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A COMPARATIVE STUDY ON VARIOUS STRATEGIES AND MODELING OF WIND ENERGY CONVERSION SYSTEMS

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A Comparative Study on Various Strategies and Modeling of Wind Energy Conversion Systems

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Abstract – Wind power production has been under the main focus for the past decade in power production and tremendous amount of research work is going on renewable energy, specifically on wind power extraction. Wind power provides an ecofriendly power generation and helps to meet the national energy demand when there is a diminishing trend in terms of non-renewable resources. This paper reviews the modeling of Wind Energy Conversion Systems (WECS), control strategies of controllers and various Maximum Power Point Tracking (MPPT) technologies that are being proposed for efficient production of wind energy from the available resource.

Wind power capacity has experienced tremendous growth in the past decade, thanks to wind power's environmental benefits, technological advance, and government incentives. This paper presents the recent developments in wind energy conversion systems, and their social and environmental benefits.

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INTRODUCTION

A wind energy conversion system consisting of a wind turbine, tower, and associated control or conversion electronics, which has a rated capacity of not more than 10 KW and which is intended to primarily reduce on-site consumption of utility power. A system is considered a residential wind energy system only if it supplies electrical power solely for on-site use, except that when a parcel on which the system is installed also receives electrical power supplied by a utility company, excess electrical power generated and not presently needed for on-site use may be used by the utility company.

Mankind has used the wind as a source of energy for several thousands of years. Together with hydro power it was the most utilized energy source for centuries. With the growing development of electrical engineering and demand for electricity, by the end of the 19th century the first experiments were carried out on usage of windmills for generating electricity.

Since then the wind power has developed dramatically, especially during last 30 years. In 1999, more than 10 000 MW of wind power capacity was installed worldwide. This year was also the first in which the world has installed more new wind power capacity than the nuclear capacity. The perspectives for wind energy are very bright: in November 1997 the European Commission published a White Paper setting out a Community Strategy and Action Plan for renewable energy.

The European leaders signed up in March 2007 to a binding EU-wide target to source 20% of their energy needs from renewable energy sources, including biomass, hydro, solar and wind power, by 2020. To meet this objective EU leaders agreed on a new directive on promoting renewable energies, which sets individual targets for each member state. In 1999, the United States Department of Energy announced the "Wind Powering America" initiative which sets a goal of 80 000 MW of wind power by the year 2020 being installed countrywide. Such an amount of wind power corresponds to approximately 5% of the U.S. electricity consumption.

The wind power industry is one of the fastest expanding industries as a result of the rapid growth of installed capacity. The wind power over the last 20-30 years has become a competitive technology for clean energy production. In the coming years it will provide two digit percentages in many countries electricity supply. There is no reason why wind power should not become as important to the world's future energy supply as nuclear power is today. The question that has to be asked is how wind power will affect the whole electrical grid, in particular the distribution network to which it is usually connected to. The role of the distribution network is to the interconnect the generation and transmission systems on one side and load centres on the second side. Networks with such an arrangement are described as passive networks. However, the integration of renewable energy sources into the distribution networks transforms them from being passive to active networks.

Wind is an indirect solar energy source. Its characteristics can be summarized as follows.

• It is environmentally clean source of energy.

• It is a dilute source of energy.

• It is perennially available.

• Its availability is unpredictable.

• Data are available about its availability pattern around the day for different months of the year.

Wind Machine : The machine that converts kinetic energy in the wind into usable form of mechanical energy (usually shaft power). Wind machines are typically used for mechanical applications like water pumping, grinding, woodcutting, or for AC or DC power generation in grid connected or isolated mode. Details of different types of wind machines are given in Table 1.

Type of machine	No. of Blades	Axis of rotation	Rotor position wrt tower	Starting torque	Rotor speed	Power
Propeller machine	2 or 3	Horizontal	Upwind or downwind	Moderate	Fast	Electrical
Multi-bladed machine	6 to 24	Horizontal	Upwind	High	Slow	Mechanical
Savonius machine	2 or 3	Vertical	-	Very high	Slow	Mechanical
Darrius machine	2 or 3	Vertical	-	Very low	Fast	Electrical

Table 1 : Different types of Wind Machines

Study of wind machines is called Molinology. It cuts across various fields including Meteorology, Aerodynamics, Machine Design, Structural Design, Materials Technology, Power Engineering, Reliability Engineering, Instrumentation and Controls Engineering.

