The Main Factors that Make Up a Wind Energy Production System: Case Study of a Wind Farm Located on the Northern Coast of the Rio De Janeiro

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Abstract

One of the ways to diversify the power grid and reduce its dependence on non-renewable energy sources is through the use of systems that produce wind energy. Wind energy is defined as the kinetic energy contained in moving air masses (wind). It can be harnessed by converting the translational kinetic energy into rotational kinetic energy, with the use of wind turbines. Currently, the growing demand for wind energy is being driven by a number of factors: the context of supply and demand for energy on a global scale, environmental issues, especially climate change, and the evolution of the technology in the wind energy sector. The object of this paper is the study of a wind farm, located in the municipality of São Francisco do Itabapoana – RJ - Brazil. The objective of this research is to identify and describe in detail the main factors that make up systems that produce wind energy. This research opted to use the case study methodology since the case study analyzes an individual, family, group, or community in order to perform an in-depth inquiry so as to examine the life cycle or some particular aspect of the object being studied. During data analysis, the research perceived that a wind energy production system is composed of three fundamental factors: a region with wind potential suitable for the production of energy; energy turbines appropriate for the wind potential in the region; as well as a highly qualified management and maintenance team.

Key words: Wind farm, system for wind energy production, wind turbine, wind potential.

1. Introduction

One of the ways to diversify the power grid and reduce its dependence on non-renewable energy sources is through the use of systems that produce wind energy. Wind energy can be defined as "the kinetic energy contained in moving air masses (wind). It can be harnessed by converting translational kinetic energy into rotational kinetic energy by means of wind turbines" (ANEEL, 2005, p. 93).

According to the Global Wind Energy Council (2012), the growth of the wind energy market is being driven by a number of factors: the drivers of supply and demand for energy on a global scale, environmental issues, especially climate change, and the evolution of the technology sector. These factors have merged in many regions of the world to encourage political support for the development of this industry.
The global demand for energy is increasing at a rapid pace, which will require significant investments in new sources of power generation and in the infrastructure of the power grid. The International Energy Agency - IEA (2012 *apud* GLOBAL WIND ENERGY COUNCIL, 2012), estimates that by 2030 the global demand for energy will be 60% higher than current levels. The IEA estimates that about 4,500 GW of new power capacity must be installed before 2030, thus requiring investments of over $1 trillion. This sharp increase in world energy demand will require significant investment in new energy production and distribution facilities, especially in emerging economies like India and China.

As demand for energy continues to increase, the main fossil fuels which are used to generate power are becoming more expensive and more difficult to extract. Soon, many of the major world economies will be even more dependent on imported fuel, sometimes coming from parts of the world where political instability and conflicts threaten the security of the supply (GLOBAL WIND ENERGY COUNCIL, 2012).

Even though uncertainties affect the supply of conventional fuels, wind energy is an energy source that is permanently available in virtually every country in the world. This renewable source of energy has no fuel costs or geopolitical risks, and does not need to be imported from politically unstable regions. Wind energy also has the advantage of being able to be deployed more quickly than other energy sources. Even large offshore wind farms, which require a higher level of infrastructure, can be installed in less than two years (GLOBAL WIND ENERGY COUNCIL, 2012).

Like all renewable sources that rely on capturing the power of natural forces, wind energy has none of the polluting effects associated with 'conventional' fuels, and also offers numerous other environmental benefits. Since it does not emit air pollutants, this energy solution does not contribute to global climate change and does not produce acid rain (TERCIOTE, 2002). Furthermore, wind energy produces no toxic waste and virtually uses no water, which favors the preservation of bodies of water (GLOBAL WIND ENERGY COUNCIL, 2012).

This source of energy reduces the reliance on fossil fuels, since wind is an abundant and renewable resource. In addition, wind farms occupy a small footprint and enable business continuity between the turbines (grazing and agriculture). It is also important to note that wind power improves the local economy, given that studies in Scotland estimate that every 0.3 to 1 GW of installed power creates between 500 and 1,500 jobs (TERCIOTE, 2002).

