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CHARACTERIZATION OF THE TECHNOLOGY USED IN WIND TURBINES IN THE BRAZILIAN MARKET

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***Abstract* - Power generation through renewable sources became a crucial need, nowadays there is a strong global tendency of governments and companies making huge investments in this field. Wind energy has shown a considerable worldwide growth rate, emerging as the one with most potential above the renewable energies. Wind turbines, the devices capable of converting kinetic into electric energy, can present diverse architectures, regarding rotation speed, power control, drive train and generator type. Different architectures lead to distinct machine operation and essentially to different maintenance approaches. This paper researched the wind farms in operation and under construction in Brazil, cataloguing the wind turbines types used in the national market. In all, 4,154 wind turbines were studied; these machines were sorted into 31 turbine models, corresponding to 7 distinct architectures. Once the predominant technology in the Brazilian market is determined, it can be used as basis for Operation & Maintenance application.**

***Keywords* -** Wind turbines, Architectures, Brazil wind technology, Wind turbine characterization

I. INTRODUCTION

In the last decade the world energy consumption has increased at an average rate of 2.1% a year, this growth was mainly caused by higher energy demand in emerging countries [1]. In fact, there is a very direct relationship between the growth of Gross Domestic Product (GDP) and the energy consumption of a country. The GDP growth reflects both the increase in industrial, commercial and service activities, as well as the population's ability to purchase more technologically advanced goods and services such as cars (requiring fuel), household appliances and electronics (which require electricity) [2].

If on the one hand the global energy consumption has been growing, on the other, the fossil fuels, the main source of energy used in the world [1], are progressively being questioned given their environmental impact or exhaustion in the near future. This scenario requires major advances in renewable energies fields. The renewable concept includes energy coming from any source that is inexhaustible and tends to have a minor environmental impact. Among these sources, wind energy has shown itself as the one with most potential. According to the BP Statistical Review of World Energy [1], the installed capacity of wind power was 18 GW in 2000, reaching just over 373 GW in 2014. An increase of almost 21 times in 14 years.

Brazil follows the world trend and is gaining recognition in this sector by its growth rate. The last year installed capacity growth rate (2013/2014) was 80.78 %, see Figure 1.In 2014 Brazil generated of 12.2 TWh of wind power, which led the country to the 10th position in the world generation ranking. The strong increase in wind generation in 2015 should lead the country to the 7th position in the ranking [3].

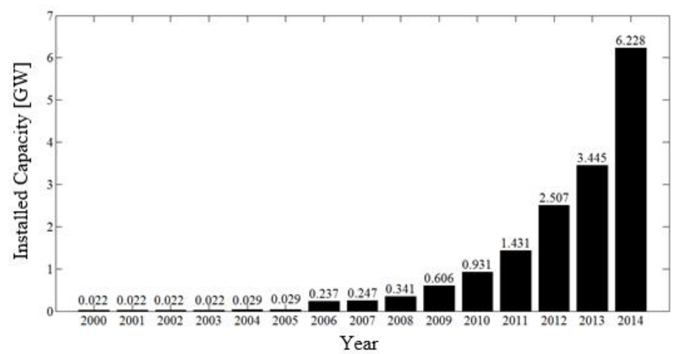

Fig. 1: Brazilian installed capacity evolution, in GW [Authors]

Brazil's current installed capacity is 8.12 GW, distributed in more than 300 wind parks [4]. This amount of wind farms represents more than 4,000 wind turbines generators (WTG) in operation, or being installed.

Brazilian energy policies grant power generation for a wind farm for 20 years, which means that this amount of wind farms and the upcoming ones will remain active for at least two decades. This paper aims to catalogue the wind turbine types used in the parks and their features, in order to determine the most used architecture in the country.

The first step to good planning Operation & Maintenance activities is the characterization of the technical system in question. Considering wind turbines, the main frame is the solid understanding of different architectures in a specific market. Once leading technologies in Brazil are determined, they can be used as guidelines for future Operation & Maintenance assessments.

