A New Control Scheme for Power Quality Improvement with STATCOM

K. Sheshu Kumar, K. Suresh Kumar, Sk Baji

Abstract

The influence of the wind turbine in the grid system concerning the power quality measurements are-the active power, reactive power, variation of voltage, flicker, harmonics, and electrical behavior of switching operation and these aremeasured according to national/international guidelines. The main functional requirements of the STATCOM in this thesis are to provide shunt compensation, operating in capacitive mode only, in terms of the following; Voltage stability control in a power system, as to compensate the loss voltage along transmissionThe paper study demonstrates the power quality problem due to installation of wind turbine with the grid. In this proposed scheme STATCOM is connected at a point of common coupling . 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.

Key words: STATCOM, BESS, Power quality, Wind energy System (WES).

I. Introduction

Flexible AC Transmission Systems, called FACTS, got in the recent years a well-knownterm for higher controllability in power systems by means of power electronic devices. Several FACTS-devices have been introduced for various applications worldwide. A number of new types of devices are in the stage of being introduced in practice. In most of the applications the controllability is used to avoid cost intensive or landscape requiring extensions of power systems, for instance like upgrades or additions of substations and power lines. FACTS-devices provide a better adaptation to varying operational conditions and improve the usage of existing installations [1]. The basic applications of FACTS-devices are Power flow control, Increase of transmission capability, Voltage control, Reactive power compensation, Stability improvement, Power quality improvement, Power conditioning, Flicker mitigation, Interconnection of renewable and distributed generation and storages.

The influence of FACTS-devices is achieved through switched or controlled shunt compensation, series compensation or phase shift control. The devices work electrically as fast current, voltage or impedance controllers. The power electronic allows very short reaction times down to far below one second.

The right column of FACTS-devices contains more advanced technology of voltage source converters based today mainly on Insulated Gate Bipolar Transistors (IGBT) or Insulated Gate Commutated Thyristors (IGCT). Voltage Source Converters provide a free controllable voltage in magnitude and phase due to a pulse width modulation of the IGBTs or IGCTs. High modulation frequencies allow to get low harmonics in the output signal and even to compensate disturbances coming from the network. The disadvantage is that with an increasing switching frequency, the losses are increasing as well. Therefore special designs of the converters are required to compensate this[2].

II. STATIC SYNCHRONOUS COMPENSATOR (STATCOM)

The STATCOM is a solid-state-based power converter version of the SVC. Operating as a shunt-connected SVC, its capacitive or inductive output currents can be controlled independently from its terminal AC bus voltage. Because of the fast-switching characteristic of power converters, STATCOM provides much faster response as compared to the SVC. In addition, in the event of a rapid change in system voltage, the capacitor voltage does not change instantaneously[2]-[5]; therefore, STATCOM effectively reacts for the desired responses. For example, if the system voltage drops for any reason, there is a tendency for STATCOM to inject capacitive power to support the dipped voltages. STATCOM is capable of high dynamic performance and its compensation does not depend on the common coupling voltage. Therefore, STATCOM is very effective during the power system disturbances.

2.1 CONTROL OF STATCOM

The controller of a STATCOM operates the converter in a particular way that the phase angle between the converter voltage and the transmission line voltage is dynamically adjusted and synchronized so that the STATCOM generates or absorbs desired VAR at the point of coupling connection. Figure 3.4 shows a simplified diagram of the STATCOM with a converter voltage source __1*E* and a tie reactance, connected to a system with a voltage source, and a Thevenin reactance, X*TIEX_THV*$_{TH}$.

