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An Integrated STATCOM Approach for Improvement of Transient Stability of Wind Farm

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ABSTRACT

In this paper a PWM based wind farm model has been presented with three wind turbines. The presented system is capable to provide the system stability in case of varying power generation because of varying speed of wind turbine as well as able to handle the fault over the system. To provide the stability over the system, the statcom based model has been represented in this work. The proposed model is to be developed in Simulink environment. The analysis of the work is in terms of voltage analysis in statcom based and without statcom wind turbine model. The obtained results show that the proposed system are effective to provide the stability over the system.

Keywords: PMSG, STATCOM, PWM based Wind Turbine.

I INTRODUCTION

Non renewable energy sources are exhausting in near future. So for the continuous growth and social progress of the country, it is necessary that power demand is met by utility of renewable energy sources like wind, biomass, solar, thermal etc. The renewable sources are inexhaustible and therefore we can readily access to have the supply of energy from the renewable sources. The various advantages of the renewable energy sources are as follows:

- The solar, wind, geothermal, ocean energy are available in the abundant quantity and free to use.
- The non-renewable sources of energy that we are using are limited and are bound to expire one day.
- Renewable energy sources have low carbon emissions and therefore they are considered as green & environment friendly.
- Renewable energy sources helps in increasing the economy and creating job opportunities. The money that is used to build these plants will provide jobs to thousands to lacs of people.
- We don’t need to depend on any third country for the supply of power as in case of non-renewable sources.

The voltage of wind power generating station generally varies due to nature of wind. When a wind power generating station (wind farm) is integrated to the power grid, power quality issues like injection of harmonics, power factor and distortion of pure sine wave from fundamental frequency. In this scheme, to minimize the power quality problems at the common coupling point of the power grid, STATCOM with battery energy Storage system storage is connected. The STATCOM balances the load and main supply source from the reactive power demand. The proposed model is simulated in MATLAB/SIMULINK power lib. The use of permanent-magnet synchronous generator is the most prime choice for variable speed wind turbines. The advantages of variable speed wind turbines are far more than that of fixed speed technology, active and reactive power balance is easily achieved with the PWM inverter, there is less mechanical stress, and no flicker problem. Variable speed turbine helps grid voltage to be controlled by varying reactive power generation. Gearbox which couples wind turbine with generator increase losses, higher cost of the unit, and increasing faults. The reliability of the variable speed wind turbine has been improved significantly by using permanent magnet synchronous generator (PMSG). Because of the self-excitation property, PMSG is highly efficient and provides higher power factor.

(A) STATCOM

The wind speed is variable in nature, which produces a continuous variable output power. Intermittent nature of wind introduces voltage sags, swells, flickers and harmonics. Integrating large amount of wind farm into existing power system introduces technical challenges, which requires consideration of voltage and frequency changes, stability, power quality problems. Shunt Flexible AC Transmission System (FACTS) devices such as synchronous static compensators (STATCOMs) have the capability to increase voltage quality with its fast response ability, reactive power compensation and voltage control. Recently developed power electronic devices, ICs and DSP system enable the introduction of low cost and faster STATCOMs. Variable speed wind turbine with fast power electronic converters injects harmonic currents in the grid. Variable nature of wind produces variable power and supplying this variable power to the grid introduces voltage variation to the grid in the form of voltage sags, voltage swells and voltage flickers. These problems have a wide impact on the system stability, power quality and it may trip the wind turbine and can damage sensitive electronic devices connected to the grid. STATCOMs connected to the point of common coupling either supply leading reactive power or absorb lagging reactive power and vice versa. So it completely removes reactive power demand part of the grid. STATCOM injects current to the point of common coupling in a way that cancel out the harmonic currents.