Three bladed propeller deign has evolved as the commercial Wind Energy Conversion System today. Designs of 225 kW, 450 kW, 650 kW or 1 MW are installed commercially in India. Design and performance details of a typical 1 MW unit installed by Suzlon are given in Table 2.

1.	Rotor diameter	61 m
2.	Blade length	30 m
3.	Rotor speeds	13 RPM / 22 RPM
4.	Tower height	60 m
5.	Wind speed range	3 m/s to 25 m/s
6.	Power control	Active blade pitching
7.	Type of generator	Induction generator
8.	Generator Speed	1000 rpm / 1500 rpm
9.	Generator rating	1 MW
10.	Annual Energy Output	1.8 to 2 GWh
11.	Machine cost	About Rs. 4.2 Crores

Table 2 : Details of a typical 1 MW Wind Energy Conversion System

The wind energy conversion system (WECS) includes wind turbines, generators, control system, interconnection apparatus. Wind Turbines are mainly classified into horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT). Modern wind turbines use HAWT with two or three blades and operate either downwind or upwind configuration. This HAWT can be designed for a constant speed application or for the variable speed operation. Among these two types variable speed wind turbine has high efficiency with reduced mechanical stress and less noise. Variable speed turbines produce more power than constant speed type, comparatively, but it needs sophisticated power converters, control equipments to provide fixed frequency and constant power factor.

The generators used for the wind energy conversion system mostly of either doubly fed induction generator (DFIG) or permanent magnet synchronous generator (PMSG) type. DFIG have windings on both stationary and rotating parts, where both windings transfer significant power between shaft and grid. In DFIG the converters have to process only about 25-30 percent of total generated power (rotor power connected to grid through converter) and the rest being fed to grid directly from stator. Whereas, converter used in PMSG has to process 100 percent power generated, where 100 percent refers to the standard WECS equipment with three stage gear box in DFIG. Majority of wind turbine manufacturers utilize DFIG for their WECS due to the advantage in terms of cost, weight and size. But the reliability associated with gearbox, the slip rings and brushes in DFIG is unsuitable for certain applications. PMSG does not need a gear box and hence, it has high efficiency with less maintenance. The PMSG drives achieve very high torque at low speeds with less noise and require no external excitation. In the present trend WECS with multibrid concept is interesting and offers the same advantage for large systems in future. Multibrid is a technology where generator, gearbox, main shaft and shaft bearing are all integrated within a common housing. This concept allows reduce in weight and size of generators combined with the gear box technology. The generators with multibrid concept become cheaper and more reliable than that of the standard one, but it loses its efficiency.

To achieve high efficient energy conversion on these drives different control strategies can be implemented like direct torque control (DTC), field oriented control (FOC). The FOC using PI controller has linear regulation and the tuning becomes easier. The wind turbine electrical and mechanical parts are mostly linear and modeling will be easier. The blade aerodynamics of the wind turbine is a nonlinear one and hence the overall system model will become nonlinear. The wind energy conversion system which will be modeled may not be optimal for extracting maximum energy from the resource and hence various optimization techniques are used to achieve the goal.

TYPES OF WIND ENERGY SYSTEMS

A. Small Wind Energy Conversion System - (SWECS) - A wind energy conversion system which has a rated capacity of up to Twenty-Five (25) kilowatts and which is incidental and subordinated to another use of the same parcel. A system is considered a small wind energy system only if it supplies electrical power for site use, except that when a parcel on which the system is installed also received electrical power supplied by a utility company, access electrical power generated and not presently needed for onsite use may be sold back to the utility company. (25 Kilowatt limit approved by the Gage County Planning Commission to increase to a maximum of 100 Kilowatts with Nebraska State Legislature authorization by future amendment)

B. Commercial Wind Energy Conversion System - (CWECS) A wind energy conversion system under common or aggregated ownership or operating control that includes substations, MET towers, cables/wires and other building accessories, who's main purpose is to supply electricity to off-site customers.

Commercial Wind Energy Conversion Systems may be included as an aggregated project. Such as those projects that are developed and operated in a coordinated fashion, but which have multiple entities separately owning one or more of the CWECS within a larger project. Associated infrastructure such as power lines and transformers that service the facility may be owned by a separate entity, but are also part of the aggregated project. All individual wind turbine towers of an aggregated project shall be in conformance with Section 6.55 (A) items one through 15.

