Wind Farms

Performance, Economic Factors and Effects on the Environment

Renewable Energy: Research, Development and Policies

Marian Dunn
Editor

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RENEWABLE ENERGY: RESEARCH, DEVELOPMENT AND POLICIES

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PERFORMANCE, ECONOMIC FACTORS AND EFFECTS ON THE ENVIRONMENT

MARIAN DUNN
EDITOR

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PREFACE

This book provides current research on the performance, economic factors and effects on the environment of wind farms. The first chapter provides a technical review of wind farm improved performance and environmental development challenges. Chapter Two explores a variety of methods to be used for assessing noise from wind farms. In Chapter Three, the potential impact of wind farms on radio devices in civil aviation and a review of the impact assessment procedure and methods of our research group is presented. Chapter Four discusses the measurement, analysis and improvement in the power quality of offshore wind farms.

Chapter 1 – The effective protection of the power converters of a Doubly Fed Induction Generator (DFIG) Variable Speed Wind Turbine (VSWT), could go a long way to improve its performance during transient conditions. A crowbar protection switch is normally used to protect the variable speed drive power converters during grid fault. The design of the pitch angle controller at the referenced coupled Rotor Side Converter (RSC) of the variable speed drive is also important in order to enhance its response during transient. This research work investigates the performance of a wind farm composed of variable speed drive considering five scenarios. In the first scenario, simulations were run for dynamic behaviour of a DFIG VSWT. The second scenario considers transient analysis for a severe 3LG fault. The third scenario shows the use of the crowbar switch to further enhance the performance of the DFIG VSWT in the second scenario. In the fourth scenario, a Flexible AC Transmission System (FACTS) device called Static Synchronous Compensator (STATCOM) was used to further enhance the stability of the variable speed drive. Finally, in the fifth scenario, a Current Controlled Voltage Source Converter (CC-VSC) was proposed to replace the conventional Voltage Controlled Voltage Source Converter (VC-VSC) used in the other scenarios. The simulated results show that the DFIG VSWT could perform better in all the scenarios based on the proposed protection and control techniques employed. Furthermore, some of the challenges of developing these variable speed wind farms ranging from environmental concern to government policies were also highlighted. Some opportunities were presented to make the establishment of these wind farms promising in the near future.

Chapter 2 – Wind farms have demonstrated impressive growth in electricity generation capacity over the past decades. Alongside this growth trend, some communities living in areas adjacent or close to existing and future wind farm sites have expressed concerns regarding possible health and environmental implications resulting from wind farm operations. Among the environmental concerns of wind turbine operations is the noise impact from wind farms. A wind farm operation should meet certain requirements in terms of noise impact. These noise limits are normally imposed by regulatory or planning authorities and are typically one of the strictest limits to be applied to potential noise sources. In many cases noise from wind farm operations is just above background or ambient noise present. Therefore monitoring and compliance checking of wind farm operation noise may be a complex scientific and engineering task. This chapter explores a variety of methods to be used for assessing noise from wind farms. The advantages and shortcomings of each approach to wind farm monitoring are discussed and considered within this chapter. Recommendations on implementations are provided based off the practicability and accuracy of results produced.

Chapter 3 – In recent years, with the quick development of offshore wind farms, there is an urgent and increasing demand on investigating the power quality of grid-connected offshore wind farm and understanding its impacts on the operation of power grid. This chapter focuses on addressing the aforementioned technical challenges and exploits the power quality issues of offshore wind farms from a number of aspects to enable us to model, analyze and protect the power quality of large-scale offshore wind farms. This chapter explores the modeling approach of semi-aggregated equivalent model of offshore wind farm based on PSCAD/EMTDC, which can be adopted for the study of measurement, analysis and improvement of power quality at point of common connection (PCC). Following to this, this chapter attempts to address this technical challenge through a simulation-based study by the use of PSCAD/EMTDC models and carries out an assessment of power quality at the Point of Common Coupling (PCC) in the scenario of offshore wind farm integrated into the power network whilst reduce the impact of index discrepancy and uncertainty. Finally, considering the integration of hybrid energy storage system (HESS) including battery energy storage system (BESS) and super-capacitors energy storage system (SCESS) to improve the power stabilization in power grid, the control strategy on managing the HESS to stabilize the power fluctuation in a real-time fashion without the need of predicting wind speed statistics is also presented. The suggested solutions are assessed through a set of simulation experiments and the result demonstrates the effectiveness in the simulated offshore wind farm scenarios.