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It is important to notice that nowadays the manufacturers are the main responsible for the O&M activities in a wind farm in Brazil. The commercial contracts establish a usual warranty period between 2 and 5 years, wherein the maintenance operations are carried out by the manufacturers. Given that the wind turbine useful life is 20 years, after the warranty period new maintenance contracts are required. In Brazil it is usual that these activities remain with manufacturers. However, this practice tends to disappear with the sector evolution. In a near future, when the maintenance activities will not be held by the manufacturers anymore, the technical characterization of wind turbines will be essential.

II. SUBSYSTEMS

Wind turbines are devices capable of converting kinetic energy from the wind into electrical power. The rotor's blades are the components responsible for the interaction with the wind flow and kinetic energy extraction. Through this interaction, the blades start rotating according to the wind speed and the blade's aerodynamic design. The rotor is connected through a shaft, regardless to the presence or absence of a gearbox, to the generator, the element that will transform mechanical movement into electric power. In order to do this energy conversion, different wind turbines architectures are possible. An effective way to classify the WTGs is according these arrangements.

The Project Upwind [5], a huge European R&D project in wind energy, has analyzed and classified the last decades wind turbines technologies. According to this study, a WTG can be classified based on four categories:

A. ROTATION SPEED;

B. POWER CONTROL;

C. DRIVE TRAIN;

D. GENERATOR TYPE.

A. Rotation speed

When the wind speed reaches the turbine cut in speed, the blades and the shaft start rotating. In that case, it is imperative that the blade be positioned in the operational position, as presented in Figure 2a, in order to produce the required forces to move the system. The generator, coupled to the shaft, will generate electrical power at a specific rotation speed or at a determined speed range, according its design. Considering this, wind turbines can be arranged in three concepts: fixed speed, limited variable speed and variable speed (Figure 3a).

In the fixed speed concept, the wind turbine produces electrical power when the rotor blades rotate at a certain speed, which is exactly the generator rated speed. Such a concept dispenses a complex power control, reducing costs and maintenance. However, the efficiency of the rotor blades is optimal only at one wind speed, causing high fluctuation of active and reactive power and thus grid flickering [5]. Besides, this fixed speed wind turbines may suffer with high wind gusts, given that the torque pulsations cause high mechanical stress in the drive trains.

To overcome the fixed speed constraints, the limited variable speed concept was developed. The most used concept for implementing limited variable speed is the OptiSlip. The difference between the rotation speed and the synchronous speed, in per cent, is called slip. Since the slip is a function of the rotor resistance, with external resistors - controlled by an electronic power converter – it is possible to vary the rotor resistance and so the slip [5]. By controlling the rotor resistance, a variation of 10% in synchronous speed can be achieved. This concept increases the performance of wind turbines in 2-3% [6] and the power output with a small power electronic converter. Once the power output quality is optimized, the flicker effects are minimized.

To enhance the WTG performance to its maximum, the generator must produce electrical power at a wide range of rotor blade speed. The variable speed technique makes use of power electronic devices containing switches coupled to the rotor, stator or both, in order to control the frequency and voltage injected into the grid [7]. The advantages of this concept are: better performance, higher power output quality and reduced mechanical stress in the drive trains (since blades can store kinetic energy from the gusts with variable speed generators). The drawback in this case are the higher costs of the more complex electronic devices, however, in the last years the component prices have become increasingly competitive.

B. Power Control

The speed power control system (Figure 3b) is responsible for regulating the power input, and therefore the output power. The first and simplest attempt to control the power input was known as passive stall control. The blades were aerodynamically designed to promote the boundary layer detachment at a certain speed (stall), as shown in the Figure 2b. The power output should increase and remain constant to its maximum with rising wind speed. However, this ideal behavior was not confirmed in real cases. Passive stall controlled turbines had shown power output instabilities once the blades were stalled, the flow separation leads to higher turbulence and blade vibration [8]. Due to these disadvantages passive stall control is rarely seen in modern turbines.

Nowadays, the power control is made by mechanically changing the blades aerodynamic angle of attack. To achieve this mechanical effect there are two possibilities: the conventional approach in which the angle will be gradually reduced in order to decrease the input power (if increasing the angle of attack, the energy input is increased), this method is known as pitch control and is widely used in the current wind industry; The other possibility of control is to change the blade angle to a higher angle of attack to the so-called critical angle of attack, at which point the air flow separates from the surface of the rotor blades (stall), known as active stall. When pitch control is used the mechanical actuators, responsible for rotating the blade through its longitudinal axes, can be electric or hydraulic.