POWER GENERATION SYSTEM OF WECS

The electrical power generation structure contains both electromagnetic and electrical subsystems. Besides the electrical generator and power electronics converter it generally contains an electrical transformer to ensure the grid voltage compatibility. However, its configuration depends on the electrical machine type and on its grid interface (Heier 2006).

Fixed-speed WECS : Fixed-speed WECS operate at constant speed. That means that, regardless of the wind speed, the wind turbine rotor speed is fixed and determined by the grid frequency. Fixed-speed WECS are typically equipped with squirrel-cage induction generators (SCIG), soft starter and capacitor bank and they are connected directly to the grid, as shown in Figure 1. This WECS configuration is also known as the "*Danish concept*" because it was developed and widely used in Denmark (Hansen and Hansen 2007).

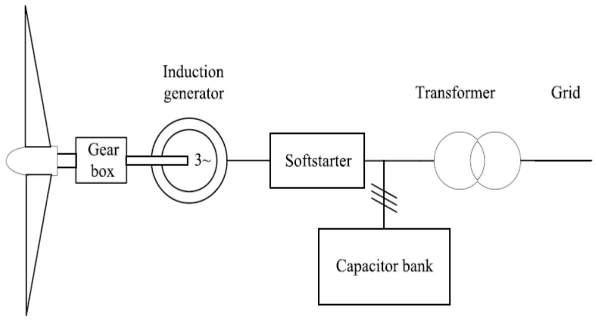

Figure 1. General structure of a fixed-speed WECS

Initially, the induction machine is connected in motoring regime such that it generates electromagnetic torque in the same direction as the wind torque. In steady-state, the rotational speed exceeds the synchronous speed and the electromagnetic torque is negative. This corresponds to the squirrel-cage induction machine operation in generation mode (or in the over-synchronous regime –Bose 2001). As it is directly connected to the grid, the SCIG works on its natural mechanical characteristic having an accentuated slope (corresponding to a small slip) given by the rotor resistance. Therefore, the SCIG rotational speed is very close to the synchronous speed imposed by the grid frequency. Furthermore, the wind velocity variations will induce only small variations in the generator speed.

As the power varies proportionally with the wind speed cubed, the associated electromagnetic variations are important. SCIG are preferred because they are mechanically simple, have high efficiency and low maintenance cost. Furthermore, they are very robust and stable. One of the major drawbacks of the SCIG is the fact that there is a unique relation between active power, reactive power, terminal voltage and rotor speed (Ackermann 2005).

That means that an increase in the active power production is possible only with an increase in the reactive power consumption, leading to a relatively low full-load power factor. In order to limit the reactive power absorption from the grid, SCIG based WECS are equipped with capacitor banks. The soft starter's role is to smooth the inrush currents during the grid connection (Iov 2003).

SCIG-based WECS are designed to achieve maximum power efficiency at a unique wind speed. In order to increase the power efficiency, the generator of some fixed-speed WECS has two winding sets, and thus two speeds. The first set is used at low wind speed (typically eight poles) and the other at medium and large wind speeds (typically four to six poles).

Fixed-speed WECS have the advantage of being simple, robust and reliable, with simple and inexpensive electric systems and well proven operation. On the other hand, due to the fixed-speed operation, the mechanical stress is important. All fluctuations in wind speed are transmitted into the mechanical torque and further, as electrical fluctuations, into the grid. Furthermore, fixed-speed WECS have very limited controllability (in terms of rotational speed), since the rotor speed is fixed, almost constant, stuck to the grid frequency.

An evolution of the fixed-speed SCIG-based WECS are the limited variablespeed WECS. They are equipped with a wound-rotor induction generator (WRIG) with variable external rotor resistance; see Figure 2. The unique feature of this WECS is that it has a variable additional rotor resistance, controlled by power electronics. Thus, the total (internal plus external) rotor resistance is adjustable, further controlling the slip of the generator and therefore the slope of the mechanical characteristic. Obviously, the range of the dynamic speed control is determined by how big the additional resistance is. Usually the control range is up to 10% over the synchronous speed.