2.2 Two Modes of Operation

There are two modes of operation for a STATCOM, inductive mode and the capacitive mode. The STATCOM regards an inductive reactance connected at its terminal when the converter voltage is higher than the transmission line voltage. Hence, from the system's point of view, it regards the STATCOM as a capacitive reactance and the STATCOM is considered to be operating in a capacitive mode. Similarly, when the system voltage is higher than the converter voltage, the system regards an inductive reactance connected at its terminal. Hence, the STATCOM regards the system as a capacitive reactance and the STATCOM is considered to be operating in an inductive mode. In other words, looking at the phasor diagrams on the right of Figure 3.4, when1*I*, the reactive current component of the STATCOM, leads (*THVE*−1) by 90º, it is in inductive mode and when it lags by 90º, it is in capacitive mode. This dual mode capability enables the STATCOM to provide inductive compensation as well as capacitive compensation to a system. Inductive compensation of the STATCOM makes it unique. This inductive compensation is to provide inductive reactance when overcompensation due to capacitors banks occurs. This happens during the night, when a typical inductive load is about 20% of the full load, and the capacitor banks along the transmission line provide with excessive capacitive reactance due to the lower load. Basically the control system for a STATCOM consists of a current control and a voltage control.

III. BASIC OPERATING PRINCIPLES OF STATCOM

The STATCOM is connected to the power system at a PCC (point of common coupling), through a step-up coupling transformer, where the voltage-quality problem is a concern. The PCC is also known as the terminal for which the terminal voltage is U_T. All required voltages and currents are measured and are fed into the controller to be compared with the commands. The controller then performs feedback control and outputs a set of switching signals (firing angle) to drive the main semiconductor switches of the power converter accordingly to either increase the voltage or to decrease it accordingly. A STATCOM[6]-[9] is a controlled reactive-power source. It provides voltage support by generating or absorbing reactive power at the point of common coupling without the need of large external reactors or capacitor banks. Using the controller, the VSC and the coupling transformer, the STATCOM operation is illustrated in Figure below.

The charged capacitor C_{dc}provides a DC voltage, $U_{dc}$to the converter, which produces a set of controllable three-phase output voltages, U in synchronism with the AC system. The synchronism of the three-phase output voltage with the transmission line voltage has to be performed by an external controller. The amount of desired voltage across STATCOM, which is the voltage reference, Uref, is set manually to the controller. The voltage control is thereby to match U_T with Uref which has been elaborated. This matching of voltages is done by varying the amplitude of the output voltage U, which is done by the firing angle set by the controller. The controller thus sets U_T equivalent to the Uref. The reactive power exchange between the converter and the AC system can also be controlled. This reactive power exchange is the reactive current injected by the STATCOM, which is the current from the capacitor produced by absorbing real power from the AC system.

IV. TOPOLOGY FOR POWER QUALITY IMPROVEMENT

The STATCOM based current control voltage source inverter injects the current into the grid in such a way that the source current are harmonic free and their phase-angle with respect to source voltage has a desired value. The injected current will cancel out the reactive part and harmonic part of the load and induction generator current, thus it improves the power factor and the power quality. To accomplish these goals, the grid voltages are sensed and are synchronized in generating the current command for the inverter. The proposed grid connected system is implemented for power quality improvement at point of common coupling (PCC), as shown in Fig. 1. The grid connected system in Fig. 1, consists of wind energy generation system and battery energy storage system with STATCOM.

4.1. Wind Energy Generating System

In this configuration, wind generations are based on constant speed topologies with pitch control turbine. The induction generator is used in the proposed scheme because of its simplicity, it does not require a separate field circuit, it can accept constant and variable loads, and has natural protection against short circuit. The available power of wind energy system is presented as under in (6).

$$P_{wind} = \frac{1}{2}\rho A V_{wind}^3 \qquad (6)$$

Where *p* (kg/m) is the air density and A (m2) is the area swept out by turbine blade, Vwind is the wind speed in mtr/s. It is not possible to extract all kinetic energy of wind, thus it extract a fraction of power in wind, called power coefficient *Cp*of the wind turbine, and is given in (7).

$$P_{mech} = C_p P_{wind} \qquad (7)$$

Where *Cp*is the power coefficient, depends on type and operating condition of wind turbine. This coefficient can be express as a function of tip speed ratio and pitch angle. The mechanical power produce by wind turbine is given in (8)

$$P_{\text{mech}} = \frac{1}{2}\rho \Pi R^2 V_{\text{wind}}^3 C_p \quad (8)$$

Where R is the radius of the blade (m).