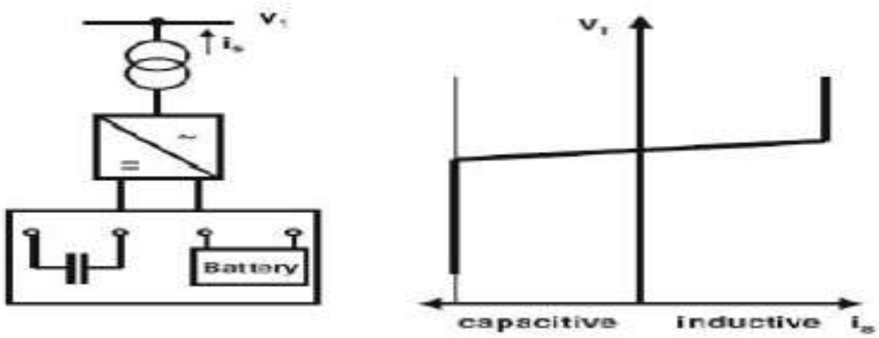

Figure 1: Statcom structure and voltage / current characteristic.

(B) PMSG MODEL

The voltage equation of PMSG are expressed in d- and q- axis reference frame are given by

$$\vec{V}_S = \vec{i}_S R_S + \frac{d\vec{\psi}_S}{dt} \qquad (1)$$

Where is stator flux linkage and can be written as

$$\vec{\psi}_S = L_S \vec{i}_S + L_m \vec{i}_r e^{j\varepsilon} \qquad (2)$$

Now for rotor field orientation we have to shift all axes to rotor field axis orientation, for that we multiply equation 1 with $e^{-j\varepsilon}$, where ε is an angle between stator axis and rotor axis.

$$\vec{V}_S E^{-JZ} = \vec{I}_S E^{-JZ} R_S + E^{-JZ} \frac{D\vec{\Psi}_S}{DT} \qquad (3a)$$

Or we can write

$$V_{sd} + jV_{sq} = \vec{i}_s e^{-jz} R_s + e^{-jz} \frac{d\vec{\Psi}_s}{dt} \qquad (3b)$$

Now differentiating $\vec{\psi}_s e^{-j\varepsilon}$ w.r.t. time we get

$$\frac{d}{dt}(\vec{\psi}_S e^{-j\varepsilon}) = -j\omega_e \vec{\psi}_S e^{-j\varepsilon} + e^{-j\varepsilon} \frac{d\vec{\psi}_S}{dt} \qquad (4a)$$

$$e^{-j\varepsilon} \frac{d\vec{\psi}_S}{dt} = j\omega_e \vec{\psi}_S e^{-j\varepsilon} + \frac{d}{dt}(\vec{\psi}_S e^{-j\varepsilon}) \qquad (4b)$$

Putting this result into equation 3b we get

$$V_{sd} + jV_{sq} = (i_{sd} + ji_{sq}) R_S + \frac{d}{dt}(\vec{\psi}_S e^{-j\varepsilon}) + j\omega_e \vec{\psi}_S e^{-j\varepsilon} \qquad (5)$$

In equation 5 the term $\vec{\psi}_s e^{-j\varepsilon}$ can be substituted from equation 2 by multiplying $e^{-j\varepsilon}$. After solving equation 5 we get

$$V_{sd} = i_{sd}R_s + L_s \frac{di_{sd}}{dt} - \omega_e L_s i_{sq} \quad (6a)$$

And

$$V_{sq} = i_{sq}R_s + L_s \frac{di_{sq}}{dt} + \omega_e L_s i_{sd} + \omega_e \Psi_f \quad (6b)$$

Where, Vsd, Isd, Vsq and Isq are d- axis and q- axis component of stator voltages and currents, Rs is the stator resistance, ωr isthe rotor speed in radian per second Ψf is the flux linkage.

(C) SELF EXCITATION OF WIND TURBINE SYSTEM

The self excitation of wind turbine system with an asynchronous generator takes place after disconnection of wind turbine system (WTGS) with local load. The risk of self excitation arises especially when WTS is equipped with compensating device i.e. capacitor. The capacitor connected to induction generator compensates the reactive power. However the voltage and frequency are determined by the speed balancing of the system. The main disadvantages of self excitation are the safety and balance between active and reactive power.

(D) CONSEQUENCES OF THE ISSUES

The voltage regulation, voltage flicker, harmonics causes the malfunctioning of equipments namely microprocessor based control system, programmable logic controllers; Variable speed drives, flickering of lights and TV screens. It might lead to the tripping of contractors, tripping of protective devices, switching off of sensitive equipments like personal computers, programmable logic control system , may stop the process control systems and even can damage of sensitive equipments. Thus it overall reduces the power quality in the grid.

