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Power Quality Improvement and Stability for Wind Turbine Generators

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ABSTRACT Power systems are complicated systems that have grown beyond the years in reply to industrial extension and continuously improving power demand as a result of increasing environmental concern, more and more electricity generated from renewable sources. Renewable energy can afford to secure energy accumulations and smoothen the transition to fossil-free energy. At present renewable energy provides 19% of electricity generation worldwide. Wind power is one of the most competitive renewable energy technologies and, in developed countries with right wind resources, onshore wind is often competitive with fossil fuel-fired generation. Wind power generation has experienced tremendous growth in the past decade and has recognized as an environmentally friendly and economically competitive means of electric power generation. Wind power generation has experienced a significant increase in the past decade and has known as an environmentally friendly and financially competitive means of electric power generation. Shortly, wind power penetration in electrical power systems will increase and will start to replace the output of conventional synchronous generators (CSGs). As a result, it may also begin to influence the overall power system behavior. Hence, the impact of wind power on the dynamics of power systems should be studied thoroughly to identify potential problems and to develop standards to alleviate those problems.

KEYWORDS: WTG, CSG, MPPT, SCIGs

I. INTRODUCTION

The subject of power system stability received significant attention in the fifties due to the rapid growth of broadcast networks along with large sized generating units. Fast acting static excitation systems having higher ceiling voltages were introduced to improve transient stability of power systems. But these excitation systems had a detrimental impact on the small signal stability of power systems. They contributed to negative damping of the electromechanical oscillations in the range of approximately 0.1 to 3.0 Hz, and the effect was more pronounced in the case of weak networks.

Historically the synchronous stability, low-frequency oscillations (1-3 Hz) and sub-synchronous resonance phenomenon were the main concern for both the planners and operators of power systems. The evolution of modern power systems with high levels of reactive power compensation and increased levels of system stress due to heavier power wheeling and deferred transmission system expansion has placed voltage stability as one of the primary concerns in system planning and operation. Voltage collapse phenomenon occurred in power systems of several developed as well as developing countries from the seventies onwards and attracted the attention of researchers in this area. Efficient algorithms for voltage stability assessment and enhancement are essential to ensure reliable system operation. Voltage stability, like any other stability, is a dynamic problem. However, from static analysis, certain usage information such as loadability limit and proximity of the operating point to this limit can be obtained. The pattern of the voltage decay in the vicinity of the voltage collapse point will not know from static analysis. Dynamic analysis, on the other hand, can be used to study as to how the system proceeds towards voltage instability and collapse. In dynamic analysis, dynamic models of system components that influence voltage stability included. The resultant differential, difference, and algebraic equations characterizing the system dynamics solved to assess the dynamic voltage stability. The dynamic analysis can be either for a small-scale disturbance or a large-scale disruption. The small disturbance voltage stability is concerned with the voltage stability of an equilibrium point for small perturbations. Here, the non-linear system model linearized around the equilibrium point, and the eigenvalues are calculated to assess the voltage stability of the system. The considerable disturbance voltage stability is concerned with the transition to the existence of a new stable state following a significant disturbance like a sudden load increase, loss of a heavily loaded line, a major generator/transformer outage, etc. An essential aspect in both small-scale and large-scale disturbance voltage stability analyses is the proper representation of the load characteristics.

II. CONTROL OF WIND TURBINE

The rotor power limited by generator rating. At high wind speeds, the power regulated by any one of the following controls

Stall Control

Stall control works by increasing the angle at which the relative wind strikes the blades called angle of attack, and it reduces the induced drag associated with lift. Stall control is simply because it can be made to happen passively (it increases automatically when the winds speed up), but it improves the cross-section of the blade face-on to the wind, and thus the ordinary drag. When a fully stalled turbine blade stopped, has the flat side of the edge facing directly into the wind. Figure 1 shows a schematic diagram of stall control.

