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Modelling and Performance Analysis of a Statcom Control for Induction Generator Based Windfarm under Unbalanced Loads

Balaji K , Madhusudanan G

Abstract— **Recently, renewable wind energy is enjoying a rapid growth globally to become an important green electricity source to replace polluting and exhausting fossil fuel. However, Injection of the wind power into an electric grid affects the power quality [1]. The paper study demonstrates the power quality problem due to installation of wind turbine with the grid and also investigations on an induction generator based wind farm in combination with a STATCOM under unbalanced load fault on grid is carried out on main line. A STATCOM control structure with the capability to coordinate the control between the positive and the negative sequence of the grid voltage is proposed. The results clarify the effect of the positive and the negative sequence voltage compensation by a STATCOM on the operation of the induction generator based wind farm [2]. The STATCOM control scheme for the grid connected wind energy generation system for power quality improvement is simulated using MATLAB/SIMULINK in power system block set. Finally the proposed scheme is applied for both balanced and unbalanced loads.**

Index Terms — **Power Quality, Wind Generating System (WGS), Induction Generator, Low-Voltage Ride Through, Statcom**

I. Introduction

TO have sustainable growth and social progress, it is necessary to meet the energy need by utilizing the renewable energy resources like wind, biomass, hydro, co-generation, etc. in sustainable energy system, energy conservation and the use of renewable source are the key paradigm. The need to integrate the renewable energy like wind energy into power system is to make it possible to minimize the environmental impact on conventional plant The integration of wind energy into existing power system presents a technical challenges and that requires consideration of voltage regulation, stability, power quality problems. The power quality is an essential customer-focused measure and is greatly affected by the operation of a distribution [3]

Permanent-magnet synchronous generator, a non-negligible percentage of 15% of the operating wind turbines in Europe in 2010 is still of the fixed-speed induction generator (FSIG)-type directly connected to the grid because this generator type cannot provide reactive power control, it cannot fulfill the demanding grid code requirements without additional devices. During voltage dips, the induction Generators may consume a large amount of reactive power as their speed deviates from the synchronous speed, which can lead to a voltage collapse and further fault propagation in the network. [2]

Today, more than 28 000 wind generating turbines are successfully operating all over the world. In the fixed-speed wind turbine operation, all the fluctuation in the wind speed are transmitted as fluctuations in the mechanical torque, electrical power on the grid and leads to large voltage fluctuations. During the normal operation, wind turbine produces a continuous variable output power. These power variations are mainly caused by the effect of turbulence, wind shear, and tower-shadow and of control system in the power system. Thus, the network needs to manage for such fluctuations. The power quality issues can be viewed with respect to the wind generation, transmission and distribution network, such as voltage sag, swells, flickers, harmonic etc. However the wind generator introduces disturbances into the distribution network. One of the simple methods of running a wind generating system is to use the induction generator connected directly to the grid system. The induction generator has inherent advantages of cost effectiveness and robustness. However; induction generators require reactive power for magnetization. When the generated active power of an induction generator is varied due to wind, absorbed reactive power and terminal voltage of an induction generator can be significantly affected. A proper control scheme in wind energy generation system is required under normal operating condition to allow the proper control over the active power production. In the event of increasing grid disturbance, a battery energy storage system for wind energy generating system is generally required to compensate the fluctuation generated by wind turbine. A STATCOM based control technology has been proposed for improving the power quality which can technically manages the power level associates with the commercial wind turbines.

The proposed STATCOM control scheme for grid connected wind energy generation for power quality improvement has following objectives.

• Unity power factor at the source side.
• Reactive power support only from STATCOM to wind Generator and Load.
• Simple bang-bang controller for STATCOM to achieve fast dynamic response. [3]

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Balaji.K, Power System Engineering, Valliammai Engineering College, Chennai, India, 9894341900

Madhusudanan.G, Electrical and Electronics Engineering, Valliammai Engineering College, Chennai, India.