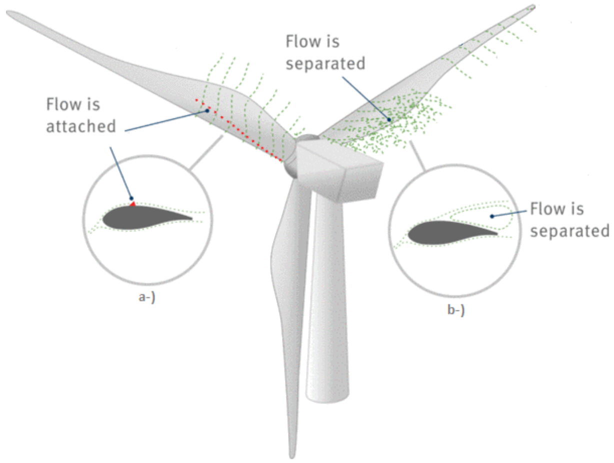

Fig. 2: How aerodynamic control works (passive stall and active stall), a-) operational position and b-) stalled blades [9].

C. Drive Train

The need to convert the low angular velocities generated in the rotor into high rotational speeds, required by generators, was one of the main problems in the first wind turbines (Figure 3c). To get around this issue, high-performance gearboxes, able to provide transmission ratios of 1:100, were coupled to the main shaft [10]. Wind turbines require multiple stages in order to achieve the necessary rotational speeds to drive the electric generator. The more traditional models applied are the planetary arrangements, they commonly are: three planetaries stages; two planetaries and one parallel; and one planetary and two parallels.

Gearboxes are not the only solution, generators capable of working at low rotational speed are also available, the so-called direct driven generators. The direct-drive configuration came mostly from the interest in increasing the reliability and reduces maintenance on wind turbines. It is important to emphasize that these advances were only made possible by the improvement efforts in frequency converters and electric generators that started bearing higher torques.

D. Generator type

The electric generator (Figure 3d) is one of the items that more evolved in the history of wind turbines, in terms of configuration and technology used. In this context, it is possible to arrange the generators into two major groups: synchronous and asynchronous (induction). Both of them make use of Electromagnetic Induction Law for production of electric current, what sets them apart is precisely how the magnetic field is generated and the mechanism by which the flow field varies through the driving elements.

Synchronous

The synchronous generator operates at a constant speed (synchronous speed), dependent on the network frequency, regardless of the applied torque on the generator. In this case, the rotor produces a constant exciter field, which rotates at synchronous speed with the rotor. It induces in the stator an alternating current, which will then be delivered to the grid [11]. The two principals synchronous generators used in wind turbines are presented below.

- PMSG – Permanent Magnet Synchronous Generator: in this generator the magnetic field is produced through permanent magnets mounted on the rotor.
- EESG – Electrically Excited Synchronous Generator: the rotor with field winding is electrically excited by a DC current.

Asynchronous

The operating mechanism in the asynchronous generator, also known as induction generator, is the relative movement between the rotor and the stator field (slip). The induction generator produces electricity when the rotor rotates faster than synchronous speed (established by the network frequency). In this generator, the stator is powered by the network (or capacitor bank) to produce the rotating field, this varying magnetic field induces a current on the rotor (and an associated magnetic field). The induced magnetic field forces the rotor to rotate, producing a relative movement between the rotor and the stator field. When the rotor is forced to rotate faster than the stator magnetic field, this induces a current back to the network [11]. There are three main wind turbine asynchronous generators:

- SCIG – Squirrel Cage Induction Generator: the rotor is a metallic cylinder containing longitudinal conductive bars, normally made by copper or aluminium.
- WRIG – Wound Rotor Induction Generator: the rotor accommodates insulated windings that will form a resistance in series with the rotor to decrease the start current.
- DFIG – Double Fed Induction Generator: in this case both the rotor and stator are connected to the grid through converters, allowing partially power conversion, around 30% of full power.

The classification made by the Project Upwind will be used to categorize the wind turbine generators in this study. The Figure 3 summarizes what has been presented so far.