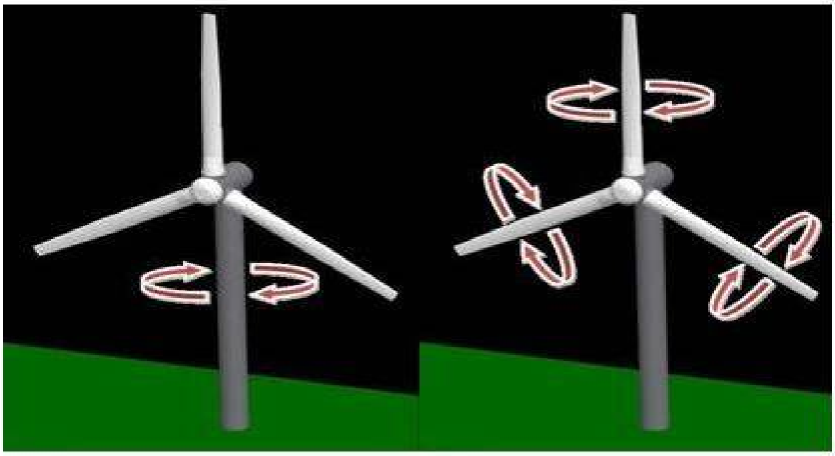

Figure 1 Schematic diagram of Stall control

The length, width, profile designed in such a way that, wind turbine creates turbulence above rated wind speed. A fixed speed wind turbine inherently increases its angle of attack at higher wind speed as the blades speed up. A natural strategy, then, is to allow the blade to stall when the wind speed increases. This technique successfully used on many new horizontal axis wind turbines (HAWTs). However, on some of these blade sets, it was observed that the degree of blade pitch tended to increase audible noise levels.

Pitch Control

Pitch angle control is the most common means for adjusting the aerodynamic torque of the wind turbine when wind speed is above rated speed. Pitch control is to work at the most efficient operating level or maximum power output level. This allows a right level of control over the angle of attack, thus control over the torque. The purpose of this control is to extend the range of operation of the wind turbine beyond the rated wind speed up to the cut-off speed. But for this pitch control, the machine should be stopped as soon as the wind speed reaches the rated wind speed. If the wind turbine operated beyond the rated wind speed without stall or pitch control, the turbine would absorb more power from the wind than its capability to withstand. So, the restriction limits the energy consumed by the turbine from the wind to its capacity, even though a much higher amount of power is available in the wind. Since the absorbed power is much less than the available power, naturally, the efficiency will be less, which means that the will be less or TSR is either more or less than the optimum. Figure 2 shows the performance characteristics of a wind turbine under pitch control [4].

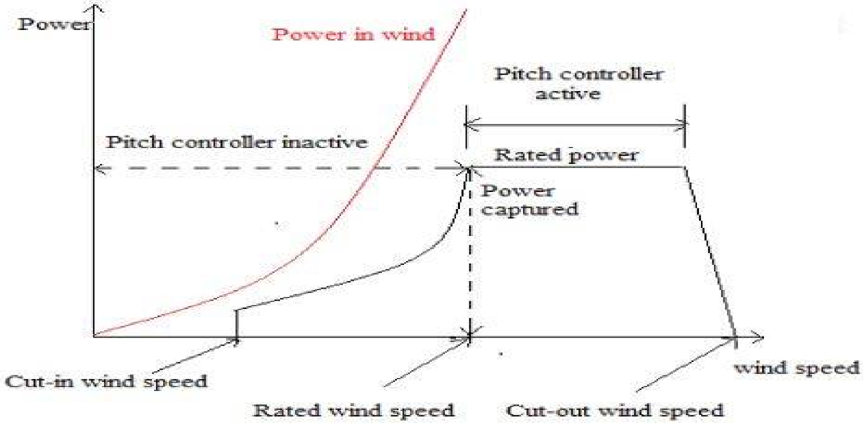

Figure 2 Performance characteristics of wind turbine under pitch control

Beyond rated wind speed, optimum power generation or maximum C_p cannot expect because the intention of the controller is only to increase the grid-connected duration in a day, i.e., overall energy per day and not power at each moment.