This paper proposes the application of a statcom that is connected to an FSIG-based wind farm and used to control the positive- and the negative-sequence voltage during grid faults. The novel contribution of this paper lies in the coordination of the positive- and the negative-sequence voltage control by the statcom and the related effect on the wind turbine behavior. While the positive-sequence voltage compensation leads to an increased voltage stability of the wind farm, the negative sequence voltage compensation leads to a reduction of torque ripple, increasing the lifetime of the generator drive train. [2]

The paper is organized as fallows. The Section II introduces the, issues and its consequences of wind energy conversion model. The Section III introduces the induction generator detailed model. The Section IV describes the topology for. The Sections IV, V, VI describes the control scheme, system performance and conclusion respectively.

This paper is structured as follows. The investigated power system is described in Section II. An analysis of the power quality issues in Section III is followed by the presentation of the proposed statcom control structure in Section IV. Simulation results are given in Section V. Under the unbalanced grid voltage condition, the statcom is controlled here to either compensate the positive- or the negative sequence voltage.

II. WIND ENERGY CONVERSION MODEL

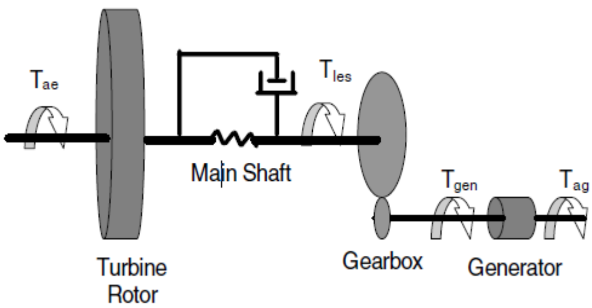

Fig 1. Detailed model of a single wind energy conversion system

A. Blade Model

The torque got from the turbine rotor is shown:

$$Tae = 1/2\ \pi\rho Ct\ (\lambda) R3\ Vw\ 2 \quad (1)$$

where ρis the air density:R is the wind turbine radius: $\lambda = \Omega R/Vw$ is the ratio of blade tip speed to wind speed

B. Hub Model

$$\frac{dTlss}{dt} = \frac{1}{Ta}(T_{ae}\text{-}T_{lss}) \quad (2)$$

Where Tae is the wind turbine torque; Tlss is the turbine shaft torque; and Ta is the hub constant in [4].

III. POWER QUALITY ISSUES

A. Voltage fluctuation on grid:

The power fluctuation from wind turbine during continuous operation causes voltage fluctuation on grid. The amplitude of this fluctuation depends on grid strength, network impedance, and phase angle and power factor [3]. The voltage fluctuation and flicker are caused due to switching operation, pitch error, yaw error, fluctuation of wind speed. Today, the measurement and assessment of power quality on grid connected wind turbine is defined by IEC 61400-21 and stated that the 10 minute average of voltage fluctuation should be within +/- 5% of nominal value

B. Switching operation of wind turbine on the grid.

Switching operations of wind turbine generating system can cause voltage fluctuations and thus voltage sag, voltage swell that may cause significant voltage variation. The acceptances of switching operation depend not only on grid voltage but also on how often this may occur. The maximum number of above specified switching operation within 10-minute period and 2-hr period are defined in IEC 61400-3-7 Standard.

C. Voltage dips on the grid.

It is a sudden reduction of voltage to a value between 1% & 90 % of nominal value after a short period of time, conventionally 1ms to 1 min.

D. Reactive Power

Traditional wind turbine is equipped with induction generator. Induction Generator is preferred because they are inexpensive, rugged and requires little maintenance. Unfortunately induction generators require reactive power from the grid to operate. The interactions between wind turbine and power system network are important aspect of wind generation system. When wind turbine is equipped with an induction generator and fixed capacitor are used for reactive compensation then the risk of self-excitation may occur during off grid operation.