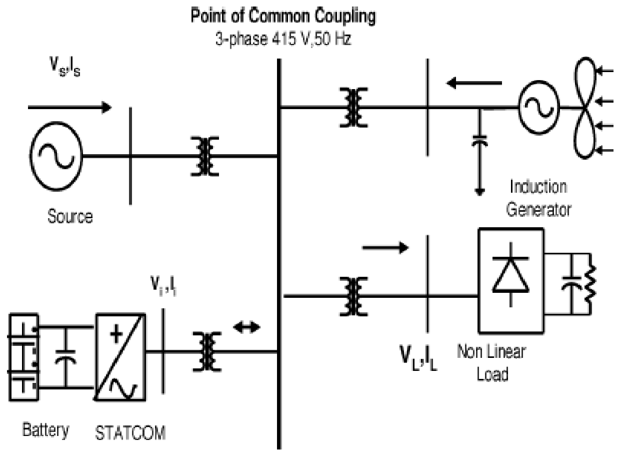

Fig. 1. Grid connected system for power quality improvement.

4.2 BESS-STATCOM

The battery energy storage system (BESS) is used as an energy storage element for the purpose of voltage regulation. The BESS will naturally maintain dc capacitor voltage constant and is best suited in STATCOM since it rapidly injects or absorbed reactive power to stabilize the grid ystem. It also controls the distribution and transmission system in a very fast rate. When power fluctuation occurs in the system, the BESS can be used to level the power fluctuation by charging and discharging operation. The battery is connected in parallel to the dc capacitor of STATCOM [4]–[9]. The STATCOM is a three-phase voltage source inverter having the capacitance on its DC link and connected at the point of common coupling. The STATCOM injects a compensating current of variable magnitude and frequency component at the bus of common coupling.

4.3. System Operation

The shunt connected STATCOM with battery energy storage is connected with the interface of the induction generator and non-linear load at the PCC in the grid system. The STATCOM compensator output is varied according to the controlled strategy, so as to maintain the power quality norms in the grid system. The current control strategy is included in the control scheme that defines the functional operation of the STATCOM compensator in the power system. A single STATCOM using insulated gate bipolar transistor is proposed to have a reactive power support, to the induction generator and to the nonlinear load in the grid system. The main block diagram of the system operational scheme is shown in Fig. 2.

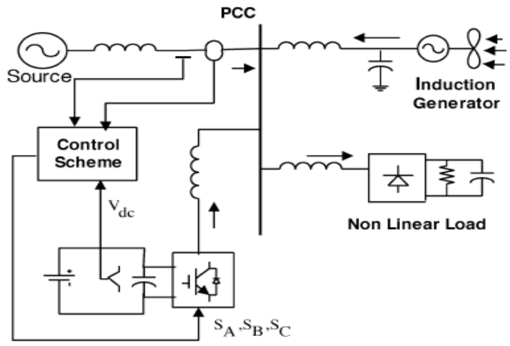

Fig. 2. System operational scheme in grid system.

V. CONTROL SCHEME

The control scheme approach is based on injecting the currents into the grid using "bang-bang controller." The controller uses a hysteresis current controlled technique. Using such technique, the controller keeps the control system variable between boundaries of hysteresis area and gives correct switching signals for STATCOM operation.
The control system scheme for generating the switching signals to the STATCOM is shown in Fig. 3.

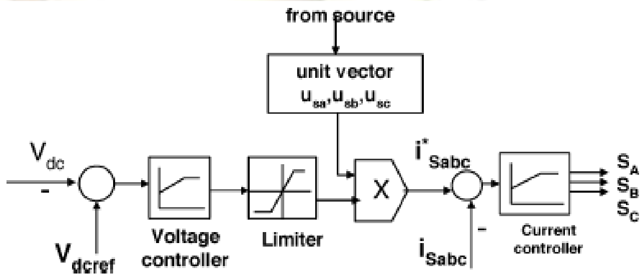

Fig. 3. Control system scheme.

The control algorithm needs the measurements of several variables such as three-phase source current isabc, DC voltage Vdc , inverter current isabc with the help of sensor. The current control block, receives an input of reference current isabc* and actual current isabc are subtracted so as to activate the operation of STATCOM in current control mode [6]–[8].