III. REVIEW OF LITERATURE

Wind power is one of the fastest growing electricity generation sources with 20% annual growth rate for the past 10 years. The vast majority of wind turbines that currently installed using one of the three main types of electromechanical conversion system: Squirrel cage induction generator, Doubly fed induction generator and Direct drive synchronous generator. Often, they are directly connected to the transmission grid and will, sooner or later, replace conventional power plants. Such wind farms will be expected to meet very high technical requirements, such as to perform frequency and voltage control, to regulate active and reactive power and to provide quick responses during transient and dynamic situations in the power system

[1] Discussed the problem of selection and tuning the parameters of neuro fuzzy controller using genetic algorithms. The neuro-fuzzy controller implemented as a multi-layer perceptron in which the weights are fuzzy membership functions. The optimal values of the parameters of the fuzzy membership functions have found during the learning method by applying an appropriate fitness function based on the controlled plant output.

[2] used Genetic Algorithm (GA) for simultaneous stabilization under state and output feedback. The parameters of a PSS that can simultaneously stabilize the set of plants can be determined off-line by minimizing an objective function based on the system eigenvalues using standard genetic algorithm.

[3] Proposed a rule-based variable gain stabilizer and applied the same on a laboratory model of a power system. The gain is adjusted on-line based on two control rules and knowledge of the oscillation status of the power system. This enables the stabilizer to suppress the oscillations in the system without the use of high gain control, especially during the transient process.

Wind turbine models that can integrate into power system simulation software need to develop. [5] Presented a general model of wind speed, rotor and rotor speed controller, generator/converter, pitch angle controller, voltage controller and protection system used to represent all types of variable speed wind turbines in power system dynamic simulations. Also, it has shown experimentally that in variable speed wind turbines, the shaft properties hardly reflected at the grid connection due to the decoupling effect of the power electronic converters.

Dynamic models of wind farms with fixed speed WTGs presented in various literature. A typical fixed speed SCIG employs a capacitor bank arrangement. Some authors have modeled fixed speed SCIGs with control strategies also. [6] Presented a fixed speed SCIG model which uses an alternative control strategy, where the rotational speed is the controlled variable tested during regular operation and transient grid fault events. [7] Explained a detailed model and three reduced order equivalent model of fixed speed SCIG and explained about how to choose an appropriate wind farm model for power system dynamic and transient studies.

The control scheme in [8] comprised of MPPT and double PWM active/reactive power independent control strategy. A DC-link over-voltage protection scheme also designed. This model possessed desirable capabilities of operation at the maximum power point as well as enhanced low voltage ride through (LVRT) function.

Modeled the wind speed, wind turbine and drive train of a variable speed direct drive PMSG. The maximum power point tracking (MPPT) concept utilized here adjusts the generator rotor speed according to instantaneous wind speed. [9] Developed a PMSG model with diode rectifier, boost dc to dc converter and inverter.

IV. TYPES OF WIND TURBINE GENERATORS

WTGs are of two types: fixed and variable speed.

Fixed Speed Wind Turbine Generators

Fixed speed WTGs are squirrel cage induction generators (SCIGs) with capacitor bank for self-excitation. Figure 3 shows the schematic representation of the fixed speed SCIG with capacitor bank. In fixed speed WTGs, owing to the different operating speeds of the wind turbine rotor and the generator, a gearbox is necessary to match these speeds. The generator slip slightly varies with the amount of generated power and is therefore not entirely constant. However, because these speed variations are in the order of 1 %, this wind turbine type is generally referred to as constant-speed or fixed speed.

In fixed speed WTGs, [10], the turbine speed is fixed (or nearly fixed) to the electrical grid’s frequency, and generates real power (P) when the turbine shaft rotates faster than the electrical grid frequency creating a negative slip (positive slip and power is motoring convention). The fixed speed WTGs only reach peak efficiency at particular wind speed. Fixed speed WTGs cannot have an optimal TSR, and hence the ability will not be maximized. Power can only be controlled through pitch angle variations.

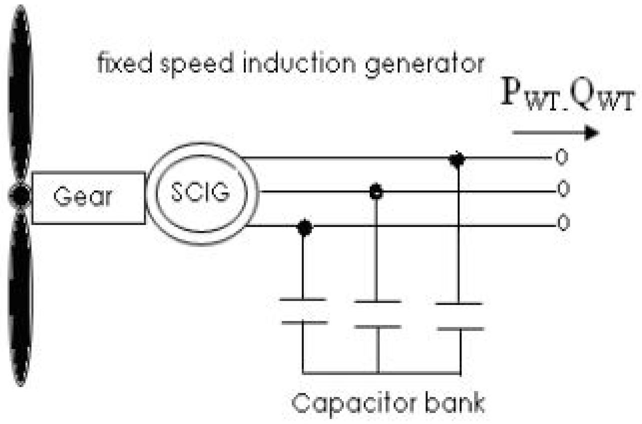

Figure 3 Schematic representation of the fixed speed wind turbine with squirrel cage induction generator