Also, according to the Global Wind Energy Council (2012), in 2008, more than € 36.5 billion was invested in wind energy worldwide, and the sector employed more than 400,000 workers. Moreover, the annual global investment in wind energy will reach € 149.4 billion in 2020 and account for more than 2.2 million jobs. In fact, the global capacity of wind power increased by 41 GW in 2011, an increase of 21%, and the production capacity in Brazil increased by 63% and now totals 1.5 GW.

Although there is a very positive scenario for new investments in wind energy, one cannot disregard the analysis of some important factors before starting any new venture. Among these factors, we can highlight three main ones:

i. the assessment of a region’s wind energy potential,
ii. the availability of technologies capable of transforming the kinetic energy of the wind into electricity, and
iii. the existence of a highly qualified team capable of managing and maintaining the wind turbines.

Taking this into account, this study chose to examine the northern coast of the State of Rio de Janeiro, more specifically the coast of the municipality of São Francisco de Itabapoana, in view of the fact that it is a region which has a wind farm with impressive results in the industry. Initially, it was necessary to analyze the wind potential of this region in order to support the main objective of the research study, which is to identify and describe the main factors that make up a wind energy production system. Once the wind potential of the region is described in detail, the technology employed in the wind farm, as well as the management and maintenance systems are also described.
2. Methodology

The object of the research study is a wind power plant situated on the northern coast of the State of Rio de Janeiro. As it was mentioned earlier, the main objective of the study is to identify and describe the main factors that make up a wind energy production system, by means of a case study.

According to Creswell (1994 apud GIL, 2009), a case study is a process in which the researcher explores a single entity or phenomenon restricted by time and activity (a program, event, process, institution or social group) and collects detailed information using a variety of data collection procedures during a defined time period. The research opted to employ the case study, due to the fact that this paper seeks to identify and describe the main factors that make up a specific process, the production of wind energy, taking as reference, a wind power plant located in the northern coast of the State of Rio de Janeiro. Since a case study needs to use a variety of data collection procedures to ensure the quality of the information (GIL, 2009), the case study decided to use bibliographical research, documentary research and data collection.

Bibliographical research "is developed based on material which has already been prepared, such as books and scientific articles" (GIL, 2002). Taking this into account, this research study examined research papers published in conferences, dissertations, PhD theses, materials available on the Internet and books by authors specialized in the area of wind energy. With respect to the documentary research, which analyzes materials that have not received any analytic treatment, or which may still be reworked in accordance with the objects of the study (Gil, 2002), it was employed in the chapter that analyzes the power plant's financial structure.

Regarding data collection, which is characterized by the direct interrogation of individuals whose behavior you want to know (GIL, 2002), it was conducted by way of a qualitative interview with an employee of the power plant at a managerial level. The questions and the subjects of the interview were previously defined, because the study wanted to make sure to collect only information relevant to the research question. The survey instrument, the interview with a pre-established questionnaire, is divided into the following parts:

- Information on the wind potential of the region;
- Information on the technology of the wind turbines;
- Information on the management and maintenance system of the plant.

3. Case Study of a wind farm located on the northern coast of the State of Rio de Janeiro - Brazil

This chapter presents information obtained during research done on a specific wind power plant. To facilitate the understanding of the factors that constitute a wind energy production system, the case study is divided into four parts. First, the case study will describe the wind potential of the region where the wind farm is located. Then it will explain the main features of the company. Subsequently, it will discuss the plant's turbine technology, and finally, it will describe the management and maintenance system of the plant. These factors were chosen to be studied because the bibliographical review indicates that every wind farm is composed of three main factors: a region with adequate wind potential; harnessing technologies capable of transforming the kinetic energy of the wind into electricity, in addition to a highly qualified team capable of managing and maintaining the wind energy production system.

