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A Study on Control Techniques for Wind Energy Systems

Ajay Kumar[1], Alka Thakur[2]
M.Tech Scholar, SSSUTMS, Sehore, (M.P.), India[1]
Associate Professor, SSSUTMS, Sehore, (M.P.), India[2]

Abstract

Renewable energy resources have become more widely integrated into the electricity system in recent years. Wind plays an essential role in the energy mix since it is a renewable, clean, and abundant source of electricity. Increased wind power penetration in the electrical system, on the other hand, might have a negative impact on electricity quality and create new operational issues. This study examines topics such as maximum power point tracking, fault ride-through capabilities, inter-area and sub-synchronous oscillations, and voltage flicker as they pertain to the integration of wind farms into the power system, as well as existing control systems. This document also outlines upcoming obstacles and possibilities. This paper presents the classification of wind turbine, its control techniques and review of literature about the earlier work done in the field of transient stability using FACTS controller.

Keywords: *WPT, PTE, Dielectric resonator, MRC.*

1. Introduction

The worldwide concern about environmental pollution and a possible energy shortage has led to increasing interest in technologies for the generation of renewable electrical energy. Among various renewable energy sources, wind power is the most rapidly growing one in Europe and the United States. With the recent progress in modern power electronics, the concept of a variable-speed wind turbine (VSWT) equipped with a doubly fed induction generator (DFIG) is receiving increasing attention because of its advantages over other wind turbine generator concepts.

In the DFIG concept, the induction generator is grid-connected at the stator terminals; the rotor is connected to the utility grid via a partially rated variable frequency ac/dc/ac converter (VFC), which only needs to handle a fraction (25%–30%) of the total DFIG power to achieve full control of the generator [1]. The VFC consists of a rotor-side converter (RSC) and a grid-side converter (GSC) connected back-to-back by a dc-link capacitor. When connected to the grid and during a grid fault, the RSC of the DFIG may be blocked to protect it from over current in the rotor circuit. The wind turbine typically trips shortly after the converter has blocked and automatically reconnects to the power network after the fault has cleared and the normal operation has been restored. The author proposed an uninterrupted operation feature of a DFIG wind turbine during grid faults. In this feature, the RSC is blocked, and the rotor circuit is short-circuited through a crowbar circuit (an external resistor); the DFIG becomes a conventional induction generator and starts to absorb reactive power. The wind turbine continues its operation to produce some active power, and the GSC can be set to control the reactive power and voltage at the grid connection [2].

The pitch angle controller might be activated to prevent the wind turbine from fatal over speeding. When the fault has cleared and when the voltage and the frequency in the utility grid have been reestablished, the RSC will restart, and the wind turbine will return to normal operation. However, in the case of a weak power network and during a grid fault, the GSC cannot provide sufficient reactive power and voltage support due to its small power capacity, and there can be a risk of voltage instability. As a result, utilities, typically, immediately disconnect the wind turbines from the grid to prevent such a contingency and reconnect them when normal operation has been restored. Therefore, voltage stability is the crucial issue in maintaining uninterrupted operation of wind turbines equipped with DFIGs. With the rapid increase in penetration of wind power in power systems, tripping of many wind turbines in a large wind farm during grid faults may begin to influence the overall power system stability.

It has been reported recently that integration of wind farms into the East Danish power system could cause severe voltage recovery problems following a three-phase fault on that network. The problem of voltage instability can be solved by using dynamic reactive compensation. Shunt flexible ac transmission system (FACTS) devices, such as the SVC, TCPAR, TCSC, SSSC, UPFC, IFPC, GUPFC, HPFC, and the STATCOM, have been widely used to provide high-performance steady state and transient voltage control at the point of common coupling (PCC). The application of an SVC or a STATCOM to a wind farm equipped with fixed-speed wind turbines

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(FSWTs) and squirrel-cage induction generators (SCIGs) [1,2].

2. Classification of Wind Turbines

Wind turbine technology has seen a significant progress in recent years and several types of wind turbines are in use [3, 4]. In general, wind turbines can be classified into four types based on their power electronics:
(1) Fixed-speed (Type I),
(2) Variable-slip (Type II),
(3) Doubly fed induction generator (DFIG) (Type III), and
(4) Full converter (Type IV) wind turbines.
Fixed-speed wind turbines operate with less than 1% variation in rotor speed, and their output power is in the range of kilowatts. Variable-slip wind turbines using a variable resistance in their rotor circuit can operate in wide range of operating speed (less than 10%) and their output power is less 1 MW. Variable-speed wind turbines based on DFIG employ a back-to-back AC-DC-AC converter in the rotor circuit which allows them to operate in the speed range of $\pm$30% of the rated speed and their output power is in the range of 1 to 5 MW. The full converter wind turbines based on permanent magnet synchronous generator (PMSG) employ a back-to-back AC-DC-AC converter, which allows them to operate in the speed range of 0 to 100% of the rated speed and their output power is in the range of 4.5 to 7 MW [5, 6]. Variable-speed wind turbines, i.e., Types III and IV, are currently the most commonly used turbines [5]. According to the JRC database (Joint Research Center of the European Commission), in 2005 40% of the North American total wind power installed capacity was Type I and II, and 60% Type III. In 2014, almost 70% of the installed capacity was Type III, 29% Type IV, and less than 1% Types I and II [24].

