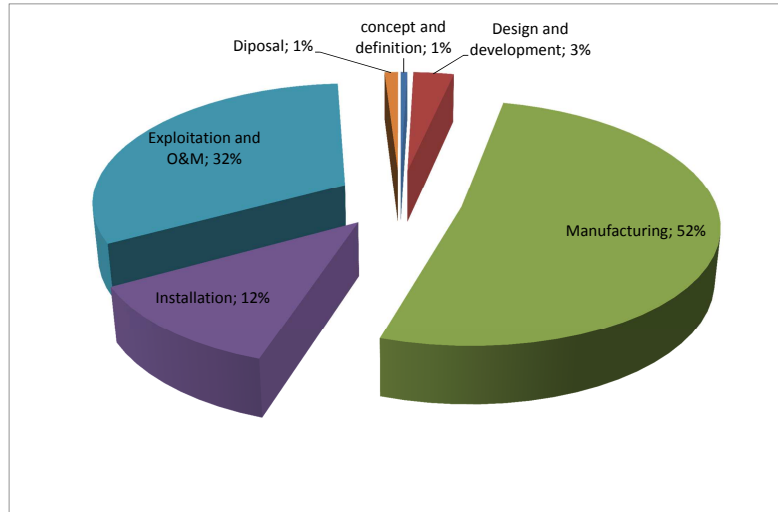


Fig. 2. LCC cost distribution

because the parts are purchased from the unit. However, it is important to take into account in the LCC computation, the number of machines produced in manufacturing phase, in order to estimate correctly the cost each produced machine. In average, this phase represents 3% of the overall cost of wind turbine life cycle.

The production is the phase of the wind turbine’s life cycle, which represents the largest part. It includes many different costs such as the installation of workshops, the labour and the production facilities. Generally, the cost of this phase is fairly simple to define using data from the design phase. Concerning the industrialization, the largest cost, at this stage, is related to the assembly of the turbine’s parts. Indeed, the tower and the blades are assembled directly on the site for transportation issues. It is important to remember that most of the manufacturing cost is due to the price of the parts that make up the wind turbine (generator, gearbox, tower, ...). The main components of the nacelle are: the gearbox, the generator, the input shaft, the base (ground), the electrical cabinet and the nacelle hood. This costing process meets the requirements of IEC 60300 International Standard. In summary, this phase represents 52% of the overall LCC of a wind turbine. It is the most important parameter in the calculation of return on investment, knowing that currently normal operation period of a wind turbine is estimated at 20 years.

The installation phase of a wind turbine takes into account the costs of sale, project logistics, installation and commissioning of the machine. It represents about 12% of the overall LCC of wind turbine.

O&M costs represent the difficult part in the LCC computation because it is estimated over a period of 20 years, and in the most cases data are not available for a so long period. Indeed, this cost includes preventive and corrective maintenance and downtime cost. The estimated costs of the latter is based on predictive models and stochastic laws. It depending on several parameters such as weather variations, the position of the farm and the quality and size of turbines.

3 O&M cost estimation

The estimation of O&M cost is the essential part of our investigations. We focus on the assessment maintenance costs that represent the most important part of the operating costs. They include several activities such as the logistics, the resources management and the effective maintenance. To do this, we used real data provided from different wind farms to define statistical model of the behavior of wind turbine and compared them to the known theoretical models. For the needs of this study we have taken the sample presented in Table 1 :

Period (Year)	1	2	3	4	5
2MW Wind turbines	200	150	100	50	25
Number of Farms	30	25	15	9	4

Table 1. History of operating data

From data collected over 5 years, we estimated two indicators MTBF (Mean Time Between Failure) to 75 days and the MTTR (Mean Time To Repair) at 25 hours / failure. We finally calculate the MTTF (Mean Time To Failure) which is about 115 days.

4 Results and Discussion

The cost of maintenance depends on several correlated parameters such as the number and frequency of failure, the quality and age of wind turbines. In order to reduce the cost O&M it is necessary to use the suitable maintenance strategy depending on the period of exploitation. Based on the collected data we have computed the number of failure per trimester for a significant sample from different wind farms. As shown in Figure 3, the analysis shows that the failure rate is high in the begging of exploitation of turbines (3.4 failure by turbine in the first trimester) and it decreases rapidly during the first year until it stabilized around 2 failure per trimester for each turbine. We have used the weighted least squares cubic spline fitting (LSQ splin) to approximate the variation of failure rate based on real data, which are represented by small circle on the Figure 3.

The duration of failure are depending also on several parameters such as the kind of failure, the age of turbine, weather conditions and experience of maintenance operators. in order to define a good maintenance strategy it is important to use the appropriate resources for the right failure at the right period. For that, we need to know as well as possible the variation of downtime of turbines. We have computed an average of downtime per trimester based on real data in order to estimate the parameters of statistical law followed by the downtime of wind turbine. We have used the weighted least squares cubic spline fitting (LSQ splin) to approximate this variation.