3.1. The wind potential of the region

The State of Rio de Janeiro is located in a region predominantly influenced by the high pressure center of the South Atlantic Anticyclone, resulting in prominent occurrences of winds coming from the east and northeast (AMARANTE, SILVA, RIOS FILHO, 2004). The region is also affected by cold fronts coming from the South Pole, which produce a distinct seasonality of winds. These mechanisms are the main atmospheric influences; however, the wind regimen is also affected by other factors such as sea, land and lake breezes; mountain-valley breezes; and nocturnal jets. According to Amarante, Silva and Rios Filho (2004), the regions with the highest wind potential in the state are located in the northern
The northern coast of the state has the largest variations of annual diurnal average speeds. In the early morning, speeds reach a minimum, however, as the day begins, the solar energy coming from the sun heats the land masses, causing the sea breezes to increase in speed. The speeds of the sea breezes reach a maximum during the period extending from the late afternoon to early evening. When the sun sets, the land masses begin to cool down, "the atmosphere becomes more stable and the intensity of the sea breezes diminish, until a new day begins, and the dynamic resumes once again" (AMARANTE, SILVA, RIOS FILHO, 2004, p. 21). The wind regimen in the northern region of the State of Rio de Janeiro, has a high seasonality, with stronger winds occurring in the spring months (September to November), and the mildest in the months of late fall and early winter (April-June).

3.2. The Company

The wind farm analyzed by the case study is located in the municipality of São Francisco do Itabapoana, northern region of the state of Rio de Janeiro. It is owned by a private equity corporation (Deloitte Touche Tohmatsu, 2011) which was established on October 17, 2007, whose purpose is to render

...study, research, feasibility, design, construction, construction management, operation and maintenance service intended for the expansion, exploration, repotentialization, production and generation of wind power (Deloitte Touche Tohmatsu, 2010, p. 7).

The company has as its shareholder a private equity corporation that was incorporated on December 6, 2002, with the purpose of

...participating in other Brazilian and foreign companies, including investment funds, which operate in the sectors of renewable energy generation, its supporting infrastructures, and derivatives; carrying out investment projects in the sector of renewable energy generation, their supporting infrastructure, and derivatives; and the rendering of consulting services for projects related to power generation (Deloitte Touche Tohmatsu, 2010, p. 7).

The permit of the initial retainer for the wind farm was approved by the National Electric Energy Agency, by means of ANEEL's Resolution No. 534 of October 1, 2002. This resolution established the retainer as an independent producer of electricity for a period of 30 years with an installed capacity of 40.0 MW. However, the production capacity of 40.0 MW was reduced to 28.05 MW by ANEEL's Authorizative Resolution No. 230 of May 5, 2004.

Subsequently, the ownership of the permit for the wind farm was transferred to the present company, in accordance with ANEEL's Authoritative Resolution No. 2145 of 27 October 2009. The project went into commercial operation on October 28, 2010. The contract of purchase and sale of energy was signed with Eletrobras by way of the PROINFA program. The validity period of the contract is of 20 years from its signing under the conditions described in the Table 1 below:
Table 1: Sales of the energy generated

<table>
<thead>
<tr>
<th>Quantity MWh/year</th>
<th>Fare (R$/MWh)*</th>
<th>Signing of the Contract</th>
<th>Signature of Addendum PF-010/2010</th>
<th>Start Date of Commercial Operation</th>
<th>Expiration of the Contract</th>
</tr>
</thead>
<tbody>
<tr>
<td>61,757</td>
<td>214.82</td>
<td>July 2004</td>
<td>19/08/2010</td>
<td>28/10/2010</td>
<td>30/07/2030</td>
</tr>
</tbody>
</table>

(*) Original Value.
Source: Deloitte Touche Tohmatsu, 2010, p.8

The price established in the contract is adjusted every year in the month of July in accordance with by the General Market Price Index - IGP-M, announced by the Getúlio Vargas Foundation. With respect to the financial structure of the project, originally, the capital structure of the project was planned to be comprised of 70% third party capital and 30% equity capital. However, due to loans later granted by the National Bank for Economic and Social Development – BNDES totaling R$ 79,513,000 (original value), this structure was modified to "43% third party capital and 57% equity capital (Deloitte Touche Tohmatsu, 2011, p. 8). On December 31, 2010, this ratio was changed again to 36% third party capital and 64% equity, of which R$ 66.4 million was released by the BNDES. The remaining amount of R$ 3,481,000 was released on January 17, 2011 and April 19, 2011.