Variable Speed Wind Turbine Generators

Variable speed operation continuously adapt the rotational speed to the present wind speed, so that, ideally the maximum obtainable power is produced by the wind energy conversion system (WECS). Variable speed operation yields 20 to 30 percent more energy than the fixed speed operation, providing benefits in reducing power fluctuations and improving VAR supply. Variable speed wind turbines are connected to the grid through power electronic converters and maximize effective turbine speed control. Variable speed generators are classified according to drive trains as direct drive and geared drive systems.

Geared Drive Doubly Fed Induction Generator

The wind turbines, which use gear ratios bigger than 1, is categorized as geared drive systems. A wind turbine with doubly fed induction generator (DFIG) comes under this category. A gearbox, located between the rotor shaft and the generator shaft, is used for increasing the rotational speed of the generator input shaft while decreasing the torque. By the help of the increased rotational speed of the generator input shaft, a small number of poles is sufficient to obtain the desired frequency as the generator output. Smaller and cheaper generators can be used in these systems. On the other hand, because of the gearbox, the complexity of the system is higher than direct drive systems and these systems are less reliable. Besides, due to the failure in the gearboxes, the operation and maintenance cost of these systems are higher.

In DFIG, the stator winding of the generator is coupled to the grid, and the rotor winding to a power electronic converter. Usually a back-to-back VSC with current control loop is used. In this way, the electrical and mechanical rotor frequencies are decoupled, because the power electronic converter compensates the difference between mechanical and electrical frequency by injecting a rotor current with variable frequency. Figure 4 shows the schematic representation of the variable speed wind turbine with DFIG.

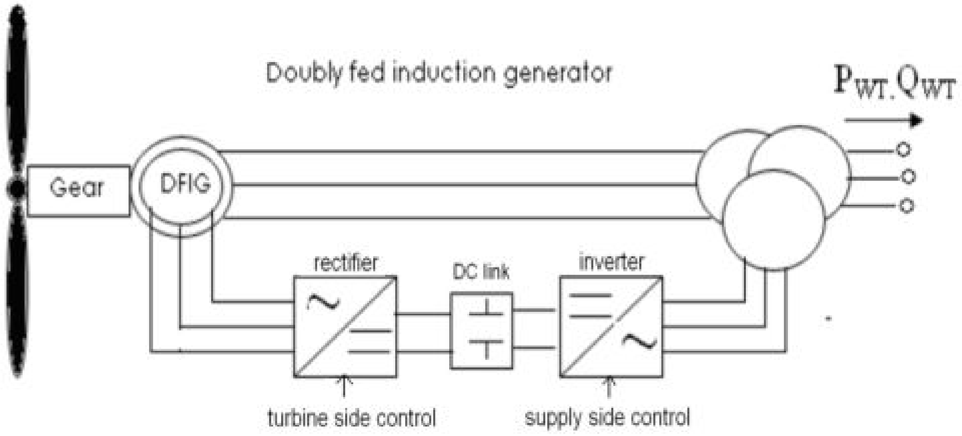

Figure 4 Schematic representation of the variable speed wind turbine with doubly fed induction generator

Direct drive synchronous generator

Indirect drive systems, the gear ratio is equal to one, which means the rotor of the wind turbine directly coupled with the generator. A low-speed multi pole synchronous generator with the same rotational speed as the wind turbine rotor converts the mechanical energy into electricity. The generator can have a wound rotor or a rotor with permanent magnets. The stator is not coupled directly to the grid but to a power electronic converter. This may consist of a back-to-back voltage source converter or a diode rectifier with a single VSC. The power automatic converter makes it possible to operate the wind turbine at variable speed.

Figure 5 shows the schematic representation of the variable speed wind turbine with a direct drive electrically excited synchronous generator (EESG).