Chapter 4 – Wind power is an attractive clean energy and wind farms increase with very high speed in recent years. However, as a particular obstacle, wind farms may degrade the performance of radio devices in civil aviation obviously. Therefore, wind farms may threaten the flight safety and correct impact assessment of wind farms on radio devices is important to guarantee the safety of civil aviation. In this chapter the potential impact of wind farms on radio devices in civil aviation and a review of the impact assessment procedure and methods of our research group is presented. The radio devices discussed in the chapter include surveillance devices such as primary surveillance radar (PSR) and second surveillance radar (SSR) and radio navigation devices such as very high frequency omnidirectional range (VOR) and instrument landing system (ILS). A wind farm usually comprises several wind turbines with very large size. The proper estimation of the scattering coefficient or radar cross section (RCS) of the wind turbine is of great importance to assess the impact of wind farms correctly. However, the intensity of electromagnetic scattering and the RCS of a wind turbine vary with several factors. Consequently a review of RCS estimation methods for a wind turbine of our research group is also presented in this chapter.

CONTENTS

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Chapter 1

TECHNICAL REVIEW OF WIND FARM IMPROVED PERFORMANCE AND ENVIRONMENTAL DEVELOPMENT CHALLENGES

K. E. Okedu[1,2], R. Uhunmwangho[2], Peter Ono Madifie[2] and C. C. Chiduole[2]
[1]Caledonian College of Engineering, Muscat,
Al Hail South, Sultanate of Oman
[2]University of Port Harcourt, Choba,
Rivers State, Nigeria

ABSTRACT

The effective protection of the power converters of a Doubly Fed Induction Generator (DFIG) Variable Speed Wind Turbine (VSWT), could go a long way to improve its performance during transient conditions. A crowbar protection switch is normally used to protect the variable speed drive power converters during grid fault. The design of the pitch angle controller at the referenced coupled Rotor Side Converter (RSC) of the variable speed drive is also important in order to enhance its response during transient. This research work investigates the performance of a wind farm composed of variable speed drive considering five scenarios. In the first scenario, simulations were run for dynamic behaviour of a DFIG VSWT. The second scenario considers transient analysis for a severe 3LG fault. The third scenario shows the use of the crowbar switch to further enhance the performance of the DFIG VSWT in the second scenario. In the fourth scenario, a Flexible AC Transmission System (FACTS) device called Static Synchronous Compensator (STATCOM) was used to further enhance the stability of the variable speed drive. Finally, in the fifth scenario, a Current Controlled Voltage Source Converter (CC-VSC) was proposed to replace the conventional Voltage Controlled Voltage Source Converter (VC-VSC) used in the other scenarios. The simulated results show that the DFIG VSWT could perform better in all the scenarios based on the proposed protection and control techniques employed. Furthermore, some of the challenges of developing these variable speed wind farms ranging from environmental concern to government policies were also highlighted. Some opportunities were presented to make the establishment of these wind farms promising in the near future.

1. INTRODUCTION

Energy conversion from wind into electrical energy system is rapidly growing because of the clean and renewable energy nature capability it possesses [1-3]. Speculations have it that by the end of 2020, the capacity of wind turbines that are going to be installed should hit 1900 GW [4]. Basically, a wind farm is a collection of various wind turbines of the same type or of different types to generate electricity.

Most of the wind turbine generators used in wind energy applications for sustainable energy production is fixed speed; however, the number of variable speed wind turbines (VSWTs) is on the increase by day [5-7]. The fact for the increase use of the VSWT is due to its ability to possibly track the changes in wind speed by shaft speed adapting; hence helps maintain optimal power generation. The control techniques of VSWT are very important and till date, more research is still going on in these areas. Principally, VSWT uses aerodynamic control systems like pitch blades or trailing devices that are variable in nature, but expensive and complex to achieve [8, 9].