5.1. Grid Synchronization

In three-phase balance system, the RMS voltage source amplitude is calculated at the sampling frequency from the source phase voltage (VsaVsbVsc) and is expressed, as sample template *Vsm*, sampled peak voltage, as in (9).

$$V_{\text{sm}} = \left\{ \frac{2}{3} \left(V_{\text{sa}}^2 + V_{\text{sb}}^2 + V_{\text{sc}}^2 \right) \right\}^{1/2} . \quad (9)$$

The in-phase unit vectors are obtained from AC source—phase voltage and the RMS value of unit vector as shown in (10).

$$u_{sa} = \frac{V_{Sa}}{V_{sm}}, \quad u_{sb} = \frac{V_{Sb}}{V_{sm}}, \quad u_{sc} = \frac{V_{Sc}}{V_{sm}}. \qquad (10)$$

The in-phase generated reference currents are derived using in-phase unit voltage template as, in (11)

$$i^*_{Sa} = I.u_{Sa}, \quad i^*_{Sb} = I.u_{Sb}, \quad i^*_{Sc} = I.u_{Sc} \qquad (11)$$

Where I is proportional to magnitude of filtered source voltage for respective phases. This ensures that the source current is controlled to be sinusoidal[4]-[9]. The unit vectors implement the important function in the grid connection for the synchronization for STATCOM. This method is simple, robust and favorable as compared with other methods [8].

The proposed control scheme is simulated using SIMULINK in power system block set. The system parameter for given system is given Table I. The system performance of proposed system under dynamic condition is also presented.

5.2. Voltage Source Current Control—Inverter Operation

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. The generation of switching signals from reference current is simulated within hysteresis band of 0.08. The choice of narrow hysteresis band switching in the system improves the current quality. The control signal of switching frequency within its operating band, as shown in Fig. 4.

The choice of the current band depends on the operating voltage and the interfacing transformer impedance. The compensated current for the nonlinear load and demanded reactive power is provided by the inverter. The real power transfer from the batteries is also supported by the controller of this inverter. The three phase inverter injected current are shown in Fig. 5

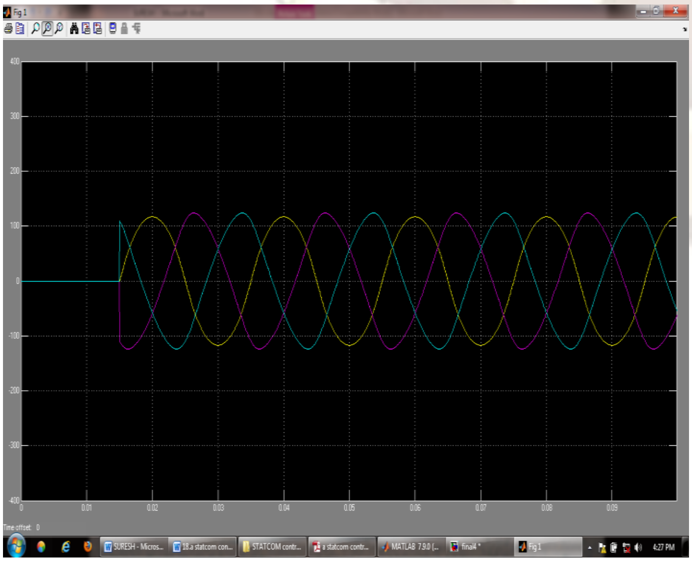

Fig.5:The three phase inverter injected current are shown in

5.3. STATCOM—Performance Under Load Variations

The wind energy generating system is connected with grid having the nonlinear load. The performance of the system is measured by switching the STATCOM at time t=0.7s 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 current, load current are shown in fig.6