3. Control Techniques for Wind Turbine

3.1 Fixed-Speed Wind Turbines (Type I)

Type 1 WTGs use squirrel-cage induction generators and operate in a very narrow slip range (about 1% rated slip). The real power versus the rotational speed is shown in Figure 4. Both the power and the rotor speed are given in per-unit quantities. Note that the induction generator is always absorbing reactive power from the line; thus, reactive compensation is usually implemented by switched capacitor banks, and the size of the capacitance is controlled so that the wind turbine generates power at unity power factor [7].
As shown in Figure 2, the normal operating point at rated wind speed is at point A, where the output power is at 1.0 per unit. The aerodynamic power driving the generator fluctuates with wind speed; thus, the pitch is continuously controlled to limit the aerodynamic power developed by the blades, which also limits the aerodynamic torque driving the induction generator. Instantaneously, individual WTGs may generate more or less at 1.0 per unit with small variation (indicated by the two-sided arrow); however, the average power will always be limited to 1.0 per unit. At the point of interconnection, the average output from hundreds of wind turbines will smooth out to an almost flat output when the wind speed is at or higher than rated wind speed.

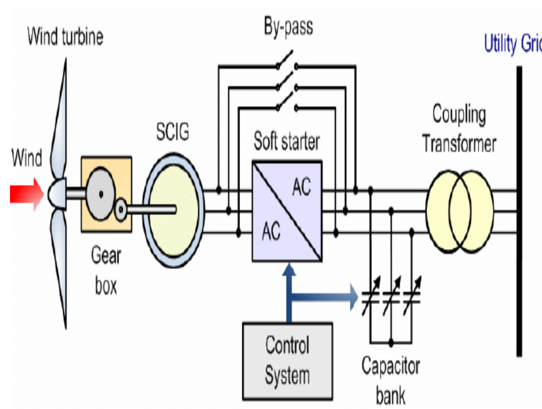

Figure 1. Schematic diagram of a Type I wind turbine

To allow power to be held in reserve, the wind turbine is operated with an output power set-point lower than what is actually available, e.g., at high wind speeds, the pitch can be controlled to generate 80% of rated power although it is capable of generating 100% of rated power. The operating point moves from A to B, as shown in Figure 2.

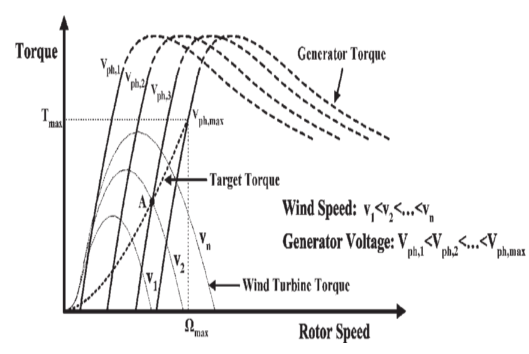

Figure 2. Output power versus rotor speed (Type 1) WTG

3.2 Variable-Slip Wind Turbines (Type II)

Variable-speed fixed-pitch (VS-FP) configuration continuously adjusts the rotor speed relative to the wind speed through power electronics controlling the synchronous speed of the generator. This type of control assumes that the generator is from the grid so that the generator’s rotor and drive train are free to rotate

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independently of grid frequency. Fixed-pitch relies heavily on the blade design to limit power through passive stalling [8].

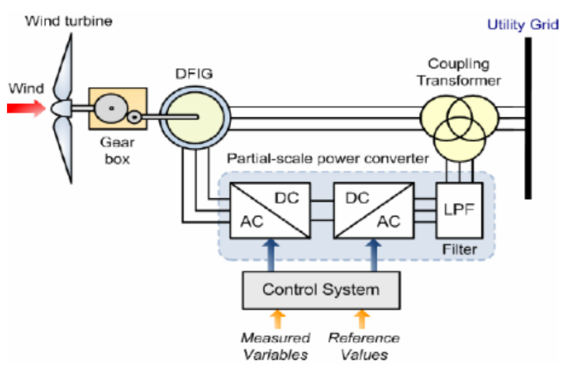

Figure 3. Schematic diagram of a Type II wind turbine

Figure 4 shows that power efficiency is maximized at low wind speeds, and you can achieve rated turbine power only at one wind speed. Passive stall regulation plays a major role in not achieving the rated power and can be attributed to poor power regulation above the rated wind speed. In lower wind speed cases, VS-FP can capture more energy and improve power quality [8].

