International Journal of Advanced Information in Engineering Technology (IJAIET) ISSN: 2454-6933
Vol.3, No.12, December 2016

Sequence Voltage Compensation by STATCOM for Voltage Stability in Wind farms

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***Abstract*—In conventional generation, the contribution of wind power is increasing nowadays. The wind plants with induction generator exhibit a different behavior than the conventional synchronous generators. The stability of fixed speed induction generator (FSIG) wind turbines can be improved by Static Synchronous Compensator STATCOM. A STATCOM control with the capability to coordinate the control between positive and negative sequence voltages, and thus compensating the reactive power and torque oscillations respectively are evaluated by means of simulations a for three phase fault.**

Keywords— wind energy, STATCOM, Reactive power contol, positive sequence voltage.

I. Introduction

For the sustainable growth of the economy energy conservation is essential. It can be achieved by meeting the energy demand using the fossil fuels in the cleanest possible way and maximize the utilization of renewable energy sources like wind, biomass, solar, hydro etc. The integration of wind energy into the existing power system causes many power quality issues like voltage variations, frequency variations, voltage transients, flickers.

There has been an extensive growth and quick development in the wind power industry in recent years[1]. There is only one way of generating electricity from wind energy, which is to use wind turbines that can convert the energy contained in flowing air into electricity. Fixed speed wind turbines utilize squirrel cage induction generator directly connected to the grid to produce the electricity[3]. Under faulty conditions, these induction generators draw large amount of reactive power. This reduces the electrical output power and terminal voltage, but the rotor speed eventually increases. So after fault clearance, the terminal voltage is to be recovered by supplying reactive power by the network itself. But this further reduces the voltage and hence the terminal voltage cannot be recovered by itself. Thus stability becomes an important aspect of power system. Moreover, the unbalanced load at the distribution line leads to unbalanced voltage conditions[4]. While the voltage is small, the negative sequence current is large and this current causes unbalanced heating in the winding resulting in the degradation of induction generator[5]. The squirrel cage induction generator needs the support of an external device (FACTS) in order to remain connected during voltage dips. The STATCOM is one of these types that deliver reactive power required to accelerate the voltage restoration.

II. Power System Stability Concepts

In conventional power system there are mainly three concepts of power system stability. These are described as follows:

(a) Voltage Stability – It is the ability of power system to maintain steady acceptable voltages at all buses in the system under normal operating conditions after being subjected to a disturbance.

(b) Rotor angle stability- When all the synchronous machines in a power system run in synchronism with each other even after being subjected to a disturbance, the power system is said to possess rotor angle stability.

(c) Frequency Stability- Whenever there is a gap in the load demand and generation in a power system its operating frequency drops. So a power system which is capable of maintaining a constant system frequency during such conditions is said to possess frequency stability.

(d) Rotor speed stability- The ability of FSIG based wind generators to maintain a fixed mechanical speed which is near to the speed corresponding to the actual power system frequency even if it is subjected to a disturbance[6].

III. Power System Description

The general layout of a power system which was simulated for study is drawn in Fig. 1 below. The simulations were carried out by power system modeling tool called SIMPOWER SYSTEM in the SIMULINK environment of MATLAB software. The power system consists of a wind farm containing 50 MVA, FSIG based wind turbines, and the induction generator connected with the turbine operates at a power factor of 0.9. For reactive power compensation a shunt capacitor has been connected at the generator terminals. Two step-up transformers of 100 MVA have been connected between the wind farm and rest of the grid.

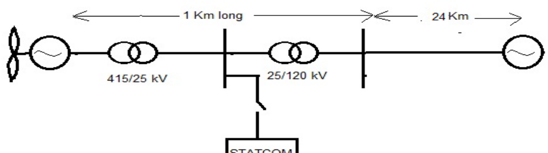

Fig. 1. Single line diagram of studied system

The wind turbine model used is a variable pitch turbine but for the given case it is run at a constant pitch of 0 degrees at a base wind speed of 12 m/s. The stiffness of the drive train is considered to be infinite and the Inertia and friction factor is considered together with the generator to which it is coupled. The wind turbine is coupled with an induction generator squirrel cage type[1]. The stator of generator is connected with the grid directly and rotor is driven by the wind turbine. The wind power captured by the turbine is converted into electrical power by the induction generator and is transmitted to the grid through the stator windings. The pitch angle of turbine is fixed or in a way the pitch angle control has been disabled to run it at a constant mechanical power output. In order to generate power the generator rotor speed must be slightly higher than its synchronous speed. Since the speed variation of squirrel cage wind generator is very less hence they are called fixed speed wind generators. The reactive power absorbed by the induction generator during transients is provided by the grid or by some devices like capacitor banks, SVC & STATCOM.