III. METHOD OF ANALYSIS

The first step to catalogue the technology applied in Brazilian's wind farms was gathering information about the wind turbines used in the power plants. To do so, the online database SIGEL (Geo-referenced Information System of the Electric Sector – Free Translation) was consulted. The website is an online data bank held by ANEEL (Brazilian Electricity Regulatory Agency) containing official information about all the generation power plants. In the SIGEL portal, it is possible to access the SIGEL-EOL (Eolic-SIGEL) [12], a specific database for wind power plants, where general information about the wind farms as well as individual data from wind turbines is available.

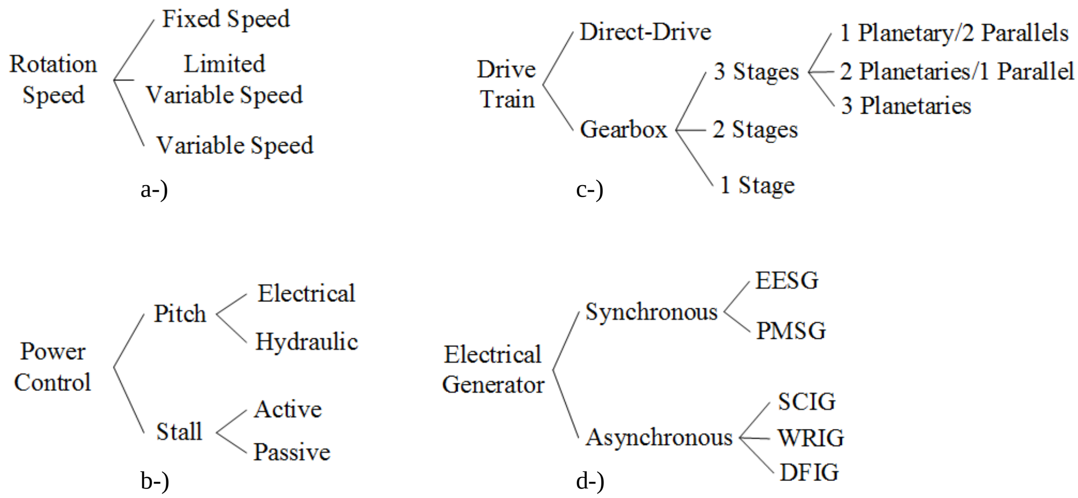

Fig. 3: Upwind classification [Author]

This study obtained data from wind parks in operation and under construction in Brazil. Wind farms that won energy auctions or have the order for grants were not considered, given that Brazilian regulation allows, in these project stages, modifications in the design and even turbine substitution, when technical reasons are presented.

The next step was to confront the data from SIGEL and the turbine manufacturer brochures [13-40] to match the information. Once SIGEL provides hub height, rotor diameter and output power for each WTG in a wind farm, it was possible to identify the turbine model used. After that, a validation was made.

SIGEL has records of 367 wind farms in operation and under construction in Brazil (until October, 2015), after the data validation, 53 wind farms were excluded from the study. The reasons for considering these wind farms unavailable were:

- 25 wind power plants have "no data" in their description, and without the information provided from SIGEL it is not possible to identify the turbine model;
- 28 wind farms (23 in operation and 5 under construction) were assumed to use WTG from the manufacturer Impsa. This Argentinian company is no more operating in Brazil and the contracts are being reviewed. Unfortunately, SIGEL does not contain new information about the turbines replaced. To not add uncertainties, all wind parks with Impsa turbines were discarded from the records.

Once the data were validated, 314 wind farms with 4,154 wind turbines were considered available to analysis.

IV. RESULTS

Among the WTGs analyzed, 9 different manufacturers and 31 turbine models were documented, Table 1 shows these results.

Taking the number of WTGs per manufacturers in operation and under construction in Brazil, it is possible to analyze the market leader.