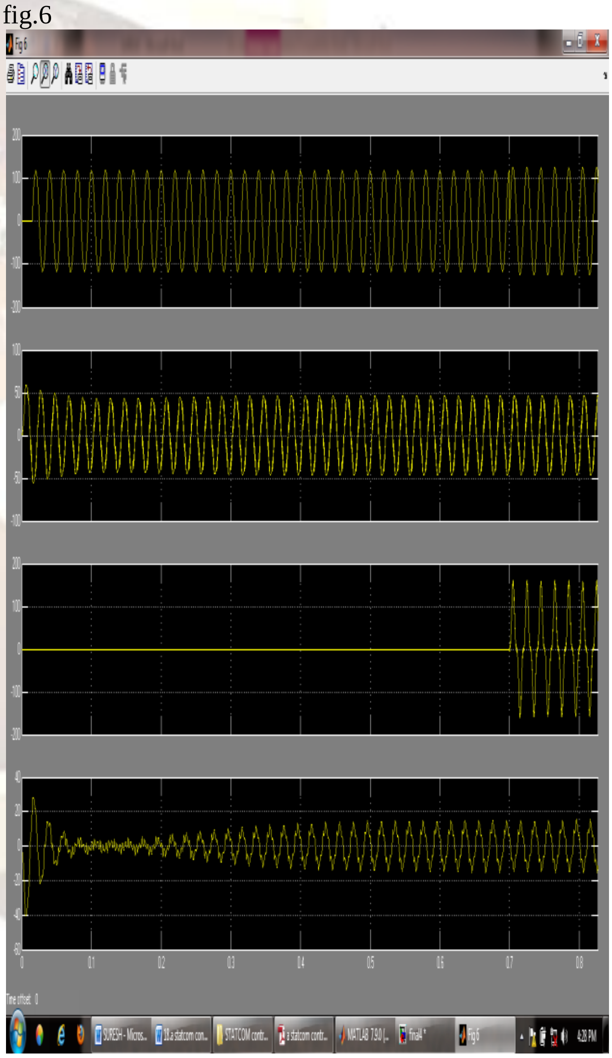

Fig. 6(a) and (b) respectively. While the result of injected current from STATCOM is shown in Fig. 6(c) and the generated current from wind generator at PCC are depicted in Fig. 6(d).

The DC link voltage regulates the source current in the grid system, so the DC link voltage is maintained constant across the capacitor as shown in

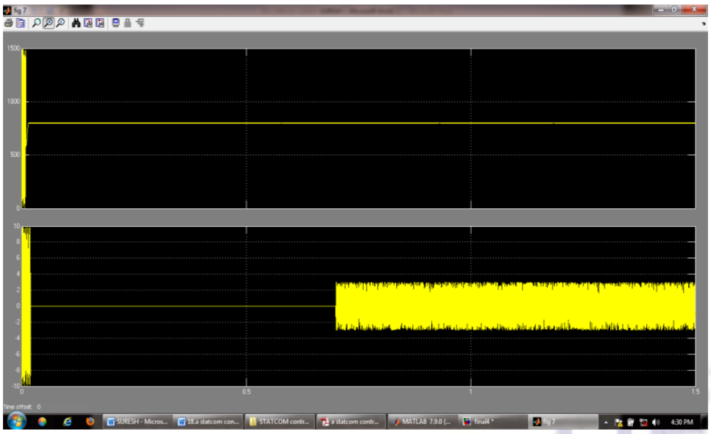

Fig. 7(a). The current through the dc link capacitor indicating the charging and discharging operation as shown in Fig. 7(b)

5.4. Power Quality Improvement

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 inverter output voltage under STATCOM operation with load variation is shown in Fig. 8[9]. The dynamic load does affect the inverter output voltage. The source current with and without STATCOM operation is shown in Fig. 9.

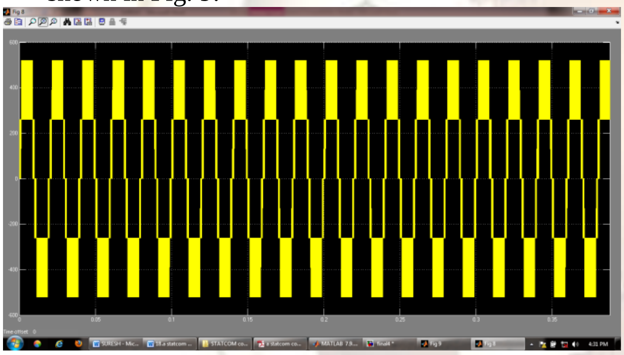

Fig. 8. The inverter output voltage under STATCOM operation with load variation

Fig.9:The source current with and without STATCOM operation

This shows that the unity power factor is maintained for the source power when the STATCOM is in operation. The current waveform before and after the STATCOM operation is analyzed. The Fourier analysis of this waveform is expressed and the THD of this source current at PCC without STATCOM is 4.71%,

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 0.7 s and source current waveform with its FFT. It is shown that the THD has been improved considerably and within the norms of the standard.