3.3. The technology of the wind turbines

The wind farm has 17 VestasV82 turbines each capable of producing 1.65 MW. (TAVARES, interview held on September 4, 2012). The 17 turbines operating simultaneously have the ability to produce "28 MW, which would be enough to power a city of about 80,000 inhabitants" (Moratelli, 20122). These turbines were manufactured in India and installed in São Francisco do Itabapoana by Vestas Brazil (TAVARES, interview held on September 4, 2012). The Vestas V82 wind turbine is suitable for large wind farms, where issues of compliance with the power grid are resolved at the turbine’s substation (VESTAS, 2012). This means that it is not necessary to invest in equipment to connect the turbine to the power grid. The V82 turbine is extremely competitive in its class and is better adapted to areas with low and medium intensity winds. The wind turbine is optimized for locations with average wind speeds of only 6.5 m/s at the height of the rotor; moreover, a breeze of only 3.5 m/s has the ability to start energy production. Winds above 20 m/s, which last more than 10 minutes, automatically shut down the rotation of the blades. The V82 operates at temperatures ranging from -30 °C to 40 °C. Taking into account these characteristics, this wind turbine was selected by the wind farm, because it better adapts to the type of wind in the region (TAVARES, interview held on September 4, 2012).

The V82 has “hydraulic Active-Stall® technology that ensures that the rotor gathers the maximum power from the prevailing wind, while minimizing loads and controlling output (VESTAS, 2012). Active-Stall® also provides protection against failures in all wind conditions, while maintaining a constant production of 1.65 MW when the wind speed is above the rated wind speed. Furthermore, Vestas grid support includes full load and static phase compensation to boost reactive power regulation and consequently keep the power factor in range. Moreover, the “grid support provides continuous active and reactive power regulation to maintain voltage balance in the grid, as well as fault ride-through in the event of disturbances” (VESTAS, 2012). The power curve of the turbine is illustrated in Figure 1. It can be observed that it reaches the maximum power when the wind speed is above 13 km/h.

Det Norske Veritas (DNV), a global provider of services for managing risk, has certified the V82 turbine as meeting the most stringent standards in the wind industry. Its simple design makes service and maintenance easier than most other turbines in the megawatt class. Furthermore, the nacelle is based on a design that has been thoroughly tested in earlier models. Over 1,400 wind turbines based on this design have been installed around the world, in places with climates ranging from tropical to arctic. The tower of the V82 is 80 meters high, its rotor has a diameter of 82m and its three blades sweep an area of 5.281m². The rotation of the blades is 14.4 rpm (VESTAS, 2012), which is equivalent to a maximum speed of 160km/h at the blade tips (Moratelli, 2011). The blades are made of fiberglass and carbon and arrived in San Francisco do Itabapoana in trucks coming from the port of Rio after arriving from Denmark on cargo ships (Moratelli, 2011).

The turbine generator is water-cooled and operates at 60 Hz and 600V, the gearbox has helical stages and all of the turbine functions are monitored by microprocessors, with the option of remote
monitoring. (VESTAS 2012). As for the weight of the turbine, the nacelle - compartment located at the top of the tower which houses the generator mechanisms - weighs 52 tons, the rotor 43t and the tower 125 t. Regarding the sound level, when the wind speed is at 6.0 m/s, which is the average wind speed in São Francisco do Itabapoana, the turbine emits between 101.5 dB (A) and 102 dB (A). The Figure 2 below illustrates in more detail the relationship between wind speed and sound level.

