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A Review of Technical Issues for Grid Connected Renewable Energy Sources

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Abstract: Renewable energy in recent years become more and more common, due to the large increase in generation from renewable energy sources such as small hydropower stations, wind turbines, photovoltaic's (PV) etc. This paper gives the report on two forms of renewable energy wind and solar energy, and on the role of smart grids in addressing the problems associated with the efficient and reliable delivery and use of electricity and with the integration of renewable sources. In this paper different power quality issues are addressed and a FACTS device STATIC COMPENSATOR (STATCOM) is connected at a point of common coupling for grid connected wind turbine to reduce the power quality problems likeharmonics in the grid current, by injecting superior reactive power in to the grid of wind turbine. And also an active power filter implemented with a four leg voltage-source inverter using DQ (Synchronous Reference Frame) based Current Reference Generator scheme is presented for renewable based distributed generation system of PV cell.

Keywords: PV Cell, Wind Turbine, STATCOM, Power Quality

1. Introduction

As the worlds electricity demand increases, more environmental constraints is given to conventional energy sources such as fossil or nuclear energy. This comes as a direct result of the problem with global warming where the emissions from energy production from fossil fuels are a big contributor. Which is clearly emphasized by the fact that in 2008, 81% of the worlds energy was produced by fossil fuels. Reasons for increasing Renewable energy sources: Declining of fossil fuel supplies

Environmental issues, Increasing cost of fossil fuels, business opportunities, Energy security, Energy independence

Wind energy: Wind turbines extract the kinetic energy from the wind and converts into generator torque. Generator converts this torque into electricity and feeds in to the grid. 1 MW of wind plant in one year can displace 1500 tons of CO_2, 6.5 tons of SO_2 and 3.2 tons of NO_x. (REPP report, Washington July 2003)

Photovoltaic (PV) cells: PV generation is the technique which uses photovoltaic cell to convert solar energy into electrical energy. Now a days, PV generation is developing increasingly fast as a renewable energy source.

Large scale power generations are connected to transmission systems where as small scale distributed power generation is connected to distribution systems. There are certain challenges in the integration of both types of systems directly. Due to this, wind energy has gained a lot of investments from all over the world. However, due to the wind speed's uncertain behavior it is difficult to obtain good quality power, since wind speed fluctuations reflect on the voltage and active power output of the electric machine connected to the wind turbine. Table 1 shows the transmittable power of grid connected wind turbines

Table 1. *Transmittable power of grid connected wind turbine.*

Rated voltage of the system	Size of wind turbine or wind farm	Transmittable power
Low voltage system less than 600V.	For small to medium wind turbines	Upto =300kW
Medium voltage systems (600V -35KV)	For medium to large wind turbines and small wind forms	Upto =10-40 MW
High Voltage (35 kV -132 KV)	For medium to large onshore wind forms	upto 100MW
Extra high Voltage (132 KV and above)	Large offshore wind forms	Greater than 0.5GW

Solar penetration also changes the voltage profile and frequency response of the system and affects the transmission and distribution systems of utility grid.

2. Power Quality Problems IN Grid Connected Renewable Energy Sources

There are certain challenges in the integration of wind and solar systems with grid directly. For grid connection of renewable energy sources we use Grid Integration – Grid-tie Inverter. The use of Inverter is to take energy from grid when renewable energy is insufficient. And supply energy when more power is generated. The connection of grid with renewable energy and disconnection is done in 100ms.The block diagram for grid connected PV array is shown in figure 1 (a), Fig.1(b) shows the grid connected wind energy system.

The main function of converter in PV array connected grid system is to correct the magnitude and phase of the output of PV system by taking the feedback from utility grid. And in case of wind turbine connected grid system it works as isolation of mechanical and electrical frequencies.

