Compensation of Reactive Power and THD Minimization in the Grid Connected Wind Energy System Using Bang-Bang Controller

Sambasiva Rao Bandreddy, Srinivas Vudumudi

Abstract— **This paper presents the design of VSI based STATCOM for eliminating harmonic currents due to nonlinear load and to compensate the reactive power in grid connected system. Normally Static compensator (SVC) can be used to improve the power quality by reducing the harmonics in the grid current. But it has less reactive power compensation. This is because at a low voltage limit, the reactive power drop off as the square at a low voltage for the SVC.That's why The Static Synchronous Compensator (STATCOM) is increasingly popular in power quality application. This VSI draw or supply a compensating current from the utility such that it cancels current harmonics on the AC side. STATCOM generates a current wave such that it compensate by cancelling out the non-linear current waveform generated by load. The performance of the wind turbine and thereby power quality are determined on the basis of measurements and the norms followed according to the guideline specified in International Electro-technical Commission standard, IEC-61400. 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 are measured according to national/international guidelines .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 constant and variable linear and non linear loads.**

***Index Terms*— International electro-technical commission (IEC), power quality, wind generating system (WGS).**

I. INTRODUCTION

Power quality is one of the most important topics that electrical engineers have been noticed in recent years.
The main problems related to power quality are Harmonic distortion and reactive power compensation. Most industries and companies prefer electrical energy with high quality. If delivered energy to these loads has poor quality, products and equipment of these loads such as microcontrollers, computers, motor drives etc are damaged. Hurt of this phenomenon in companies that dealing with information technology systems is serious. Nowadays, Custom Power equipment's are used for this purpose. Until now, to filter these harmonics and to compensate reactive power at factory level, only capacitor and passive filters were used. More, new PWM based converters for motor control is able to provide almost unity power factor operations. We cannot depend on this capacitor to filter out those harmonics. This is one of the reasons that the research is being done in the area of FACTS (STATCOM) devices.
The STATCOM is a shunt-connected reactive power compensation device that is capable of generating or absorbing reactive power. The output voltage of the STATCOM can be varied to control the specific parameters of an electric power system. The voltage source inverter (VSI), employing turn-off capability semiconductor switches, is an important part in the STATCOM because it can operate at high switching frequencies and provides a fast dynamic response.
The proposed STATCOM control scheme for grid connected wind energy generation for power quality improvement has following objectives.[1]

- 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.
- Harmonic reduction in the grid connected source current.

The paper is organized as fallows. The Section II introduces the power quality standards, issues and its consequences of wind turbine. The Section III introduces Design of the Statcom. The Sections IV, V, VI describes the control scheme, system performance and conclusion respectively.

II. POWER QUALITY STANDARDS, ISSUES AND IT'S CONSEQUENCES

A. Voltage Variation

The voltage variation issue results from the wind velocity and generator torque. The voltage variation is directly related to real and reactive power variations. The voltage variation is commonly classified as under:

- Voltage Sag/Voltage Dips.
- Voltage Swells.
- Short Interruptions.
- Long duration voltage variation.

The voltage flicker issue describes dynamic variations in the network caused by wind turbine or by varying loads. Thus the

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power fluctuation from wind turbine occurs during continuous operation. The amplitude of voltage fluctuation depends on grid strength, network impedance, and phase-angle and power factor of the wind turbines. It is defined as a fluctuation of voltage in a frequency 10–35 Hz.

B. Harmonics

The harmonic results due to the operation of power electronic converters. The harmonic voltage and current should be limited to the acceptable level at the point of wind turbine connection to the network. To ensure the harmonic voltage within limit, each source of harmonic current can allow only a limited contribution, as per the IEC-61400-36 guideline. The rapid switching gives a large reduction in lower order harmonic current compared to the line commutated converter.

C. Wind Turbine Location in Power System

The way of connecting the wind generating system into the power system highly influences the power quality. Thus the operation and its influence on power system depend on the structure of the adjoining power network.