E. Harmonics

The harmonics distortion caused by non-linear load, Saturation of magnetization of transformer and a distorted line current. The current generated by such load interact with power system impedance and gives rise to harmonics. The effect of harmonics in the power system can lead to degradation of power quality at the consumer's terminal, increase of power losses, and malfunction in communication system [16]

IV. STATCOM CONTROL STRUCTURE

STATCOM is a controlled reactive power source. It provides the reactive power generation and absorption by using a Voltage Source Converter (VSC).The active power absorption or generation capability of the STATCOM **is** normally used under special circumstances such as to enhance the steady state and transient voltage control, and to improve the sag elimination capability [5].

The Statcom control structure is based on a voltage oriented vector control as usually applied to three phase grid connected converters. It is a cascade control structure with inner PI current controllers in a rotating dq reference frame with grid voltage orientation. Resonant controllers tuned at 100 Hz in the same positive dq reference frame are added to realize the negative sequence current control. Note, that the control of the negative sequence currents can also be performed in a negative rotating reference frame with PI controllers, but by using resonant controllers in a positive rotating reference frame there is no need for a sequence separation of the currents.

The overall control structure is shown in Fig 2. Note that a possible Statcom power circuit is shown here as a voltage source converter connected to the grid by an LCL filter, while the Statcom is modeled as a three phase controlled voltage source in the simulations neglecting the switching behavior.

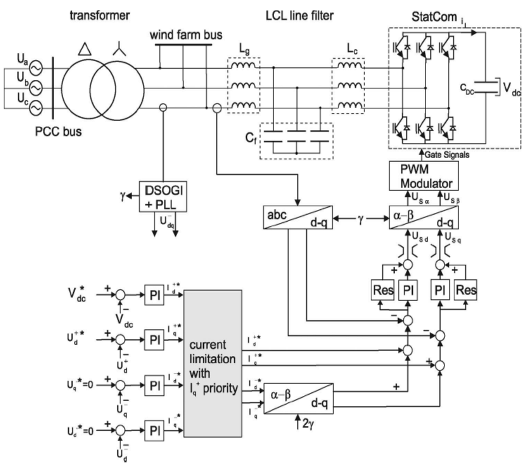

Fig.2 Proposed control structure of the Statcom to control the positive- and the negative-sequence voltage independently.

The outer control loops are designed to control the DC voltage and the positive and negative sequence of the voltage at the connection point of the Statcom. Therefore a precise sequence separation of the measured voltage into positive and negative sequence components is necessary, which is performed based on dual second order generalized integrators. Using the sequence separation the positive and negative sequence of the voltage appears as DC values and can be controlled by PI controllers. To ensure a safe operation of the Statcom within its current capability the current references given by the four outer controllers must be limited to the maximum statcom current. [6]

For the investigations under unbalanced grid fault different control targets will be compared to clarify the effect of positive or negative sequence voltage compensation on the operation of the induction generators. The target of the first method is to compensate the positive sequence voltage, while the negative sequence voltage will remain unchanged. The target of the second method is to eliminate the negative sequence of the voltage, while the positive sequence voltage will remain unchanged.

V. SIMULATION AND ANALYSIS

Fig.4 shows the complete MATLAB model of Wind energy generating system along with STATCOM control circuit. The power circuit as well as control system are modeled using Power System Block Set and Simulink. The grid source is represented by three phase AC source (wind energy and ac supply are injected through grid by using linear transformer).Three phase AC loads are connected at the load end. STATCOM is connected in shunt and it consists of PWM voltage source inverter circuit and a DC capacitor connected at its DC bus. The three phase injected current into the grid from STATCOM will cancel out the distortion caused by the nonlinear load and wind generator. The IGBT based three-phase inverter is connected to grid through the transformer.