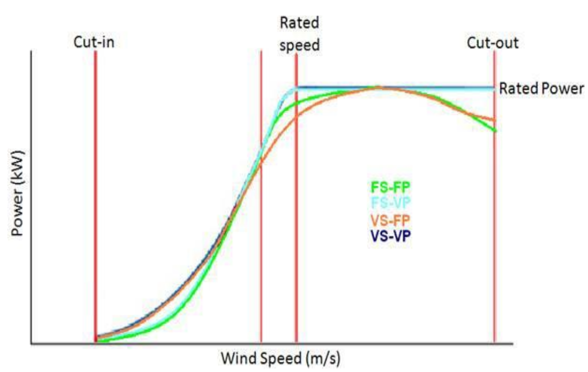

Figure 4 shows the power curve for VS-FP

Variable-speed variable-pitch (VS-VP) configuration is a derivation of VS-FP and FS-VP. Operating below the rated wind speed, variable speed and fixed pitch are used to maximize energy capture and increase power quality. Operating above the rated wind speed, fixed speed and variable pitch permit efficient power regulation at the rated power. VS-VP is the only control strategy that theoretically achieves the ideal power curve shown in Figure 4.

3.3 DFIG Wind Turbines (Type III)

The DFIG is fundamentally a wound rotor induction generator in which the rotor circuit can be controlled by external power electronics devices to achieve variable speed operation. A typical block diagram of the DFIG wind energy system is shown in Figure 5. Three-phase alternative current windings are at both the stator and the rotor that provides operating speed range around synchronous speed ±30% [9].The stator windings of the generator are directly connected to the electric grid through a step-up transformer, whereas the rotor windings of the DFIG are connected to the grid through rotor-side converter (RSCs), grid-side converters (GSCs), harmonic filters, and the step-up transformer[10]. The active power delivered from the stator generator to the grid is unidirectional. However, the active power flow from the rotor to the grid is bidirectional depending on the generator operation mode whether it is above or below the synchronous speed. The power rating of the converter circuit is based on the range of the speed of the wind turbine. The power rating of the converter circuit is typically around 25-30% of the nominal rated power output of the wind turbine [9]. The doubly fed induction generator wind energy system is widely established in today's wind energy market. The possibility of controlling the active and reactive power fed to the grid from the stator independently of the generator turning speed makes the major advantage of DFIG that it can provide a constant source of active power and voltage with variable wind turbine speed .It is capable of generating the maximum output power during a limited wind speed availability in comparison to fixed speed wind turbines. The low power losses in the converters enhance the overall efficiency [9, 10].

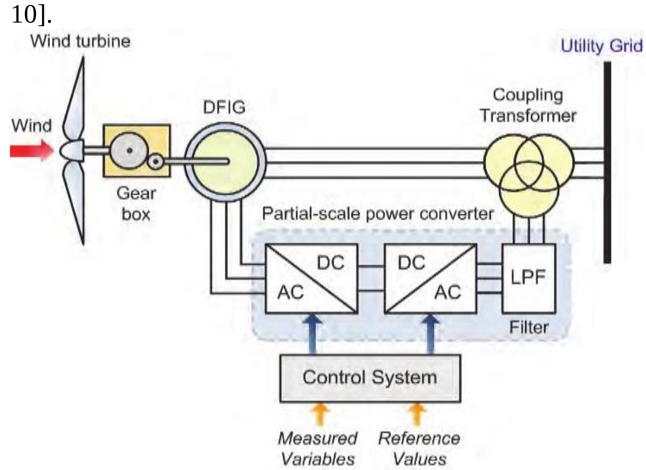

Figure 5 Block Diagram for Doubly Fed Induction Generator (Type III) Wind Energy System [10]

4. Related Work

Transient Stability of Wind Power Systems Viewpoint

This paper presents a study of a DFIG wind power generation system for real-time simulations. For real-time simulations, the Real-Time Digital Simulator (RTDS) and its user friendly interface simulation software RSCAD are used. A 2.2MW grid-connected variable speed DFIG wind power generation system is modeled and analyzed in this