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. When wind turbine is equipped with an induction generator and fixed capacitor are used for reactive power compensation then risk of self excitation may occur during off grid operation. Thus the sensitive equipments may be subjected to over/under voltage, over/under frequency operation and other disadvantage of safety aspect. The effective control of reactive power can improve the power quality and stabilizes the grid. The suggested control technique is capable of controlling reactive power to zero at PCC. [10]

III. DESIGN OF THE VSI BASED STATCOM

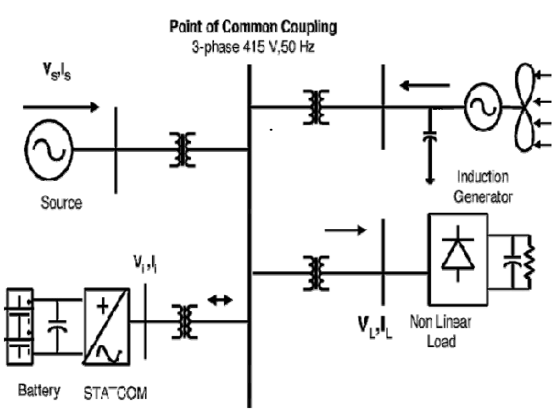


Fig 1Grid connected system for power quality improvement.

A. Voltage Source Converter (VSI):

A voltage-source converter is Power-Electronics device that connected in shunt to the existing system. The VSI used to either completely replace the voltage or to inject the 'missing voltage'. The "missing voltage "is the difference between the nominal voltage and actual .It also converts the DC voltage across storage devices into a set of three phase AC output voltage. In addition, STATCOM is also capable to generate or absorbs reactive power. If the output voltage of the VSI is greater than AC bus terminal voltages, STATCOM is said to be in capacitive mode. So, it will compensate the reactive power through AC system and regulates missing voltages. These voltages are in phase and coupling transformers. Suitable adjustment of phase and magnitude of the STATCOM and AC system. In addition, the converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage

B. 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 system. 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.[3],[4]

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.

C. CAPACITIVE DESIGN

When the current in the system is higher than in the STATCOM and is discharged when the current is lower. For inverter the most important part is the sequences of operation of the IGBTs. The difference in current between the current before and after the fault is considered as current faults. a suitable range of DC capacitor is needed to store the energy to mitigate the voltage sag. The DC capacitor, CDC is used to inject reactive power to the STATCOM when the voltage is in sag condition. In the design, the harmonic effects must be considered because the load is inductive and this may affect the value of CDC. The following equation is used to calculate CDC

$$1/2C_{DC}[V_{CMAX}^2-V_{DC}^2]=1/2V_{sM}*\Delta I_L*T$$

Equation is used for harmonic mitigation in single phase system but for a three phase system the equation is given by

$$C_{DC}=[3\times V_s\cdot \Delta I_L T]\div[V_{cmax}^2-V_{DC}^2]$$

Where Vs = peak phase voltage

I_L =step drop of load current

T=period of one cycle of voltage and current

V_{CMAX} =pre-set upper limit of the energy storage C(per phase).

V_{DC}=voltage across capacitor.

The value of ΔI_L can be found by measuring the load current before and during the voltage sag.

The value of V_{DC} is given by

$$V_{DC}=\{3\sqrt{3}V_S\cos\alpha\}/\pi:$$

Where α=delay angle:
If α=0, the equation becomes
$V_{DC} = \{3\sqrt{3}V_s\}/\pi$.