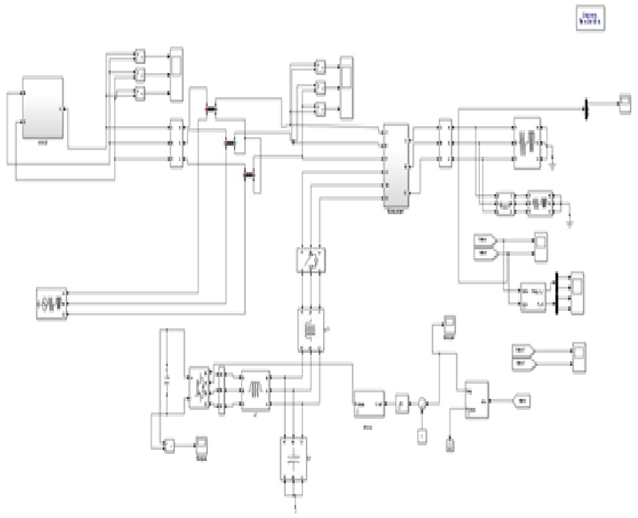

Fig.4 MATLAB/SIMULINK Modeling Of Grid Connected WECS with STATCOM Controller

A. STATCOM –Performance Under Voltage Variations

The wind energy generating system is connected with grid having the nonlinear load. The performance of the system is measured by switching the STACOM at time t=0.5s in the system and how the STATCOM responds to the step change command for increase in additional load at 1.0 s is shown in the simulation. When STATCOM controller is made ON, without change in any other load condition parameters, it starts to mitigate for reactive demand as well as harmonic current. The dynamic performance is also carried out by step change in a load, when applied at 1.0 s. This additional demand is fulfill by STATCOM compensator. Thus, STATCOM can regulate the available real power from source. The result of source side three phase voltages, load current and voltage are shown in Fig.5 and 6 respectively.

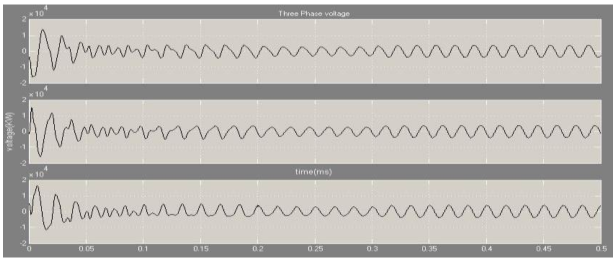

Fig.5 Source side three phase voltage waveform

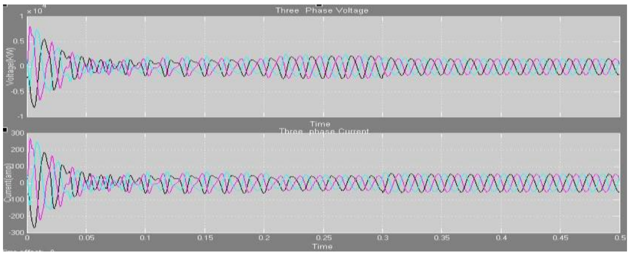

Fig.6 Load side current and voltage waveform

B. *Positive and negative sequences voltage*

The results of this section enhance the understanding of the voltage control performed by the Statcom and the resulting operation of the induction generators. A STATCOM control structure with the capability to coordinate the control between the positive and the negative sequence of the grid voltage is proposed. The results clarify the effect of the positive and the negative sequence voltage compensation by a STATCOM on the operation of the induction generator based wind farm. The capability of the statcom to compensate a voltage component depends on the chosen current rating of the statcom and the impedance of the power system. For a high current rating of the statcom and a weak power system (with high system impedance), the voltage compensation capability of the statcom is also increased.