II LITERATURE REVIEW

Elezabeth Skaria et.al [1] provides an optimized STATCOM control for wind electric generator. The transient behavior of fixed-speed wind farms can be improved by injecting large amounts of reactive power during the fault recovery. This application requires a high dynamic converter, which must also be capable of working under transient unbalanced conditions. The reactive power demand by squirrel cage wind electric generator (SCWEG) during grid faults is not met by capacitor banks installed near SCWEG. This paper analyses the transient stability margin of SCWEG which can be increased to a great extend by means of STATCOM. Here the application of Static Compensator (DSTATCOM) for restoring the voltage level at the Wind Farm terminals under fault conditions is considered. Simulation is done in MATLAB SIMULINK for various conditions and measurement results for both real and reactive power confirm that the STATCOM provide clear transient stability margin increase.

Li Yaohua et.al [7] investigated direct torque control (DTC) for permanent magnet synchronous machine (PMSM). Voltage vector method is preferred over the switching table to reduce the torque ripple. Voltage vector selection based on the control of stator flux, torque angle and torque, voltage vector selection strategy of outputs of hysteresis comparators for stator flux and torque, angular position of stator flux and torque angle, which is further modified by vector modulation (SVM). As compared to conventional DTC results show reduced torque ripple, reduced harmonics of stator current and fixed switching frequency.

J. Khedri [8] et al. presented an inverter voltage moment approach for current and speed control of PMSM. Controllers were designed considering time domain constraints. The Linear Matrix Inequality (LMI) formalism is used for the controller synthesis. Controller ensures the closed-loop stability and specifies transient performances in regard with a reference model. Speed tracking performance of the controller has given satisfactory results.

Seyed Zeinolabedin Moussavi et.al [11] analyzed the permanent magnet dc machine (PMDC) using state space approach. The use of this approach eliminates the possibility of fluctuations in voltage, power and load. They tried to reduce the dangerous results of short circuit and load fluctuation. To achieve this purpose they analyzed classical control and modern control method. Results showed that classical method is related to the external description of system such as input and output, while in modern control method interior description is required. This description is provided by state variables. They used MATLAB for coding and designed a model to reduce the dangerous results of mistakes.

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III PROPOSED MODEL

PMSG model, vector controller and converter which have been simulated in MATLAB Simulink, gives voltage reference to PWM converter to develop the same voltage. The controller gives the reference voltage to converter from the rotor field oriented vector control which is oriented in a synchronously rotating frame. The STATCOM is mainly used for voltage sags mitigation and harmonic elimination at the point of connection. The STATCOM contains the same blocks as that of DVR, but in this application the coupling transformer is connected in shunt with the ac system, as illustrated in Fig 1. The VSC generates a three-phase ac output current which is controllable in phase and magnitude. These currents are injected into the ac distribution system to maintain the proper load voltage at the desired voltage reference. Active and reactive power transfers between the VSC connected in shunt with the ac system gives the multifunctional topology which is to be used for up to three quite distinct purposes:

1) Voltage regulation and reactive power compensation
2) Improvement of power factor;
3) Elimination of current harmonics.

IV SYSTEM OVERVIEW

Figure 2 shows the proposed structure of the wind farm model using PMSG with STATCOM.