Table 1: Turbine manufacturers and models catalogued in the study [Author]

Manufacturer	Turbine model	Market Share
GE	GE 1.5 XLE	27%
	GE 1.6-100	
	GE 1.6-82.5	
	GE 1.68-82.5	
	GE 1.7-100	
	GE 1.7-103	
	GE 1.85-82.5	
Gamesa	Gamesa G87	25%
	Gamesa G90	
	Gamesa G97	
	Gamesa G114	
Enercon	Enercon E-40	17%
	Enercon E-44	
	Enercon E-48	
	Enercon E-66	
	Enercon E-82	
	Enercon E-92	
Alstom	Alstom ECO 100	11%
	Alstom ECO 110	
	Alstom ECO 122	
	Alstom ECO 86	
Suzlon	Suzlon S88	9%
	Suzlon S95	
Vestas	Vestas V100	6%
	Vestas V112	
	Vestas V90	
	Vestas V82	
Siemens	Siemens SWT 2.3-108	3%
	Siemens SWT 2.3-101	
Acciona	Acciona AW116	1%
WEG	WEG AGW 110	1%

The brochures from the 31 turbine types were studied to allow organizing the WTGs by the Upwind classification. All the 4,154 (100%) turbines make use of the variable speed concept, none of them presented fixed or limited variable speed.

Considering power control method, the pitch system was prevailing, see Figure 4. Within the pitch category approximately two thirds of the actuators were electrical devices. Passive stall concept was not found among the WTGs, confirming the idea that this approach is obsolete.

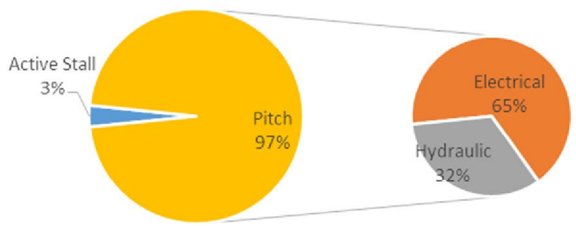

Fig. 4: Power control systems [Author]

The Figure 5 shows the drive train types distribution. The presence of gearboxes still dominates the market, however direct driven machines represent nearly one third of this total. Expanding the gearbox sets, all turbines driven by gearboxes work with 3 stages, mostly 3 planetary stages, but concepts with planetaries and parallels stages are also seen.

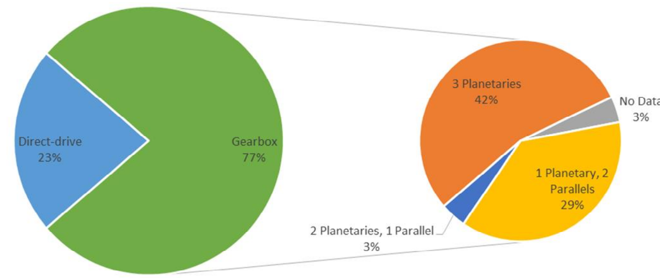

Fig. 5: Drive trains solutions [Author]

The generator types were also assessed. Analyzing the Figure 6, it is possible to notice that the asynchronous technology holds 64% of all data; in fact just the Doubly Fed Induction Generator represents more than half of the records.

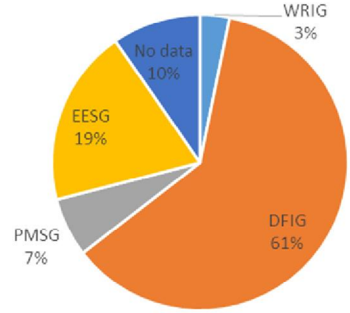

Fig. 6: Generator types [Author]

Table 2: Possible configuration for Brazilian existent WTGs [Author]

Rotation Speed	Power Control	Drive Train	Electrical Generator	Total
Variable Speed	Pitch	3 Stages Gearbox	DFIG	73.8 %
			PMSG	0.2 %
			WRIG	2.4 %
			No Data	3.4 %
		Direct	EESG	16.8 %
			PMSG	0.6 %
	Active Stall	3 Stage Gearbox	No Data	2.9 %

After the data sorting, it was viable to summarize all the existent architecture of wind turbine devices in Brazil. The Table 2 contains this information, the last column shows the percentage of the 4,154 WTGs using each architecture.

IV. CONCLUSIONS

This paper analyzed data from 314 wind farms, summing 4,154 WTGs, this amount being distributed into 31 different turbine models from 9 manufacturers. GE is the leading company in the Brazilian market, representing 27% of the total installed market. Right behind GE, with 25% of total is Gamesa and Enercon with 17%.