D. 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

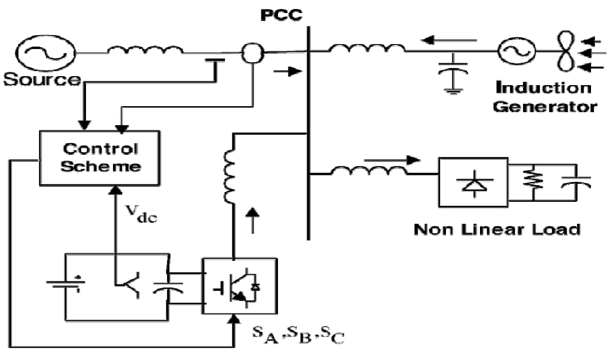


Fig 2 System operation scheme in grid system

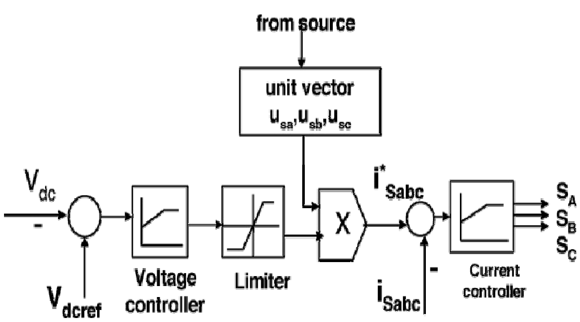
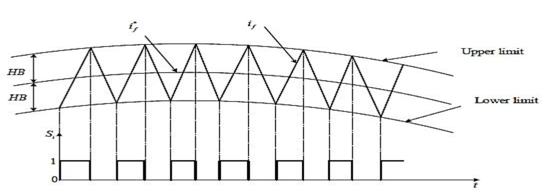


Fig 3 control system scheme

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.

IV. CONTROL SCHEME



The control scheme approach is based on injecting the cur-rents 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.

The control algorithm needs the measurements of several variables such as three-phase source current, DC voltage, inverter current with the help of sensor. The current control block, receives an input of reference current and actual current are subtracted so as to activate the operation of STATCOM in current control mode.[7],[8],[2]

A. Grid Synchronization

In three-phase balance system, the RMS voltage source am-plitude is calculated at the sampling frequency from the source phase voltage ($V_{sa}V_{sb}V_{sc}$) and is expressed, as sample tem-plate V_{sm}, sampled peak voltage, as in [3].

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

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

$$u_{sa} = \frac{V_{sa}}{V_{sm}}, \quad u_{sb} = \frac{V_{sb}}{V_{sm}}, \quad u_{sc} = \frac{V_{sc}}{V_{sm}}. \quad (2)$$

The in-phase generated reference currents are derived using in-phase unit voltage template as, in [4]

$$i^*_{Sa} = I.u_{Sa}, \quad i^*_{Sb} = I.u_{Sb}, \quad i^*_{Sc} = I.u_{Sc} \quad (3)$$

Where I is proportional to magnitude of filtered source voltage for respective phases. This ensures that the source current is controlled to be sinusoidal. 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].

B. Bang-Bang Current Controller

Bang-Bang current controller is implemented in the current control scheme. The reference current is generated as in (3) and actual current are detected by current sensors and are subtracted for obtaining a current error for a hysteresis based bang-bang controller. Thus the ON/OFF switching signals for IGBT of STATCOM are derived from hysteresis controller [2].

The switching function S_A for phase 'a' is expressed as.

$$i_{sa} < (i^*_{sa} - HB) \rightarrow S_A = 0$$
$$i_{sa} > (i^*_{sa} - HB) \rightarrow S_A = 1 \quad (4)$$

Where HB is a hysteresis current-band, similarly the switching function $S_B S_C$ can be derived for phases "b" and "c".

V. SYSTEM PERFORMANCE

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.

A. Voltage Source Current Control—Inverter Operation

The three phase injected current into the grid from STATCOM will cancel out the distortion caused by the non-linear 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.

TABLE 1SYSTEM PARAMETERS

S.N.	Parameters	Ratings
1	Grid Voltage	3-phase ,415V,50 Hz
2	Induction Motor/Generator	3.35 kVA,415V, 50 Hz, P = 4, Speed = 1440 rpm, Rs = 0.01Ω, Rr=0.015Ω,Ls =0.06H,Lr=0.06H
3	Line Series Inductance	0.05mH
4	Inverter Parameters	DC Link Voltage = 800V, DC link Capacitance = 100 µF. Switching frequency = 2 kHz,
5	IGBT Rating	Collector Voltage =1200V, Forward Current =50A,Gate voltage =20V, Power dissipation = 310W
6	Load Parameter	Non-linear Load 25kW.