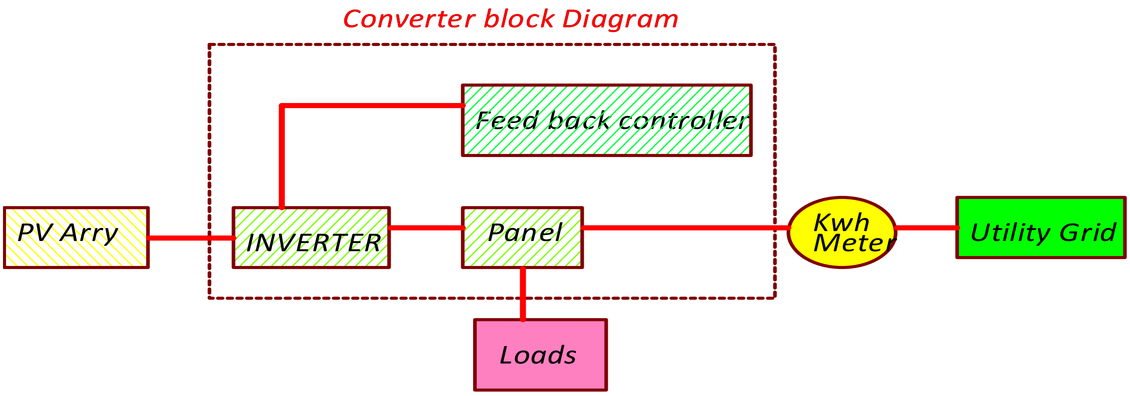

Fig. 1(a). *Block Diagram for Gridconnected PV Array.*

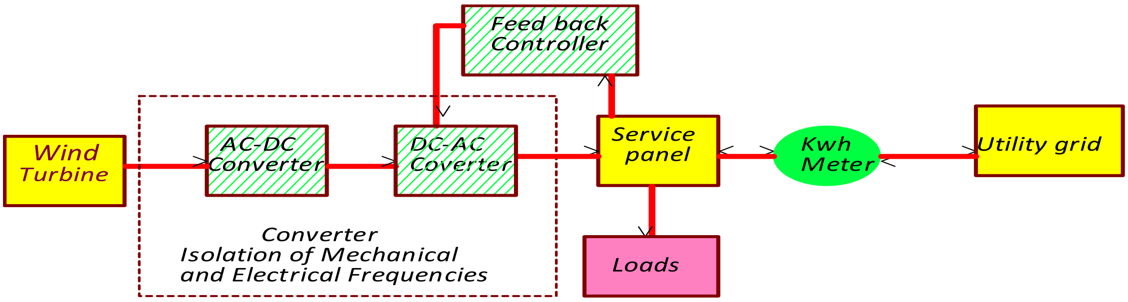

Fig. 1(b). *Block Diagram for Grid connected Wind Turbine.*

There are several technical issues associated with grid connected systems like Power Quality Issues, Power and voltage fluctuations, Storage, Protection issues, Islanding.

Power Quality issues are harmonics and voltage and frequency fluctuations.

2.1. Harmonics

Harmonics are currents or voltages with frequencies that are integer multiples of the fundamental power frequency. Electrical appliances and generators all produce harmonics and in large volumes (eg. computers and compact fluorescent lamps), can cause interference that results in a number of power quality problems.

Most grid-connected inverters for DG applications put out very low levels of harmonic current, and because of their distribution on the network are unlikely to cause harmonic issues, even at high penetration levels.

While the most common type of inverters (current-source) can not provide the harmonic support required by the grid, voltage-source inverters can, but do so at an energy cost and there are a variety of harmonic compensators that are likely to be cheaper. Labeling that identifies the type of inverter (voltage or current source) would help purchase of voltage source or current source inverters as required, as would financial compensation for reducing energy losses if voltage source inverters are installed. Note that, unless specially configured, PV inverters disconnect from the grid when there is insufficient sunlight to cover the switching losses, meaning that no harmonic support would be provided outside daylight hours.

2.2 Frequency and Voltage Fluctuations

Frequency and voltage fluctuation again classified as

1. Grid-derived voltage fluctuations
2. Voltage imbalance
3. Voltage rise and reverse power flow
4. Power factor Correction

(i). Grid-Derived Voltage Fluctuations

Inverters are generally configured to operate in grid 'voltage-following' mode and to disconnect DG when the grid voltage moves outside set parameters, This is both to help ensure they contribute suitable power quality as well as help to protect against unintentional islanding. Where there are large numbers of DG systems or large DG systems on a particular feeder, their automatic disconnection due to the grid voltage being out of range can be problematic because other generators on the network will suddenly have to provide additional power[9,10].