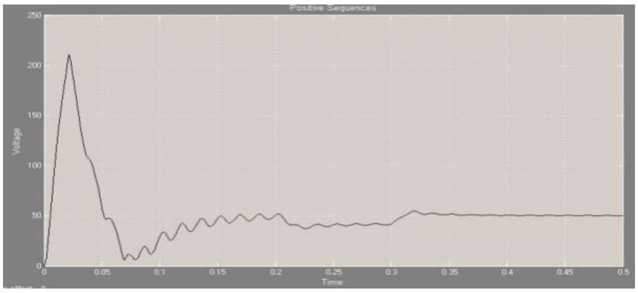

Fig.7 Positive Sequence Voltage Waveform

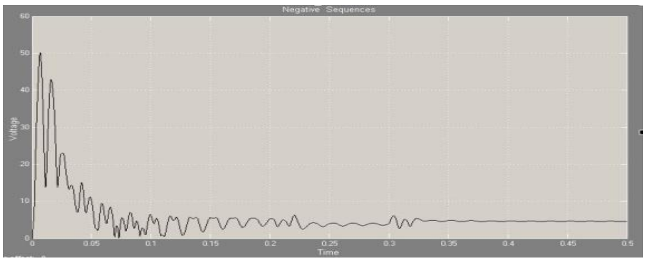

Fig.8 Negative Sequence Voltage Waveform

C. *Power Quality Improvements*

It is observed that the source current on the grid is affected due to the effects of nonlinear load and wind generator, thus purity of waveform may be lost on both sides in the system. The dynamic load does affect the inverter output voltage. The Fourier analysis of this waveform is expressed and the THD of this source current at PCC without STATCOM is 8.71%, as shown in Fig. 5.9. The power quality improvement is observed at point of common coupling, when the controller is in ON condition. The STATCOM is placed in the operation at 0.5 s and source current waveform is shown in Fig. 5.9 with its FFT. It is shown that the THD has been improved considerably and within the norms of the standard.

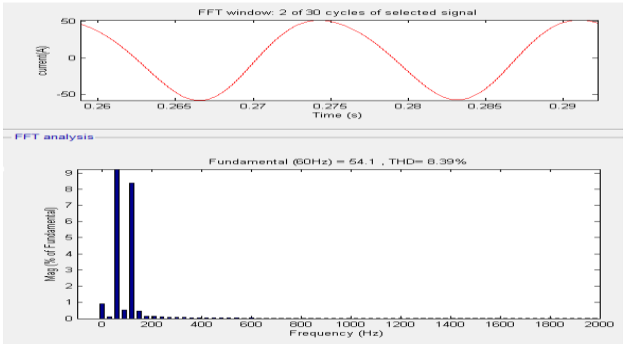

Fig.9 Source current and fft of source current

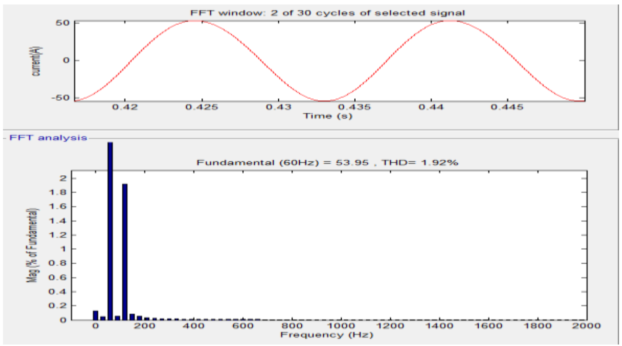

Fig.10 Source current and fft of source current

VI. Conclusion

In this project investigate the power quality problem due to installation of wind turbine with the grid and also investigations on an induction generator based wind farm in combination with a STATCOM under unbalanced load fault on grid is carried out on main line is simulated and analyzed. A STATCOM control structure with the capability to coordinate the control between the positive and the negative sequence of the grid voltage is analyzed. The results clarify the effect of the positive and the negative sequence voltage compensation by a STATCOM on the operation of the induction generator based wind farm. The effectiveness of the proposed scheme relives the main supply source from the reactive power demand of the load and the induction generator

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Balaji.K, Power System Engineering, Valliammai Engineering College, Chennai, India, 9894341900

Madhusudanan.G, Electrical and Electronics Engineering, Valliammai Engineering College, Chennai, India.