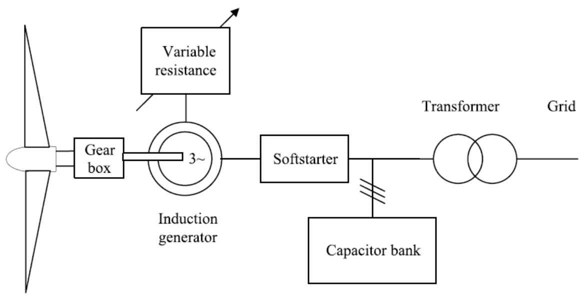

Figure 2. General structure of a limited variable-speed WECS

Variable-speed WECS : Variable-speed wind turbines are currently the most used WECS. The variablespeed operation is possible due to the power electronic converters interface, allowing a full (or partial) decoupling from the grid. The doubly-fed-induction-generator (DFIG)-based WECS (Figure 3), also known as improved variable-speed WECS, is presently the most used by the wind turbine industry.

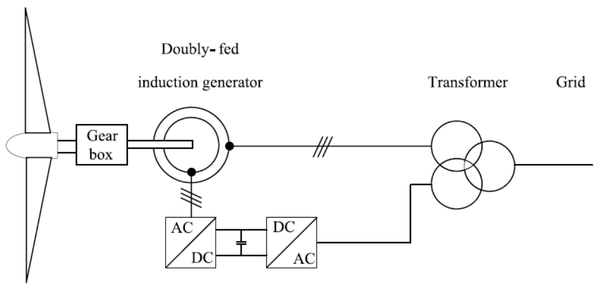

Figure 3. General structure of an improved variable-speed WECS

The DFIG is a WRIG with the stator windings connected directly to the three phase, constant-frequency grid and the rotor windings connected to a back-to-back (AC–AC) voltage source converter (Akhmatov 2003; Ackermann 2005). Thus, the term “doubly-fed” comes from the fact that the stator voltage is applied from the grid and the rotor voltage is impressed by the power converter. This system allows variable-speed operation over a large, but still restricted, range, with the generator behavior being governed by the power electronics converter and its controllers.

CONTROL STRATEGIES

DFIG-WECS control : Controller is designed to adjust the turbine speed to extract the maximum power from wind source. Usually PI controller is designed for this purpose according to the estimated parameters either offline or online and the observed disturbance torque is feed forward to increase system robustness. But this type of classical controller is not enough to serve the purpose efficiently. Hence various improvements are made for the controller to achieve the requirement as stated below.

The general structure of control block diagram in the DFIG-WECS having two levels of control is shown in Fig. 4. The highest level is WECS optimization which is explained in section IV. The lower level control being the electrical control system, i.e. torque and reactive power control. The rotor side controller (RSC) and grid side controller (GSC) are employed to serve the electrical control system. To compromise the dynamics of variable speed WECS Poitiers et al.

has implemented a two degree freedom Regulation-Solution-Tracking (R-S-T) controller, which is a widely preferred digital controller and Linear Quadratic Gaussian (LQG) controller with state feedback. For the ease of implementation of controller tuning the LQG controller is preferred than R-S-T controller.

To reduce the output power fluctuations of DFIG with a flywheel energy storage system (FESS) Jerbi et al. has proposed a fuzzy supervisor using sugeno fuzzy model based on two parameters flywheel speed and wind power accessibility so as to ensure a smooth reactive power to the load supplied by the wind generator. This ensures to reduce the voltage fluctuations. For the variable speed WECS has proposed a method which will combine fuzzy neural network and sliding mode speed observer. This technique allows faster

convergence to a simple linear dynamic behavior, even in presence of parameter changes and uncertainties which are the major problems expected from variable speed drive control. As most of the controllers depends on torque control M.

Pucci proposes a method based on speed control of the machine. This is achieved through total least squares (TLS) EXIN full order observer which turns as an intelligent sensor less technique for wind generation control.

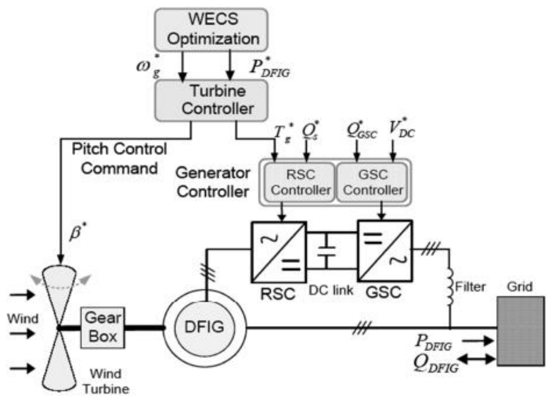

Fig. 4. Control Block Diagram of DFIG Based WECS

There are other types of controllers using PID for controlling the WECS with optimal power output. Muhando et.al proposes a self-tuning regulator by incorporating recursive least square algorithm to predict the process parameters and update the states. This regulator gives more efficient compared to classical PID controller. To achieve optimal power, adaptive fuzzy PID control strategies are proposed and proved the performance is improved than that of conventional one.