The 4,154 wind turbines studied presented 7 distinct architectures (Table 2), the combination variable speed, pitch control, 3 stage gearbox and generator DFIG detains approximately 74% from total, which means 3,064 WTGs. This information has two main purposes: firstly, it shows the Brazilian technological level is convergent in comparison to the rest of the world [5,10] and presents a trend for wind turbines, demonstrating the most consolidated technology. In 2007 the Upwind Project [5] had already presented similar worldwide results, where at that time the DFIG generator combined with 3 stage gearbox, pitch control and variable speed was dominant. It is remarkable that in the past 8 years the wind turbine core has not changed, which shows that this technology has achieved a high maturity level. Secondly, this information is vital for decision-making in maintenance. Once it is possible to know which architecture is dominant, its main components and its maturity level, the players in this area can establish strategies to attend specific demands and plan the maintenance activities especially for Brazil.

SIGEL, the official Brazilian government online database, was the data source for this study. During the data validation from the SIGEL-EOL archive, some disagreements were found. Sometimes the inputs for hub height, rotor diameter or power output were questionable. When registered information in the database was considered questionable, other sources were surveyed. Despite these cases, SIGEL-Data were used as the basis of this work, the overall quality of the information registered in SIGEL is good, matching the manufacturers brochures, and above all, it is the official database of the government.

Along with SIGEL, the manufacturers catalogues supplied the information for this study. The Siemens SWT 2.3-103, SWT 2.3-108 and Vestas V82 brochures described the generators as "asynchronous", no further information was given. In both cases, it was not possible to classify the generator type, the data was sorted as "No Data" in the charts. In the Vestas V82 General Specification [13] technical information about the transformer was found, the transformer allocated in the tower contains just one secondary voltage output, this makes it impossible the use of the DFIG in the turbine (DFIG requires minimum two voltage output). The description given by the Windindustrie in Deutschland website says that this model uses a "asynchronous with switchable poles generator" [14]. Compiling this information with some experience in the field, the authors believe that this generator is SCIG. For the Siemens models no other helpful data was found and no answer from the manufacturer was obtained when asked about it.

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REFERENCES

[1] BP Statistical Review of World Energy, Available online: <http://www.bp.com/content/dam/bp/pdf/energy-economics/statistical-review-2015/bp-statistical-review-of-world-energy-2015-full-report.pdf > (accessed on 8th November, 2015).

[2] ANEEL, Available online: http://www.aneel.gov.br/arquivos/pdf/atlas_par1_cap2.pdf (accessed on 7th November, 2015).

[3] Brazilian Ministry of Mines and Energy, Available online:

<http://www.mme.gov.br/documents/10584/1139093/Ranking+Mundial+de+Energia+2015.pdf/f088fe16-e0d2-49ad-b72c-8376f749c661> (accessed on 10th November, 2015).

[4] Abeeólica, Available online: < http://www.portalabeeolica.org.br/> (accessed on 3th November, 2015).

[5] Project UPWIND, Concept Report on Generator Topologies, Mechanical and Electromagnetic Optimization, 2007.

[6] Danish Wind Industry Association, Available online: <http://ele.aut.ac.ir/~wind/en/tour/wtrb/async.htm#slip> (accessed on 10th November, 2015).

[7] Burton, Tony; Sharpe, David; Jenkins, Nick; Bossanyi, Ervin. Wind Energy Handbook, Chichester, England, John Wiley & Sons Ltd, 2011.

[8] Carlin, P. W.; Laxson, A. S.; Muljadi, E. B. The History and State of the Art of Variable Speed wind Turbine Technology, Wind Energy Magazine, Vol. 6 - Issue 2, 2003.

[9] Smart Blade, Available online: <http://ele.aut.ac.ir/~wind/en/tour/wtrb/async.htm#slip> (accessed on 23th November, 2015).

[10] Hau, Erich, Wind Turbines: Fundamentals, Technologies, Application, Economics, 2nd Edition, Springer, 2006.

[11] Kosow, Irving L., Máquinas Elétricas e Transformadores, 4th Edition, Editora Globo, Rio de Janeiro, 1982.