Figure 4 shows the average of downtime per wind turbine. We note that this average has an exponential trend and tends to stabilize around 40 hours/turbine from the first year of operation. We not also that the variation of downtime is not similar to failure rate variation presented in Figure 3 because the downtime increase when there is a lot of failures. The tow parameters coincide with the theoretical models of failure variation regarding the age of wind turbine (bathtub curve)[11].

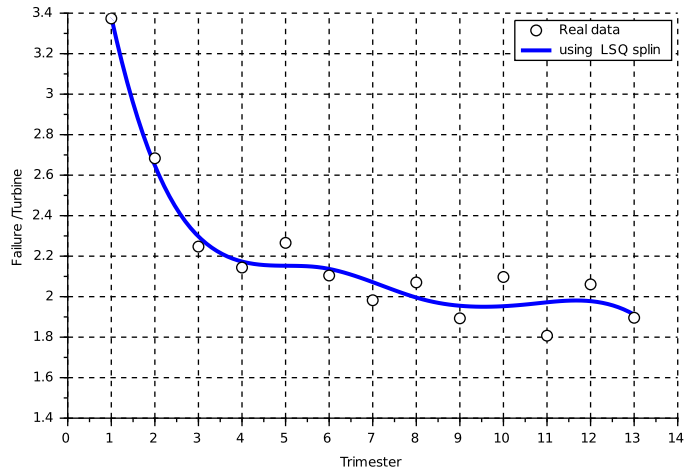


Fig. 3. Failure rate per wind turbine over 5 years

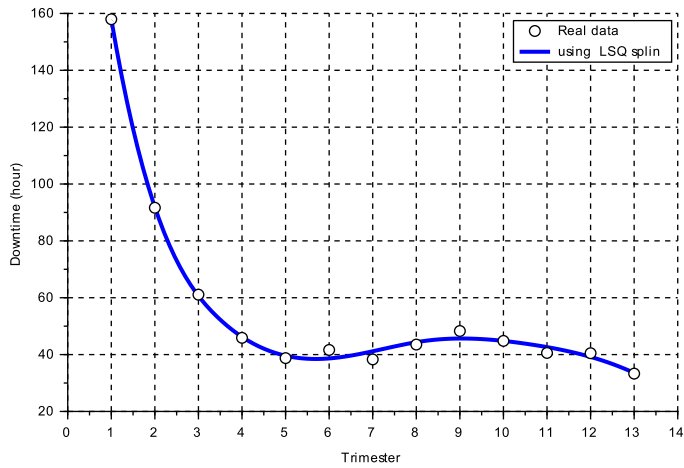


Fig. 4. Average of downtime per turbine over 5 years

The type of failure has a direct impact on the downtime of turbines. Generally, a maintenance task of concerning an electric failure varies between 1 to 3 hours while a failure concerning the gearbox may last several days. A good O&M strategy should be adaptable according to the failure type.

A detailed analysis of failure for each part of the turbine, showed that during the first year of operation, maintenance, mainly concerned 4 parts as shown in the Table 2. These 4 parts cause 85% of the total downtime. We can conclude also that they represent the most complex parts to repair because of their high values of downtime mean. This part are very important and should be inspected frequently to avoid long downtime period especially in the first year of exploitation.

Other parameters can explain the high number and duration of failure in the first year of exploitation like the lack of maintenance operators experience or the poor crisis management.

Parts	Downtime per failure (h)	Annual failure rate (%)
Converter	50	35
Rotor, Pitch	35	25
Grid	30	15
Gearbox	60	10

Table 2. History of operating data

From the 3rd year, the distribution of failures becomes more homogeneous between the different parts of the turbine. The first results from these data have allowed us to give a first estimation of the necessary parameters for the computation of the cost of operating a wind farm and calculate various useful indicators for O&M planning. Currently, we are developing a model that will allow us to do simulations on offshore wind farms and other wind turbine models.

5 Conclusion

it is important to use several kind of energy source to ensure the stability of electrical network. The Life cycle cost is considered as the best way to assess the environmental and economic impact of this type of energy. The LCC of a wind turbine can be divided into six parts: the design, development, manufacture, installation, operation and decommissioning. The work we have presented in this article is a contribution to the evaluation of the operating costs of wind farms of 2MW representing the deterministic part in the calculation of LCC. A database over 5 years of operation of more than 200 wind turbines spread over 35 farms has served to provide an initial forecast of the distribution of production costs of each turbine and define the temporal trends of MTBF and MTTR. Based on this data, we have defined some indications to define a good maintenance strategy. This parameters will be used to calibrate a simulator under development for the estimation of O&M cost over a long period of exploitation.

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