PMSG-WECS control : Figure 5 shows the block diagram of PMSG based WECS with two stages as optimization and electrical controllers. The various techniques are discussed as below.

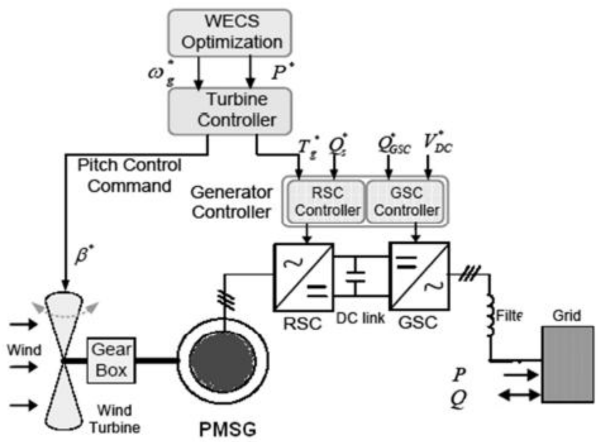

Fig. 5. Control Block Diagram of PMSG Based WECS

Jordi Zaragoza et al. discusses the control of PMSG based WECS using field oriented control (FOC) for controlling speed regulation and generating current. A PI controller is used for this purpose and the tuning parameters are determined through zero-pole cancellation (ZPC) strategy. Jemaa Brahmi et.al compares three control methods for PMSG based WECS. In the first model MRAS observer is used to estimate the parameters of the controller by comparing output of reference model and adaptive model. Secondly artificial neural network (ANN) based observer were trained to produce desired output correction to the estimated speed. And lastly, sliding mode observer (SMO) based control is discussed. Among these three techniques SMO and ANN observer gives good results when static resistance varies and chattering phenomenon is observed with SMO. The static resistance causes a static error in case of MRAS observer. The SMO is more robust than the other two methods.

CONTROL OBJECTIVES

Control plays an ever increasing role in modern WECS. There are numerous research articles dedicated to WECS control, all of them having starting from the idea that control can and does significantly improve all aspects of WECS. In any process, control has two main objectives: protection and optimization of operation. Furthermore, when applied to WECS, control becomes more important, in all aspects, as the main characteristic of WECS is that they have to cope with the highly variable, intermittent and unpredictable nature of the wind.

To this end, as previously mentioned, all WECS have some sort of power control. The passive-stall wind turbines manage to limit the aerodynamic power, for protection reasons, without any active controllers. This approach is simple and offers hardware robustness, but can lead to unacceptable levels of mechanical loads (Burton *et al.* 2001). Thus, control in that sense has as its only objective the protection of wind turbines.

Active stall implies that WECS are equipped with several additional hardware components: electromechanical or hydraulic actuators used to move the blades (or parts of them), sensors and controllers. All of these add complexity and increase the operation and maintenance costs but they also allow one to extend the control objectives to increase the power capture, thus optimizing the WECS operation.

Fixed-speed WECS, with either passive or active stall, dominated the wind power industry for a long time. Their main drawback is their rigidity, as the fixed generator speed does not offer any control flexibility. This disappears with the use of DFIG-based WECS and, later, with the use of full scale power converter WECS. Variable-speed operation became possible by incorporating power electronics converters.

Test Facilities for Wind Energy Conversion Systems

To meet the increasing demands for wind power applications, tremendous R&D effort is needed to develop safe, reliable and cost effective technologies for wind energy conversion. Supported by the Canadian Foundation of Innovation, Atlantic Wind Test Site Inc., Natural Resources Canada and Université de Moncton, the University of New Brunswick has established a unique R&D and test facility for wind and solar energy conversion systems. It is located close to the 5 MW wind plant at the Atlantic Wind Test Site in PEI. As illustrated in Figure 6, this facility includes wind and solar energy conversion components of various structures, such as high speed generators (fixed or variable speed, up to100 kW), direct drive variable speed generators (wound field and permanent magnet synchronous generators, up to 50 kW), a three-phase inverter (100 kW), single-phase inverters (grid-connected or autonomous, up to 25 kW), and storage batteries.