The main aim of VSWT is power extractor maximization and in order to achieve this; the tip speed ratio of the turbine should be maintained constant at its optimum value despite changes of wind energy supplied. However, there exist mechanical and electrical constraints that are most common on the generator and the converter system. Therefore, regulation strategy of the effective power produced by VSWT is always one of the basic aims for the eminent and rapidly use of the turbine for energy production. Some of the merits of the VSWT over the Fixed Speed Wind Turbine (FSWT) are; cost effective, capability of pitch angle control, reduced mechanical stress, improve power control quality, improve system efficiency, reduced acoustic noise, etc. However, despite some of the above mentioned merits of the VSWT, there are some demerits of the wind turbine like fragile converter system that is vulnerable to damage during transient and also has a complex control topology.

In this study, the Doubly Fed Induction Generator (DFIG) is the VSWT. The DFIG possess reduction of inverter (20-30%) of the total energy system, potential to control torque and slight increase in efficiency of wind energy extraction [10]. However, the DFIG based VSWTs are very sensitive to grid disturbances especially to voltage dips. DFIG is made up of two converter control systems (rotor side converter and the grid side converter) which has a restricted over current limit, and needs special attention during transient conditions to avoid damage. When grid fault or transient occurs in the system, voltage dip is caused at the terminal voltage of the DFIG, consequently, the current flowing through the power converter may be very high current. In such situation, the conventional way could be to block the converters to avoid risk of damage because of their fragile nature, thereafter, disconnecting the generator and the wind farm from the grid. This act leads to the establishment of international grid codes. The grid codes require that wind turbine generators or wind farms must stay connected to the grid during grid fault or system disturbances and support or contribute to the network voltage and frequency. Thus, the DFIG based VSWT must comply with the Fault Ride Through (FRT) or Low Voltage Ride Through (LVRT) capabilities required by the grid codes. This practically means some requirements for the safe operation of the Rotor Side Converter (RSC) of the DFIG, because the rotor current and DC-link voltage of the wind generator will become very large during grid fault.

This work proposes a crowbar switch with effective resistance value to disconnect the RSC converter of the DFIG in order to protect it, thus operating the DFIG VSWT as a FSWT squirrel cage machine at transient conditions. As a further way of enhancing the DFIG capability, an investigation of different sizes of the crowbar switch resistor is necessary as different values of the crowbar resistor result in different behavior of the DFIG. Crowbar switch consist of set of thyristors or IGBTs that short circuits the rotor windings when triggered based on set optimal conditions. Consequently, the rotor voltage is limited, thus providing additional path for the rotor current, with improved DC-link voltage. Also, the output energy of the wind turbine depends on the methods of tracking the peak power points on the turbine characteristics due to fluctuating wind conditions [11].

An improved maximum power point tracking (MPPT) was employed in this work, whereby, the wind turbine is allowed to work with a speed close to its nominal value that permits the maximum power extraction. Thus, the pitch angle is kept constant at zero degree until the speed reaches a reference speed of the tracking characteristics. Beyond the reference point, the pitch angle is proportional to the speed deviation from the reference speed. In a bid to improve the performance of the VSWT, a detailed modeling of the turbine and its components were analyzed in this work. Different control strategies were employed ranging from the use of crowbar switch, FACTS device, different converter topologies (Voltage and Current controlled Voltage Source Converters) in addition to the MPPT tracking control system and pitch angle techniques. Simulations were run using the platform of Power System Computer Aided Design and Electromagnetic Transient including DC (PSCAD/EMTDC) visual environment. Dynamic (wind speed changes) and transient (grid fault) analyses were carried out to show the performance of the DFIG wind farm system respectively. Some challenges of siting the variable speed wind farm and some recommendations to enhance its effective operation were also given.