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study. The stator-flux oriented vector control scheme is applied to the stator/rotor side converter control, and the back-to-back PWM converters are implemented for the decoupled control. This literature proposed a new doubly-fed induction generator (DFIG) system using a matrix converter controlled by direct duty ratio pulse-width modulation (DDPWM) scheme. DDPWM is a recently proposed carrier based modulation strategy for matrix converters which employs a triangular carrier and voltage references in a voltage source inverter. By using DDPWM, the matrix converter can directly and effectively generate rotor voltages following the voltage references within the closed control loop. The operation of the proposed DFIG system was verified through computer simulation and experimental works with a hardware simulator of a wind power turbine, which was built using a motor-generator set with vector drive. The simulation and experimental results confirm that a matrix converter with a DDPWM modulation scheme can be effectively applied for a DFIG wind power system [11]. Cost effective simulation schemes for Wind Power Generation Systems (WPGS) considering wind turbine types, generators and load capacities have been strongly investigated by researchers. As an alternative, a true weather conditions based simulation using real time digital simulators (RTDS) is experimented in this literature for the online real time simulation of the WPGS [12].

Loadability of Wind Power System Viewpoint:

Reference [12], has been presented an approach for enhancement of voltage stability of an interconnected power system employing distributed generators (DG) along with conventional generators. When the DG is from wind then voltage instability in the system is of great concern. In this paper a 28 bus test system is considered where the wind penetration varies from 10% to 99% over the day. This causes a large variation at different bus voltages violating the grid code. A shunt FACT device such as SVC is used to mitigate this problem at the buses connected to wind generators. Thereafter, suitable locations for the SVC placement are identified to enhance the voltage stability and reduce system power loss. In [13], the wind power industry has expanded greatly during the past few years, has served a growing market, and has spawned the development of larger wind turbines.

Voltage Security Viewpoint

This literature presented a novel voltage stabilization and power quality enhancement scheme using a PWM switched modulated power filter compensator (MPFC), which is controlled by a dynamic tri-loop (voltage, current and dynamic power signals at the load bus).The error driven tri-loop controller is used to stabilize a standalone wind driven induction generator scheme. Full voltage stabilization and power quality enhancement is validated under electric load excursions [14].

Reduce Active power and Energy Losses Viewpoint:

The wind turbine is in several ways a unique power generating system because power train components are subject to highly irregular loading from turbulent wind conditions. The number of fatigue cycles experienced by major structural components can be far greater than that found for other rotating machines [15]. A wind turbines extreme conditions and high loads make coordination of maintenance an interesting issue. How much maintenance is needed? Are there any ways to minimize maintenance and yet have wind turbines ready to harvest power? These wind power plant issues are discussed today in research and development, and in operations and maintenance. The technical availability of wind turbines is high, around 98%, and is not only due to good reliability or maintenance management, but also due to fast and frequent service [16], [17]. Manufacturers seldom reveal data about their products and even more rarely share information about their failures, which is quite understandable. Preventive and corrective maintenance are performed as given in [18]. At the right moment, preventive maintenance will save money for the wind power plant owner. This is especially noticeable for remote site wind power plants situated, for example, offshore.

Dynamic Performance of Wind Power System Viewpoint:

Application of FACTS controller called Static Synchronous Compensator STATCOM to improve the performance of power grid with Wind Farms is investigated .The essential feature of the STATCOM is that it has the ability to absorb or inject fastly the reactive power with power grid. Therefore the voltage regulation of the power grid with STATCOM FACTS device is achieved. Moreover restoring the stability of the power system having wind farm after occurring severe disturbance such as faults or wind farm mechanical power variation is obtained with STATCOM controller [19]. The dynamic model of the power system having wind farm controlled by proposed STATCOM is developed. To validate the powerful of the STATCOM FACTS controller, the studied power system is simulated and subjected to different severe disturbances. The results prove the effectiveness of the proposed STATCOM controller in terms of fast damping the power system oscillations and restoring the power system stability [20]. Flexible AC transmission system a FACTS device such as Static Synchronous Compensator STATCOM to improve the stability in wind farm is studied [21].

5. Conclusion

This paper presents the classification of wind turbine, control techniques and their related work. Renewable energy resources have made substantial inroads into the power system. When a large-scale wind power facility is connected to a bulk power grid, several key issues occur, including maximum power point tracking, fault ride-through capabilities, interarea and subsynchronous oscillations, and flicker caused by voltage fluctuations. The common control strategies for various types of wind turbines are reviewed. In this work. Furthermore, a complete evaluation of existing additional control approaches for wind turbines is offered, together with a summary of their possible benefits and drawbacks. This report also discusses the difficulties and possibilities that will face us in the future.

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