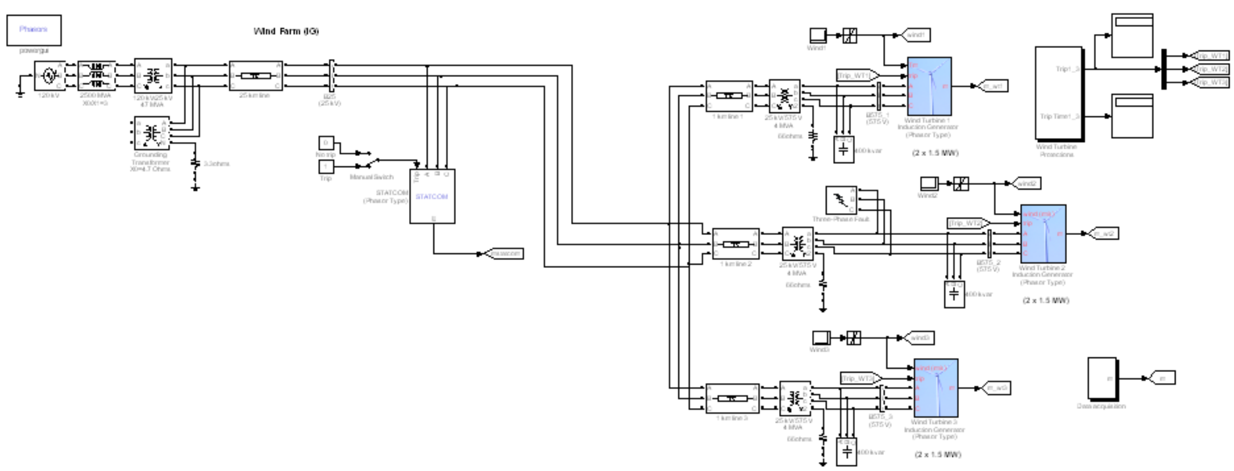

Figure 2: Wind Farm Model using PMSG with STATCOM

As we can see that statcom is connected as the control unit to control the voltage and current of the circuit. The controller provides the stability in case of overloaded and under-load conditions. The result is driven for the bus system.

V Wind Farm Model using PMSG without STATCOM

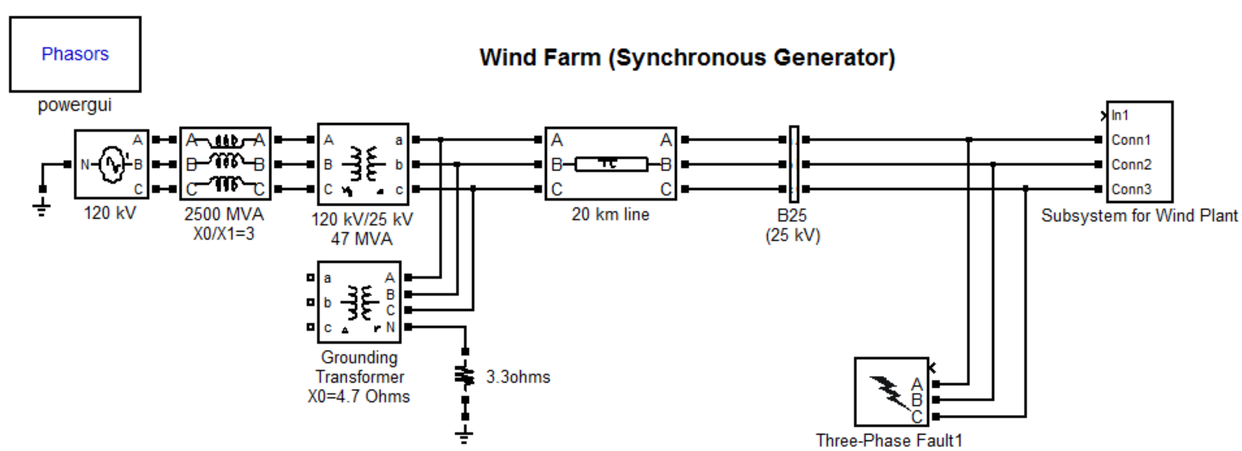

Figure 3: Wind Farm model using PMSG without STATCOM

Here figure 3 is showing the final PMSG based model without STATCOM. As we can see, the system is having the generator and the transformer is attached as the central control unit to control the voltage and current over the circuit. The controller here provides the stability But in case of overloaded and under-load conditions the system will not work.

VI. RESULTS AND DISCUSSION

Using Matlab, we develop a model of wind turbine connected to grid system with statcom, which provide protection to the system against under-load and overload problems. It reveals that, this model gives solution for removing problems and improves power quality.