3.4. Management and maintenance of the plant

The modern wind turbines are designed to operate for 120,000 hours throughout its estimated lifespan of 20 years, which is equivalent to approximately 66% of its lifespan (WIND MEASUREMENT INTERNATIONAL, 2012). This is much more than an engine of a modern car, given that it is built to last between 4000-6000 hours. Maintenance costs of wind turbines are very low at the beginning of their life, but over time these costs increase. Studies in Denmark, which were conducted on 5000 wind turbines installed in the country since 1975, show that each new generation of wind turbines has lower maintenance costs than the previous generation.

Previous generations of wind turbines have an annual maintenance cost of around 3% of the original cost of the turbine. Because newer turbines are generally substantially more powerful, an economy of scale is generated: lower maintenance costs per kW of rated power. This occurs simply because you do not need to give maintenance to a big turbine more often than a small turbine. Couple this with the constant development of new materials and new techniques and maintenance costs are reduced significantly. Regarding modern turbines, the maintenance costs are estimated at around 1.5% to 2% of the initial investment per year.

The wind farm covers an area of 500 hectares, the equivalent of 833 soccer fields, however only 1.7 hectares are built on (Moratelli, 2011). Although the wind turbines occupy a significant area, only 7 people take care of the management and maintenance of the plant (TAVARES, interview held on September 4, 2012). The maintenance team is comprised of 3 people and the management team is comprised of four. The monitoring of the turbines is done 24 hours a day, and each of the three service technicians is responsible for an 8 hour shift (Moratelli, 2011). According to Tavares (2012), the maintenance of the turbines is carried out by Vestas Brazil. Vestas offers a maintenance service called AOM - Active Output Management, which consists of 4 elements: operation and maintenance, infrastructure, people, and intelligence (VESTAS, 2011).

With regards to the operation and maintenance of the turbines, this process runs like clockwork, and is designed to maximize productivity. Vestas’ performance monitoring system collects data 24 hours a day, seven days a week, using sensor systems for remote monitoring built into each turbine. Then Vestas develops an accurate maintenance program based on the site characteristics. The data which is collected is continually updated and fed back into the research and development department, thus allowing improvements to be made in the diagnosis models. This “continuous improvement minimizes both production loss and operation and maintenance costs” (VESTAS, 2011). Regarding infrastructure, Vestas has a supply chain with global coverage, ensuring that parts and components are delivered on
time even in remote locations. From the warehouses strategically located around the world, the customers can purchase parts in a way that minimizes costs and delivery time. Moreover, stocks are continuously replenished and optimized by means of kanban systems and forecasting (VESTAS, 2011).

On the topic of people, Vestas technicians work under the most stringent safety standards. The plant managers and technicians not only understand the details of service and maintenance, but also how these processes affect the long term performance of the plant. The service and maintenance training provided to the regional managers ensures that they have the specialist skills and capabilities to guarantee both results and a ‘safety-first’ policies (VESTAS, 2011). In addition, the Vestas team operates globally so as to provide identical service levels in all major markets (VESTAS, 2011). On the subject of intelligence, the experience of the company is supported by a research database that continuously monitors the wind speed, temperature, vibration and air pressure of more than 21,000 turbines worldwide. This information is transmitted to the Vestas Diagnostics and Performance Center and processed by a supercomputer capable of performing more than 150 trillion calculations per second. The performance data is then used to create predictive maintenance models. This helps eliminate lost production and provide predictable product performance (VESTAS, 2011).

4. Analysis of the results

This chapter analyzes the data collected during the field research. The goal is to extract the relevant information in order to answer the research question: What are the key factors that make up a wind energy production system?

During the research it was observed that a wind energy production system is composed of three fundamental factors: a region with wind potential suitable for the production of wind energy; wind turbines suitable for the wind potential of the region; along with a highly-qualified management and maintenance team.