2. Review of Variable Speed Drives

The study of variable speed wind energy conversion system based on a doubly fed induction generator (DFIG) has been widely reported in the literature. Also, the Fault Ride Through (FRT) and Low Voltage Ride Through (LVRT) capabilities of this machine based on grid codes have been presented in the literature. References [12, 13], proposed sliding mode controls of active and reactive power of DFIG with MPPT for variable speed wind energy conversion. In these papers, the proposed control algorithm is applied to a DFIG whose stator is directly connected to the grid and the rotor is connected to the Pulse Width Modulation (PWM) converter. Wind energy integration for DFIG based wind turbines fault ride through and wind generation systems based on doubly fed induction machines were investigated in [2, 14, 15]. The authors did the FRT assessment of a DFIG and a Matlab Simulink for the DFIG variable speed wind turbine respectively. An MPPT using pitch angle with various control algorithms in wind energy conversion system was reported in [16] with the use of various intelligent control schemes in extracting maximum wind power using DFIG. Also, a sensorless MPPT fuzzy controller for DFIG wind turbine and hybrid sliding mode control of DFIG with MPPT using three multicellular converters were investigated and reported in [17, 18] respectively. It was concluded in the literature that the MPPT fuzzy logic control can capture the maximum wind energy without measuring the wind velocity and also that the DFIG MPPT connected by rotor side to three bridges of Multicellular Converters (MCCs), in conjunction with the Lyapunov stability method could improve the performance of the DFIG system during grid fault.

The integration of DFIG with a network having wind energy conversion system was carried out in [1], where two indirect converters associated with the principle of power distribution can operate the system conversion in a wide range of speed variation. DFIG with cycloconverter for variable speed wind energy conversion system for active and reactive power control was reported in [19]. In this paper, an MPPT control was included in the control system for improved performance of the DFIG system. Again, the modeling and MPPT control in DFIG based variable speed wind energy conversion system by using RTDS was investigated in [20], where the proposed control solution aims at driving the position of the operating point near the optimal set value.

The use of DC chopper, static series compensators, dynamic voltage restorer, Flexible AC Transmission Systems (FACTS) device, series dynamic braking resistor, super conducting fault current limiter, passive resistance network and antiparallel thyristors to improve the performance of DFIG VSWT have been presented in the literature. This work tends to review how the DFIG VSWT performance could be improved both in dynamic and transient conditions considering the magnitude of an active crowbar switch connected to the RSC of the machine, FACTS device and the power converter control topologies.

2.1. Crowbar Switch

Crowbar is made up of a symmetric three phase Y- connected resistance. It is usually connected to the rotor of the DFIG through a controllable breaker. In practice, the crowbar may be made up of one resistance fed through a switched rectifier bridge that would be sufficient to assess the overall impact of the crowbar protection on DFIG VSWT during transient. The breaker is normally open, but it is closed short-circuiting the rotor through the resistance if either the rotor current or the DC-link capacitor voltage becomes too high.

At the same time, the switching of the RSC Route Switch Controller is stopped [21, 22].

The value of the crowbar resistance is chosen according to [15, 23], as 20 times the rotor resistance. The choice of the crowbar resistance is important because it determines how much reactive power the DFIG will draw while the crowbar is inserted.

2.2. Concept of DFIG Pitch Control and MPPT

A lot of work have been done in the area of DFIG pitch control and MPPT techniques in the literature. However, how the crowbar switch affects some of the parameters of the DFIG VSWT would be investigated in this work. With the advancements in variable speed system design and control mechanisms of wind energy systems, energy capture and efficiency or reliability are paramount. Intelligent control techniques have been used to improve the performance and reliability of wind energy conversion system as reported in [24]. A further research was also carried out by same authors using fuzzy controller along with Hill Climbing Search (HCS) algorithm. As a brief, pitch control is the most common means for regulating the aerodynamic torque of the wind turbine and it works by searching for the peak power by varying the speed in the desired direction. The operation of the generator however, is in accordance with the magnitude and direction of change of active power.

The power gotten from wind energy systems depend on the power set point traced by MPPT. Tip Speed Ratio (TSR) affects the mechanical power from the wind turbine and thus, is defined as the ratio of turbine rotor tip speed to the wind speed. For a given wind speed, optimal TSR occurs during the maximum wind turbine efficiency. And in order to maintain this, the turbine rotor speed changes as the wind speed changes, thus extracting maximum power from wind. TSR calculation requires the measured value of wind speed and turbine speed data, but in the other hand, wind speed measurement increases the system cost and also leads to practical complexities.

2.3. Description of DFIG VSWT Simulation Models

One of the salient reasons for the wide use of the doubly fed wind induction generators connected to grid system is its ability to supply power at constant voltage and frequency, while the rotor speed varies. DFIG VSWT