The above tests with proposed scheme has not only power quality improvement feature but it also has sustain capability to support the load with the energy storage through the batteries.

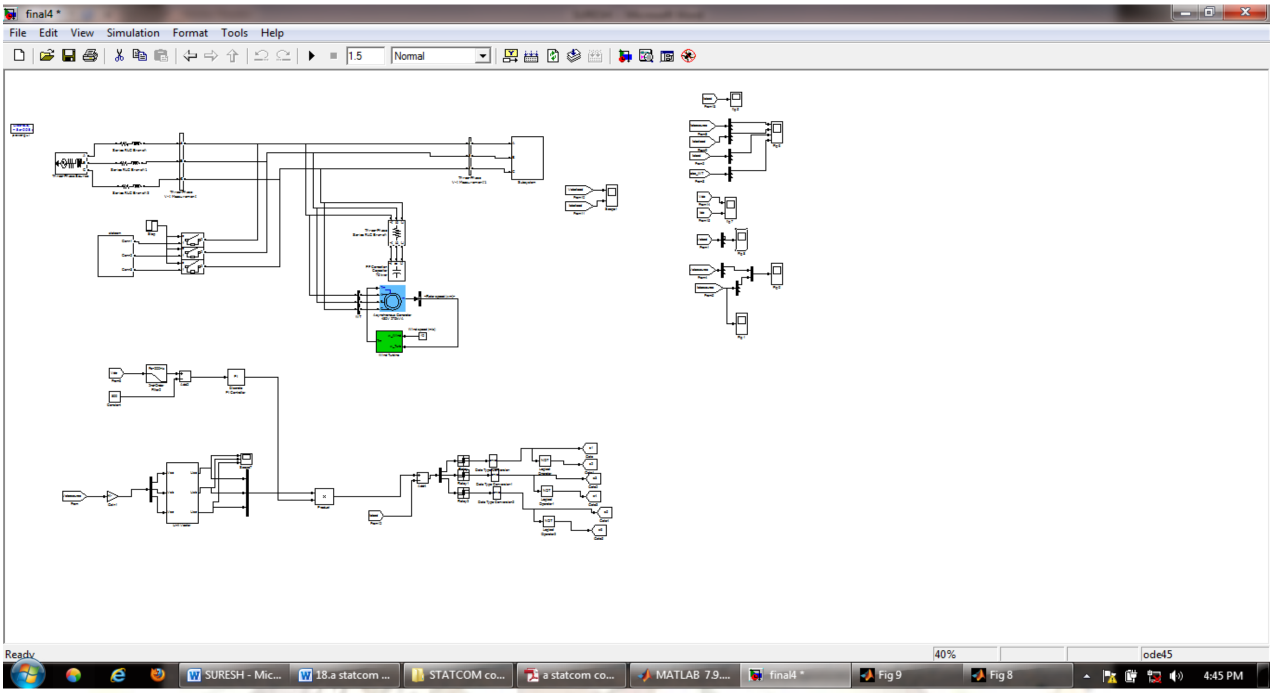

Fig.10: Mat lab model of proposed circuit.

VI. CONCLUSION

The paper presents the STATCOM-based control scheme for power quality improvement in grid connected wind generating system and with nonlinear load. The power quality issues and its consequences on the consumer and electric utility are presented. The operation of the control system developed for the STATCOM-BESS in MATLAB/ SIMULINK for maintaining the power quality is simulated. It has a capability to cancel out the harmonic parts of the load current. It maintains the source voltage and current in-phase and support the reactive power demand for the wind generator and load at PCC in the grid system, thus it gives an opportunity to enhance the utilization factor of transmission line. The integrated wind generation and STATCOM with BESS have shown the outstanding performance.

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