With regards to the wind potential of the location of the plant, a detailed study of the wind potential in the region needs to be conducted over several years (TAVARES, interview held on September 4, 2012). This study will determine the annual wind regime of the region. Regarding the wind potential of the State of Rio de Janeiro, the most suitable regions for the construction of a wind farm are: the northern coast of the state, the lakes district and the Pirai-Vassouras-Petrópolis polygon (AMARANTE, SILVA, RIOS FILHO, 2004). Figure 3 illustrates the intensity of the wind on the northern coast of the state of Rio de Janeiro. And Figure 4 illustrates the intensity of the wind in the lakes district.
The intensity of the winds in the Lake District must always take into account the safety standards to emphasize that maintenance must be carried out according to the operating manual of the wind turbines. Furthermore, it is important to consider that high initial costs may not be justified if the maintenance costs are excessive.

It is also important to determine the intervals of scheduled maintenance in order to find an optimal balance between the cost of planned and unplanned maintenance. A deficit of planned maintenance can have a low initial cost, but a high risk of costly failures, and an excess of planned maintenance is costly, but the additional benefits may be irrelevant (MILBORROW, 2012). Furthermore, it is important to emphasize that maintenance must be carried out according to the operating manual of the wind turbine and always take into account the safety standards.

Regarding the management and maintenance of a wind farm, this procedure must be performed by a highly qualified and experienced team. It is important to monitor the performance of the turbines 24 hours a day, 7 days a week, using sensors embedded in the turbines (VESTAS, 2012). Ideally, the data collected should be continuously analyzed to improve the diagnostic models, and optimize the planning capabilities. This continuous improvement also minimizes lost production and operation and maintenance costs.

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The three regions are suitable for the installation of wind farms, due to the high intensity of the winds. However it is important to emphasize that in addition to a region having a high wind potential, other variables must be considered. A flat place with few buildings in the vicinity is also desired (Moratelli, 2011). Taking this into consideration, the northern coast of Rio de Janeiro is preferable to the other regions, since it is flatter and less urbanized.

On the subject of turbine technologies, these need to be adapted to the region where they will be installed (TAVARES, interview held on September 4, 2012). There are dozens of manufacturers of wind turbines. The ten largest manufacturers in terms of installed capacity are: Vestas (Denmark), GE (USA), Gamesa (Spain), Enercon (Germany), Suzlon (India), Siemens (Denmark), Acciona (Spain), Goldwind (China), Nordex (Germany) and Sinovel (China) (MWPS, 2011). Vestas was chosen among these. The wind farm has 17 Vestas V82 turbines each capable of producing 1.65 MW.

Generally large turbines available on the market are mostly three-blade horizontal axis wind turbines (ALE, ROSSI, OLIVEIRA, 2012). These consist of the components shown in Figure 6.

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The Figure 5 illustrates the wind strength in the Pirai-Vassouras-Petrópolis polygon.
6. Considerations and recommendations

Wind power is being used in many countries of the world due to its advantages over other energy sources. Wind energy is inexhaustible; does not emit greenhouse gases or generate waste; reduces the emission of greenhouse gases; is compatible with other land uses such as agriculture and livestock; creates jobs; generates investment in disadvantaged areas; reduces the high dependence on fossil fuels; is one of the cheapest sources of energy; does not need refueling; requires little maintenance; besides being an excellent financial investment (PORTAL ENERGIA, 2012). Taking all of these points into consideration, it is clear that wind power is here to stay and will be a major source of energy in the 21st century.

Regarding future researches which may be conducted in this area, the detailed study of the wind potential of the northern coast of Rio de Janeiro is a fertile area. The study of the characteristics of the turbines produced by Vestas’s competitors is another area that could be investigated in future studies. The importance of the relationship between turbine performance and the type of maintenance being performed could also be investigated. The management and maintenance of wind farms is another area of limitless research. Another research which could be researched in detail is the technology of the different components that make up a wind turbine: rotor blades, generator, gearbox, hydraulic system, etc.

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