IV. Mathematical Modelling Of Few Power System Components

A. Wind Turbine Model

The model of wind turbine used for the purpose of simulation is a per unit model based on the steady state power equation of a wind turbine. The gear train used for coupling the generator with the grid is assumed to have infinite stiffness while the friction factor component and the inertia of the turbine is aggregated with these quantities of the electric generator coupled with the turbine.

$$P_m = C_p(\lambda\ \beta)\ \rho\ AV^3_{wind} \qquad (1)$$

Here P_m= mechanical power developed by the wind turbine, Cp= power coefficient of the turbine, ρ is the density of air striking the turbine blades (kg/m^3), A is the swept area of the rotor blades of the turbine (m^2), λ is the tip-speed ratio, β is the pitch angle (degrees).

B. STATCOM Model

A STATCOM (Fig. 2) consists of a three phase inverter (generally a PWM inverter) using IGBTs, a dc capacitor which provides the dc voltage for the inverter, a link reactor which links the inverter output to the ac supply side, filter components to filter out the high frequency components due to the PWM inverter. From the dc side capacitor, a three phase voltage is generated by the inverter. This is synchronized with the ac supply. The link inductor links this voltage to the ac supply side. This is the basic principle of operation of STATCOM[2].

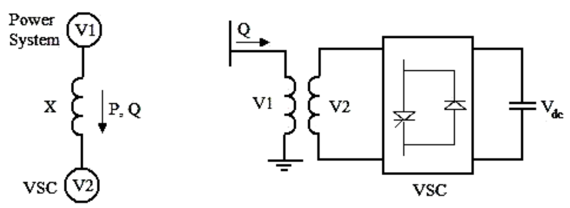

Fig. 2. A Statcom

For two AC sources which have the same frequency and are connected through a series inductance, the active power flows from the leading source to the lagging source and the reactive power flows from the higher voltage magnitude source to the lower voltage magnitude source. The phase angle difference between the sources determines the active power flow and the voltage magnitude difference between the sources determines the reactive power flow. Thus, a STATCOM can be used to regulate the reactive power flow by changing the magnitude of the VSC voltage with respect to source bus voltage.

V. Approach Used For Stability Enhancement By STATCOM In Given System

In the simulated power system represented in fig.1, a transient condition i.e. a three phase fault was simulated in the power system. For this purpose the 25 km. transmission line which connects the grid with the wind power plant was divided into two parts having the length of 1 km. and 24 km respectively. In order to analyze the performance of STATCOM in improving the transient stability margin of the given power system three parameters of the power system were monitored during a three phase fault for a time duration from 0.1 sec to 0.2 sec. These parameters are the voltage and reactive power at the point of common coupling (PCC) and electromagnetic torque. A relative comparison of voltage recovery time at PCC of the wind generator is performed by the simulation when the power system is supported with and without STATCOM.

The StatCom control structure is based on the voltage oriented vector control scheme [26] as usually applied to three-phase grid-connected converters. It is a cascade control structure with inner proportional integral (PI) current controllers in a rotating dq reference frame. Resonant controllers (Res) tuned at 100 Hz in the same positive dq reference frame are added to realize the negative sequence current control. The outer control loops are designed to control

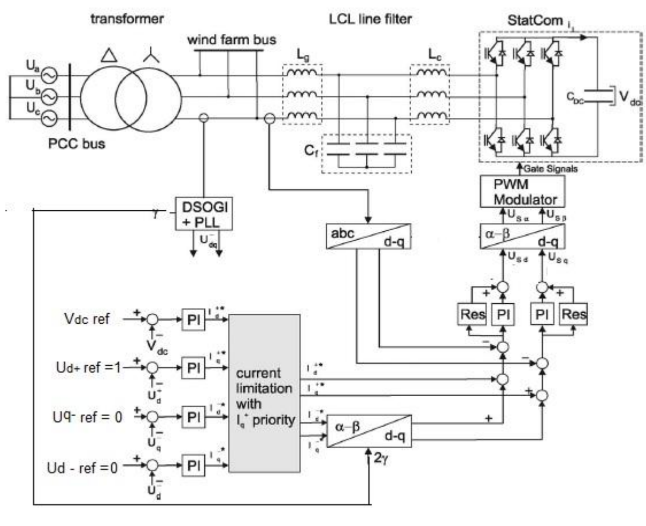

Fig. 3 Control structure of STATCOM

the dc voltage and the positive and negative sequences of the voltage at the connection point of the StatCom. The separation of the measured voltage into positive- and negative sequence components is necessary performed based on dual second-order generalized integrators (DSOGI-PLL).

To ensure a safe operation of the STATCOM, the current references of the four outer controllers must be limited to the maximum STATCOM current with the priority to positive-sequence reactive current Iq^{+}. Thus, the STATCOM ensures the maximum fault-ride-through enhancement of the wind farm. If there is a remaining STATCOM current capability, the STATCOM compensates the negative-sequence voltage and reduces the torque ripple during the grid fault. The positive- and negative-sequence current references are added. The negative-sequence current references must be transformed into the positive rotating reference frame by a coordinate transformation with twice the grid voltage angle.

VI. SIMULATION AND RESULTS

The first parameter to be monitored is the voltage at PCC. It can be observed from Fig.4 that prior to the fault occurrence; the voltage at PCC was 1.74 p.u. value. During the fault, the voltage is dipped to 0.76. But even after the fault recovery time, voltage is not recovered to its original value, that is voltage instability has occurred. By using a dynamic reactive power support like STATCOM, the voltage is recovered soon after the fault recovery to its pre fault value, Fig 5. This stability is achieved by injecting positive sequence STACOM voltage.