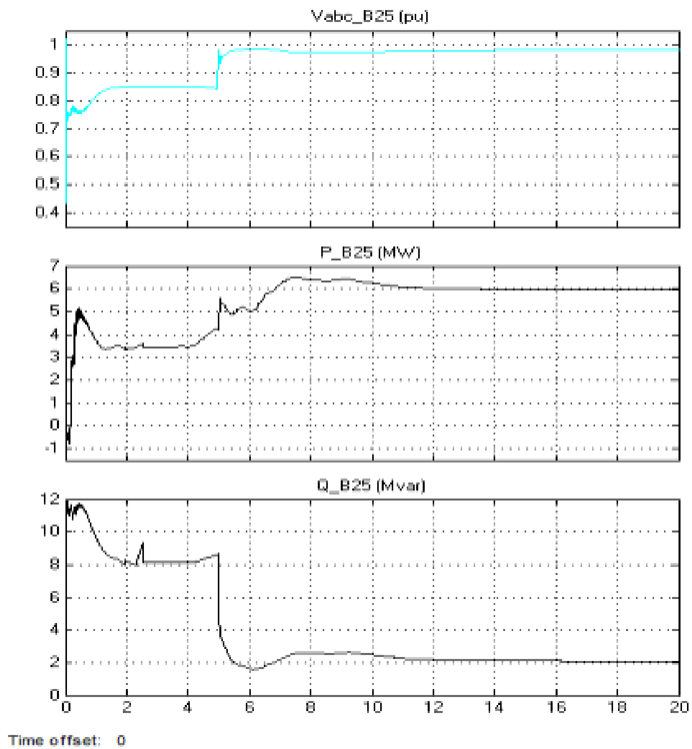

Figure 4: Result of Bus System for both Active and Reactive Power

Here figure 4 is showing the result of bus system in case of statcom based implementation. As we can see the presented system has provided the stability in terms of voltage stability and Active power and reactive power of the system.

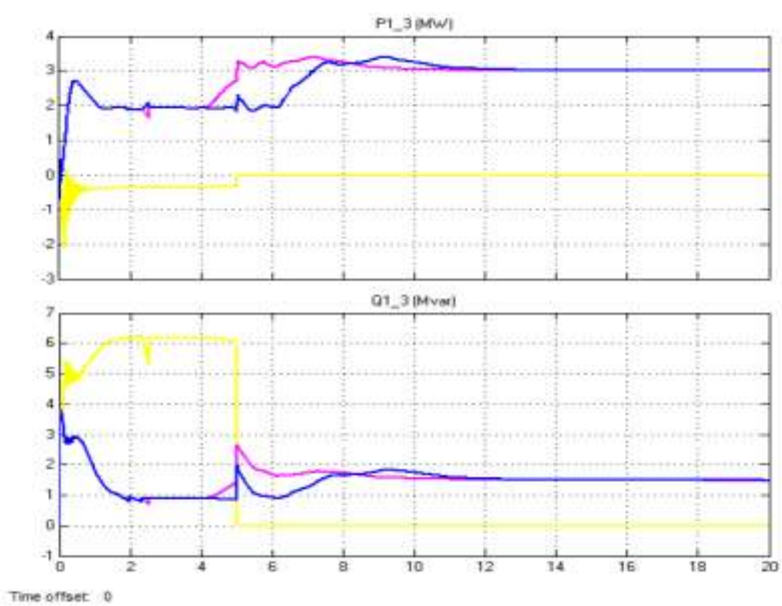

Figure 5: Final Result curve for Active and Reactive Power

Here figure 5 is showing the final result driven in terms of voltage and current over the system. The figure is showing the up and down in initial stage. But the statcom provides the stability of the system.

CONCLUSION

The results are found to be encouraging. In this work, a wind turbine is designed using Statcom based controller. The presented system is effective enough to control the voltage changes and current harmonics over the system. The complete power drive train contains generator, inverter, and Statcom based controller. The system has been verified under the overload and under-load conditions. The system is defined to provide the voltage and current stability over the system. The system is simulated in MATLAB Simulink. The direct driven wind power extraction can give maximum possible efficiency because machine can run at optimum speed. Vector control method provides better performance since lower current harmonic distortion is obtained. The implemented voltage control technique is suitable to drive for wind turbine applications.

FUTURE SCOPE

In this present paper, the wind farm is defined with Statcom based controller. The work can be extended in different directions in future.

- In this paper, the stability of the system is achieved in case of under-load, overload and a three phase fault is created. In future, the system can also be implemented for different kind of faults over the system.
- The Statcom based voltage controller is used in this paper. In future the DSTATCOM or some other controller can be used.

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