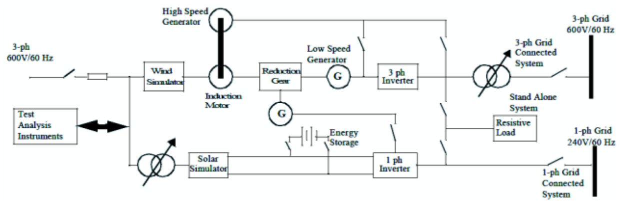

Figure 6: Single Line Diagram for UNB test facility for wind and solar energy conversion systems.

In particular, the wind turbine simulator provides researchers with a controlled test environment for wind turbine generators, inverters and system operations, resulting in improved research productivity. The facility also provides an infrastructure for the development of advanced control methodologies to improve aspects of system performance such as maximum power extraction from wind or solar sources. The wind turbine simulator emulates the output characteristics of a wind turbine at various wind speeds using an adjustable speed induction drive system. For the turbine generator and power electronic converters, the induction motor drive behaves the same as a variable speed wind turbine.

CONCLUSION

An attempt has been made in this paper to discuss the most-recent research trends in the field of wind energy conversion systems. From the study, it can be concluded that in case of generators and converters, most system adopts DFIG with back-to-back converter due to their less weight and cost. However, for the large capacity wind turbines where efficiency and reliability plays a major role has been utilizing PMSG's even though it has more weight and increased installation cost. Moreover, WECS based on the multibrid concept, will become more attractive alternative technology in the future.

Regarding the controllers for the WECS, is still the most important and challenging topic of research as there are various controllers had been proposed by various researchers has been discussed in this paper. As there are lot of ongoing developments takes place at various stages of WECS, it is noted that the most suitable (optimized) solutions to extract maximum power of the installed system is ad-hoc, rather than generalized solution.

A dynamic model that represents the proposed system and a closed-loop controller to track the desired active and reactive powers delivered to the grid are developed. The desired power is used as the reference for the closed-loop control of the power injected into the grid. The controller uses an algorithm to derive the maximum power that can be achieved at a given wind velocity. In order to track maximum power, MC adjusts the induction generator terminal frequency, and thus the turbine shaft speed. MC adjusts the reactive power transfer at the grid interface to achieve voltage regulation or power factor correction.

REFERENCES

- V. Singh and J. Fehrs, The Work that Goes into Renewable Energy, Renewable Energy Policy Project, Nov. 2001.
- Carl Brothers, Cost Analysis, Atlantic Wind Test Site Inc., Feb. 2002.
- Andersen, P.D., Global Perspectives for Wind Power, Proceedings of the European Wind Energy Conference (EWEC '99), March 1999, Nice, France, p. 71 - 76.
- Johnson G.L.. Wind Energy Systems, Prentice Hall. 1985.
- Ministry of Non-conventional Energy Sources (MNES), Wind Power Development in India – Towards Global Leadership, MNES. Government of India. October 2002.
- Rangarajan S.. Wind Energy Resource Survey in India, Vol.5. Indian Institute of Tropical Meteorology, Bangalore. 1998
- Spera D.A. (Ed.), Wind Turbine Technology : Fundamental Concepts of Wind Turbine Engineering, ASME Press, New York. 1994.
- Melicio, R.; Mendes, V.M.F.; and Catalao, J.P.S. (2010). Power converter topologies for wind energy conversion system: Integrated modeling, control strategy, performance simulation. *Renewable Energy*, 35(10), 2165-2174.
- Mayurappriyan, P.S.; Jerome, J.; Ramkumar, M.; and Rajambal, K. (2009). Dynamic modeling and

analysis of wind turbine driven doubly fed induction generator. *International Journal of Recent Trends in Engineering*, 2(5), 367-372.

- Brahmi, J.; Krichen, L.; and Ouali, A. (2009). A comparative study between three sensorless control strategies for PMSG in wind energy conversion system. *Applied Energy*, 86(9), 1565-1573.

- Kazmi, S.M.R.; Goto, H.; Guo, H.J.; and Ichinokura, O. (2011). A Novel algorithm for fast and efficient speed-sensorless maximum power point tracking in wind energy conversion systems. *IEEE Transactions on Industrial Electronics*, 58(1), 29-36.