[12] Sigel - Geo-referenced Information System of the Electric Sector – Free Translation, Available online:

< http://sigel.aneel.gov.br/eol/sigel.html> (accessed on October, 2015).

[13] Vestas, General Specification V82 – 1.65 MW MK II NM82/1650 Vers. 2, Denmark 2005.

[14] Windindustrie in Deutschland, Available online: http://www.windindustrie-in-deutschland.de/windenergieanlagen/vestas-v82-15-mw-neg-micon-nm-821500/151/ (accessed on 30th November, 2015).

[15] Acciona Windpower, Acciona AW-3000 Wind Turbine Brochure, Spain.

[16] Alstom, ECO 80 Platform – ECO 80 e ECO 86 Wind Turbines Brochure, Spain 2011.

[17] Alstom, ECO 100 Platform & PowerOF3™ - ECO 100, ECO 110, ECO 122 Wind Turbines Brochure, Spain 2014.

[18] Enercon, Enercon Product Overview – E-44, E-48, E-53, E-70, E-82 E2, E-82 E4, E-92, E-101, E-101 E2, E-115, E-126 EP4, E-126, Germany 2015.

[19] Enercon, Enercon Wind Turbines – Technology & Service E-53, E-70, E-82, Germany.

[20] European Wind Energy Association (EWEA), Wind Energy – The Facts. Earthscan, England, 2009.

[21] Gamesa, Gamesa 2.0 MW Technological Evolution – G80, G87, G90, G97 and G114, Spain 2012.

[22] Gamesa, New Gamesa G9X-2.0 MW Brochure, Germany 2010.

[23] Gamesa, Gamesa G114 – 2.0 MW Data Sheet, Spain 2012.

[24] GE Power & Water Renewable Energy, Introducing GE's 1.6 – 100, Germany 2009.

[25] GE Power & Water Renewable Energy, GE's 1.7 – 100, 2015.

[26] GE Power & Water Renewable Energy, GE's 1.6 – 82.5, 2011.

[27] Siemens, The new standard for moderate wind conditions – Siemens SWT 2.3 – 101, Germany 2009.

[28] Siemens, The new productivity benchmark – Siemens SWT 2.3 – 108, Germany 2011.

[29] Suzlon, S88 – 2.1MW Technical Overview, China.

[30] Suzlon, S9X – S95 and S97 Brochure, China.

[31] Suzlon, S95 – 2.1 MW Wind Turbine Generator Technical Specification, Germany 2012.

[32] The Wind Power – Wind Energy Market Intelligence – GE, Available online:

<http://www.thewindpower.net/manufacturer_en_5_ge-energy.php> (accessed on 24th November, 2015).

[33] The Wind Power – Wind Energy Market Intelligence – Enercon, Available online:

<http://www.thewindpower.net/manufacturer_en_3_enercon.php > (accessed on 24th November, 2015).

[34] The Wind Power – Wind Energy Market Intelligence – Siemens, Available online:

<http://www.thewindpower.net/manufacturer_en_10_siemens.php> (accessed on 24th November, 2015).

[35] Vestas, V90 – 1.8 MW Brochure, USA.

[36] Vestas, V100 – 1.8 MW Brochure, Denmark 2010.

[37] Vestas, V112 – 3.0 MW Brochure, Denmark.

[38] Vestas, 3 MW – V112 – 3.0 MW and V126 – 3.0 MW Onshore, Denmark 2012.

[39] Vestas, General Specification V100 – 2.0 MW VCSS 60 Hz, Denmark 2012.

[40] WEG, Aerogerador AGW 110 /2.1, Brazil 2015.

[41] Blaabjerg, F; Christensen, Eskildsen, K.; H. C.; Hansen, L. H.; Lindhard, U.; Madsen, P. H. Generators and Power Electronics Technology for Wind Turbines, IECON'01: The 27th Annual Conference of the IEEE Industrial Electronics Society, 2001.

[42] Blaabjerg, F.; Chen, Z., Guerrero, J. M. A review of the State of the Art of Power Electronics of Wind Turbines, IEEE Transactions on Power Electronics, 2009.

[43] Butterfield, C.P.; Muljadi, E. Pitch-Controlled Variable-Speed Wind Turbine Generation, IEEE Industry Applications Society Annual Meeting, 1999