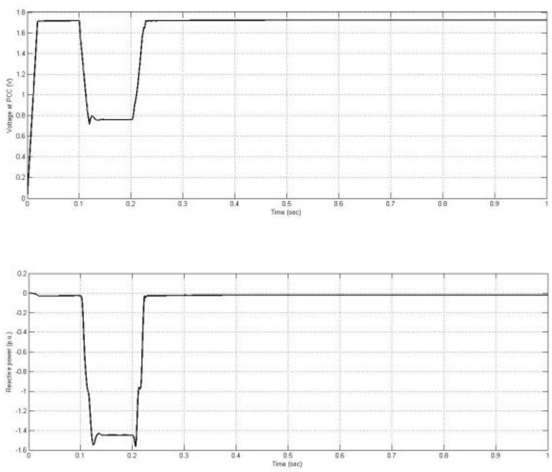

Fig 4. Variations of Voltage and reactive power at PCC without STATCOM during three-line to ground fault

Similarly, comparing the reactive powers at PCC in the power system it can be observed that the reactive power absorption at PCC after the fault and its recovery suddenly increases and never returns to its pre fault value. STATCOM helps in bringing the reactive power to its pre fault value.

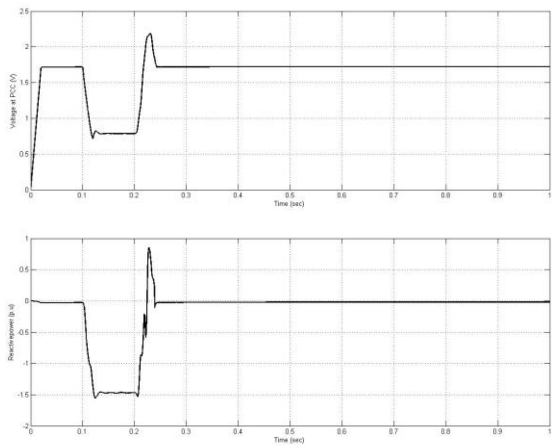

Fig.5. Variations of Voltage at PCC and reactive power during three-line to ground fault- with STATCOM

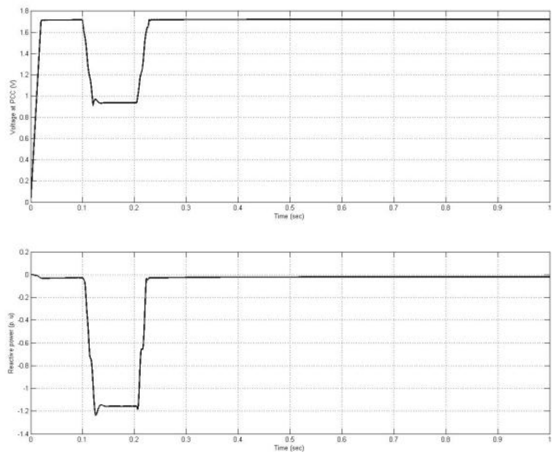

Fig 6. Variations of Voltage and reactive power at PCC without STATCOM during double-line to ground fault

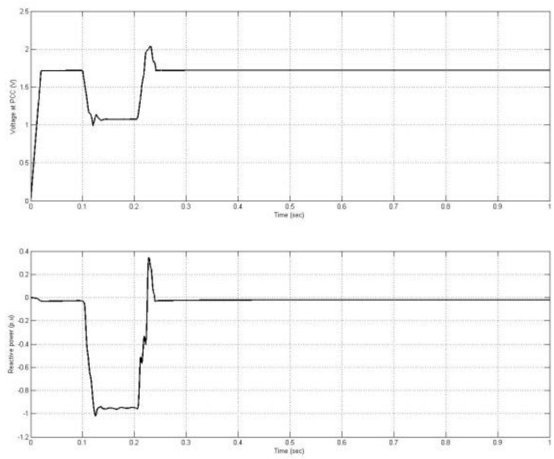

Fig.7. Variations of Voltage at PCC and reactive power during double-line to ground fault- with STATCOM

TABLE I. REACTIVE POWER RECOVERY TIME

Fact Devices	***No Fact device***	***STATCOM***	***STATCOM***
		LLL-G fault	*LL-G fault*
Reactive power (Q) recovery time (sec)	No recovery	0.243	0.251

Conclusion

The effects of fault on the behavior of wind farm interconnected during different fault types are studied. Also, the impact of Static Synchronous Compensator STATCOM with the ability to compensate the sequence voltages, on the stability of the system is also analyzed. The wind farm terminal voltage and reactive power are monitored in steady state and fault states are analyzed. STATCOM is a power electronic device that is capable of improving the power system transients' performance and the quality of power. Whenever a fault occurs, the positive sequence voltage compensation leads to voltage stability and the negative sequence voltage compensation leads to reduction of torque ripple. The reactive power compensation is also performed by the STATCOM during the fault.

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