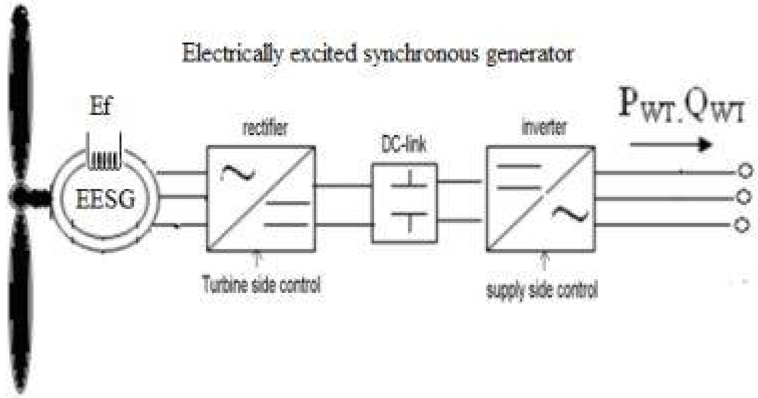

Figure 5 Schematic representation of the variable speed wind turbine with direct drive electrically excited synchronous generator.

EESGs are salient pole machines excited from the power grid. For low-speed operation, high pole count synchronous generators recommended. With EESGs, overexcitation is easily possible. So, a process at a unity power factor is utilized to reduce machine side inverter to the real power value. High pole count increases the field ampere turns, which leads to an increase in excitation losses.

PMSGs eliminate the excitation losses, which lead to an increase in efficiency and reduce thermal problems on the rotor side. No brushes and slip rings are necessary, thus reduces the maintenance costs [11].

V. SIMULATION RESULTS

The simulation study carried out on IEEE 9-bus system for analysis of transient stability using the WTGs. Figure 6 shows the one-line diagram of IEEE 9-bus test system. IEEE 9- bus system consists of 3 generator buses, 3 load buses, 3 transformers and 6 transmission lines.

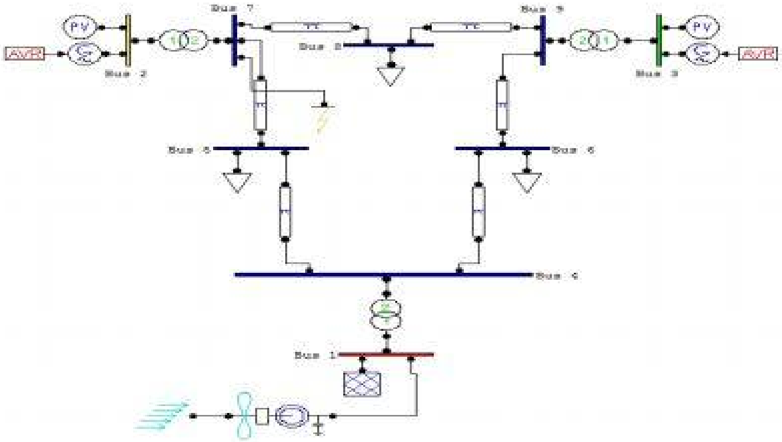

Fig 6: One-line diagram of IEEE 9 bus system

Figures 6 (a-e) show the simulation results of transient stability with CSG only. Simulation is carried out from 0 to 10 sec. time period. Figure 6(a) shows the voltage at generator buses along with the CCT value. The CCT in this case is calculated as 0.250 sec. (12.5 cycles). With AVR in CSGs, the magnitude of the rotor oscillations, subsequent to the first swing after the fault, was reduced. Furthermore, the AVR helped to return the terminal voltage of the CSG to its pre-fault level after the grid fault.