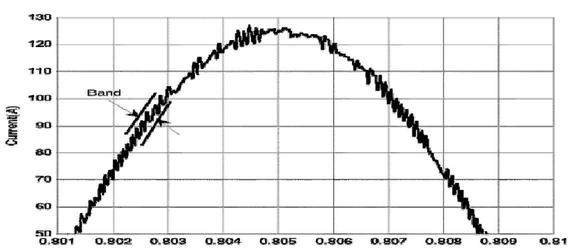


Fig 4 Switching signal within a control hysteresis band

B. STATCOM—Performance

The wind energy generating system is connected with grid having the nonlinear load. The fig's from '5' to '9' represents Performance of the proposed system without statcom and fig's from '10' to '15' are the results of with statcom and The performance of the system is measured by switching the STATCOM at time t=0.7 s in the system. 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. While the result of injected current from STATCOM are shown in Fig. 12 and the generated current from wind generator at PCC are depicted in Fig. 9.

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. 13(a). The current through the dc link capacitor indicating the charging and discharging operation as shown in Fig. 13(b)

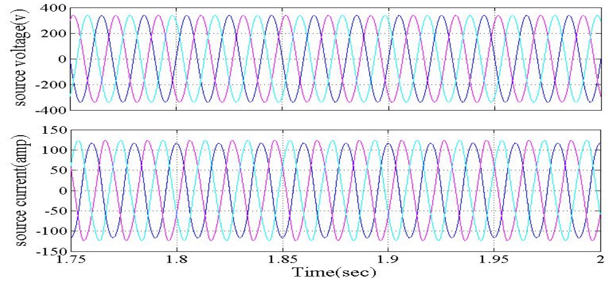


Fig 5 Source voltage and source current

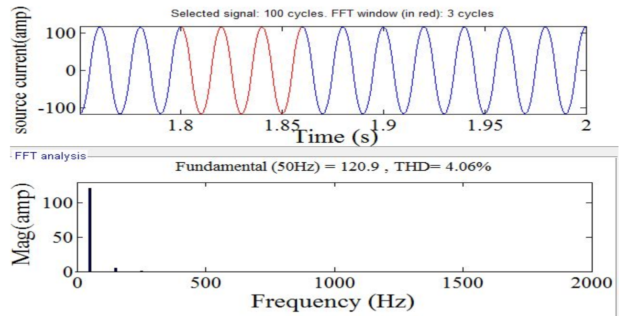


Fig 6 FFT analysis of Source current

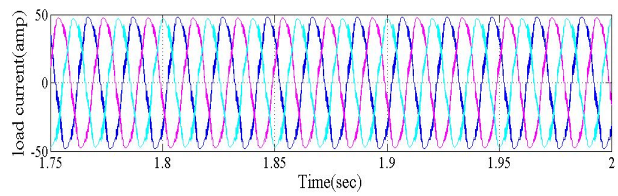


Fig 7 non linear load current

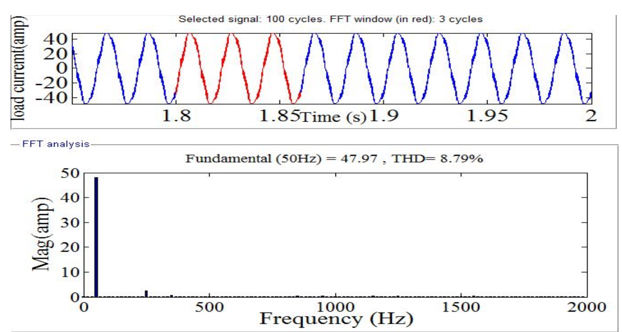


Fig 8 FFT analysis of load current

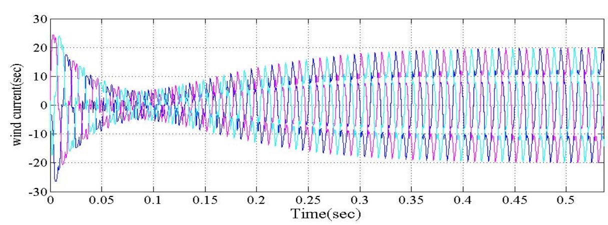


Fig 9 wind current