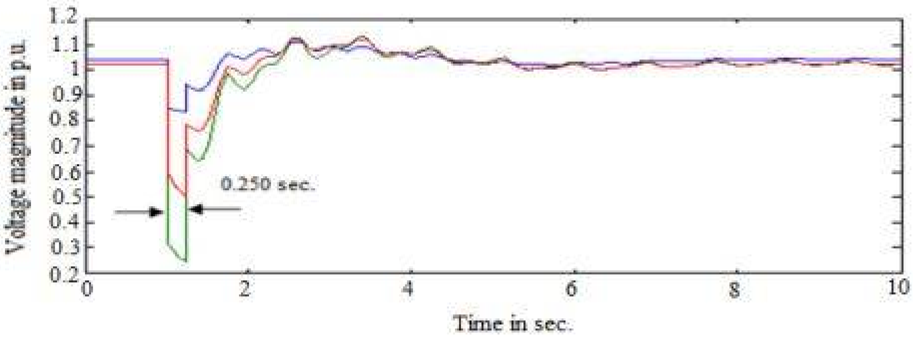

Figure 6 (a) Voltage at generator buses with CCT with only CSG

Figure 6 (b) shows the rotor angle deviation at bus-2 and bus-3

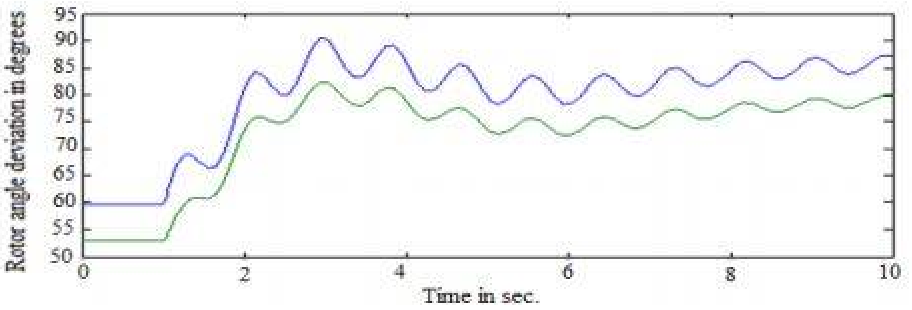

Figure 6 (b) Rotor angle deviations at generator bus-2 and bus-3 with only CSGs

From Figure 6 (b), it is found that rotor angle swing, after disturbance has reached a maximum of 900 and settled around 870 with CSGs.

Figure 6 (c) shows the rotor speed oscillations at bus-2 and bus3 with only CSGs.

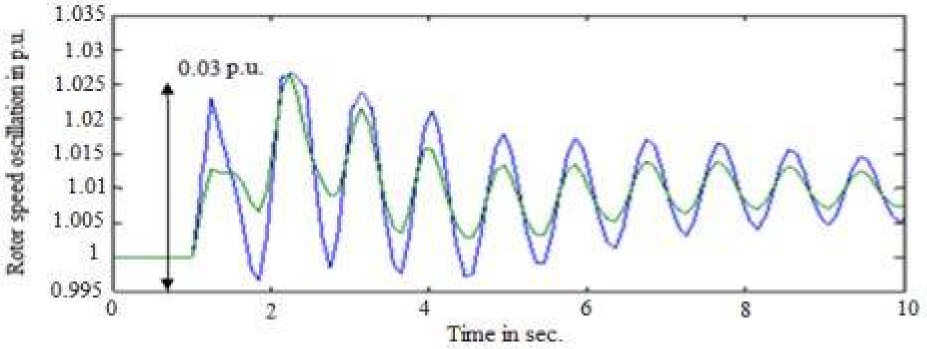

Figure 6 (c) Rotor speed oscillation at generator bus-2 and bus-3 with only CSGs

From Figure 5.3(c) (i), it is found that rotor speed oscillation varies between 0.995 p.u. and 1.025 p.u. and the bandwidth is 0.03 p.u. To analyze the rotor speed oscillation duration, simulation is done upto 30 sec.

VI. CONCLUSION

This research work has focused on modeling and simulation of variable speed direct drive WTGs and analyzed the impact of fixed and variable speed WTGs on voltage stability and transient stability. The variable speed direct drive EESG has been modeled with d-q current controlled VSC. The variable speed direct drive PMSG has been modeled with MPPT controlled DC-DC boost converter and adaptive hysteresis band current controlled VSC. The voltage stability of the system is analyzed under base case and severe line outage conditions in IEEE 14 bus test system. Fixed speed SCIGs are incapable of avoiding a voltage collapse event. The variable speed DFIGs with standard control and direct drive EESGs and PMSGs with modified controllers could assist the grid to delay or prevent a voltage collapse event. The improvement of voltage stability of a system when WTGs are connected with modified controllers is high compared to the system with only CSGs and variable speed DFIGs with standard control. The instability is completely avoided with variable speed direct drive WTGs with modified controllers.

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