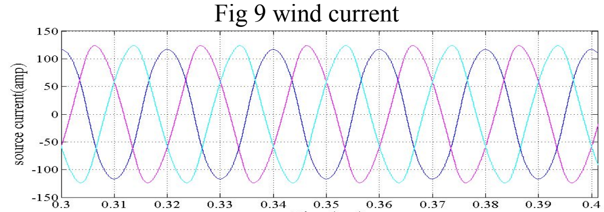


Fig 10 source current

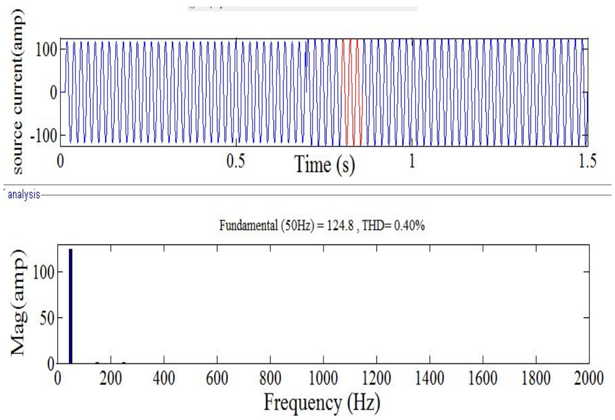


Fig 11 FFT analysis of source current

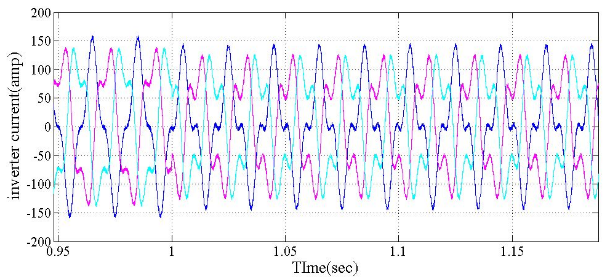


Fig 12 inverter current

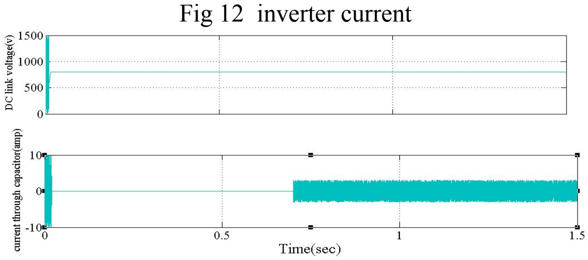


Fig 13 (a)DC link capacitance (b) capacitor current

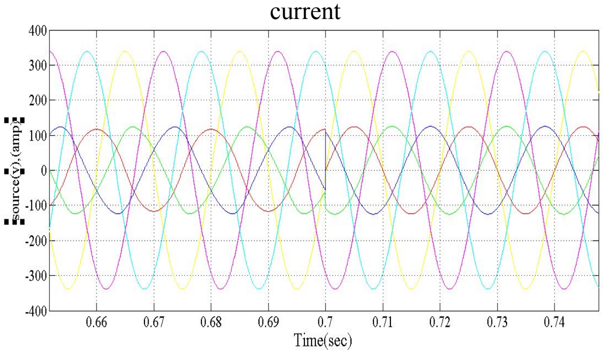


Fig 14 supply voltage and current

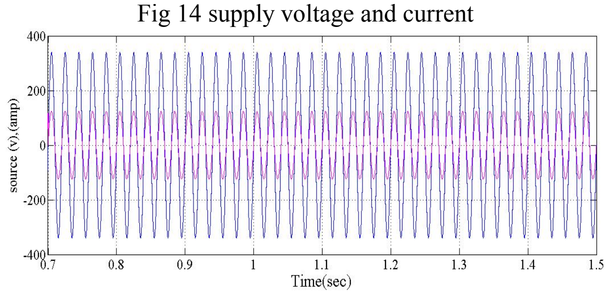


Fig 15supply voltage and current of single phase

C. 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 source current FFT with and without STATCOM operation is shown in Fig.(5),(10) 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%, as shown in Fig.(6).

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 is shown in Fig. (11) 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.

CONCLUSION

The paper presents the STATCOM-based control scheme for Reactive power control and THD minimization in grid connected wind generating system and with non linear load. 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 distribution line. The integrated wind generation and STATCOM with BESS have shown the outstanding performance.

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