To avoid this happening, voltage sag tolerances could be broadened and where possible, Low Voltage Ride-through Techniques (LVRT) could be incorporated into inverter design. LVRT allows inverters to continue to operate for a defined period if the grid voltage is moderately low but they will still disconnect rapidly if the grid voltage drops below a set level. Inverters can also be configured to operate in 'voltage-regulating' mode, where they actively attempt to influence the network voltage. Inverters operating in voltage-regulating mode help boost network voltage by injecting reactive power during voltage sags, as well as reduce network voltage by drawing reactive power during voltage rise.Thus, connection standards need to be developed to incorporate and allow inverters to provide reactive power where appropriate, in a manner that did not interfere with any islanding detection systems. Utility staff may also need to be trained regarding integration of such inverters with other options used to provide voltage regulation - such as SVCs (Static VAr Compensator) or STATCOMS (static synchronous compensators)[1].

(ii). Voltage Imbalance

Voltage imbalance is when the amplitude of each phase voltage is different in a three-phase system or the phase difference is not exactly 120°. Single phase systems installed disproportionately on a single phase may cause severely unbalanced networks leading to damage to controls, transformers, DG, motors and power electronic devices. Thus, at high PV penetrations, the cumulative size of all systems connected to each phase should be as equal as possible. All systems above a minimum power output level of between 5-10kW typically should have a balanced three phase output.

(iii). Voltage Rise and Reverse Power Flow

Traditional centralized power networks involve power flow in one direction only: from power plant to transmission network, to distribution network, to load. In order to accommodate line losses, voltage is usually supplied at 5-10% higher than the nominal end use voltage. Voltage regulators are also used to compensate for voltage drop and maintain the voltage in the designated range along the line.

(iv). Power Factor Correction

Because of poor power factor line losses increases and voltage regulation become difficult.Poor power factor on the grid increases line losses and makes voltage regulation more difficult. Inverters configured to be voltage-following have unity power factor, while inverters in voltage-regulating mode provide current that is out of phase with the grid voltage and so provide power factor correction. This can be either a simple fixed power factor or one that is automatically controlled by, for example, the power system voltage.[8,9]

A number of factors need to be taken into consideration when using inverters to provide power factor correction

- To provide reactive power injection while supplying maximum active power, the inverter size must be increased.
- The provision of reactive power support comes at an energy cost, and how the VAr compensation is valued and who pays for the energy has generally not been addressed.
- Simple reactive power support can probably be provided more cost-effectively by SVCs or STATCOMS[1,2], which have lower energy losses, however inverter VAr compensation is infinitely variable and has very fast response times. In areas where rapid changes in voltage are experienced due to large load transients (eg. motor starts) then an inverter VAr compensator may be justified.
- While this sort of reactive power compensation is effective for voltage control on most networks, in fringe of grid locations system impedances seen at the point of connection are considerably more resistive, and so VAr compensation is less effective for voltage control. In these situations, real power injection is more effective for voltage regulation.

Studies into the use of inverters to regulate network voltage at high PV penetrations have found that in order to achieve optimal operation of the network as a whole, some form of centralized control was also required. In addition, reactive power injection by inverters may be limited by the feeder voltage limits, and so coordinated control of utility equipment and inverters, as well as additional utility equipment, may be required.

3. Grid Connected PVGeneration System

Figure 2shows the configuration of the grid-connected PV /Battery generation system. PV array and battery are connected to the common dc bus via a DCIDC converter respectively, and then interconnected to the ac grid via a common DC/AC inverter. Battery energy storage can charge and discharge to help balance the power between PV generation and loads demand. When the generation exceeds the demand, PV array will charge the battery to store the extra power, meanwhile, when the generation is less than the demand, the battery will discharge the stored power to supply loads. Each of PV system, battery energy storage system and the inverter has its independent control objective, and by controlling each part, the entire system is operating safely.

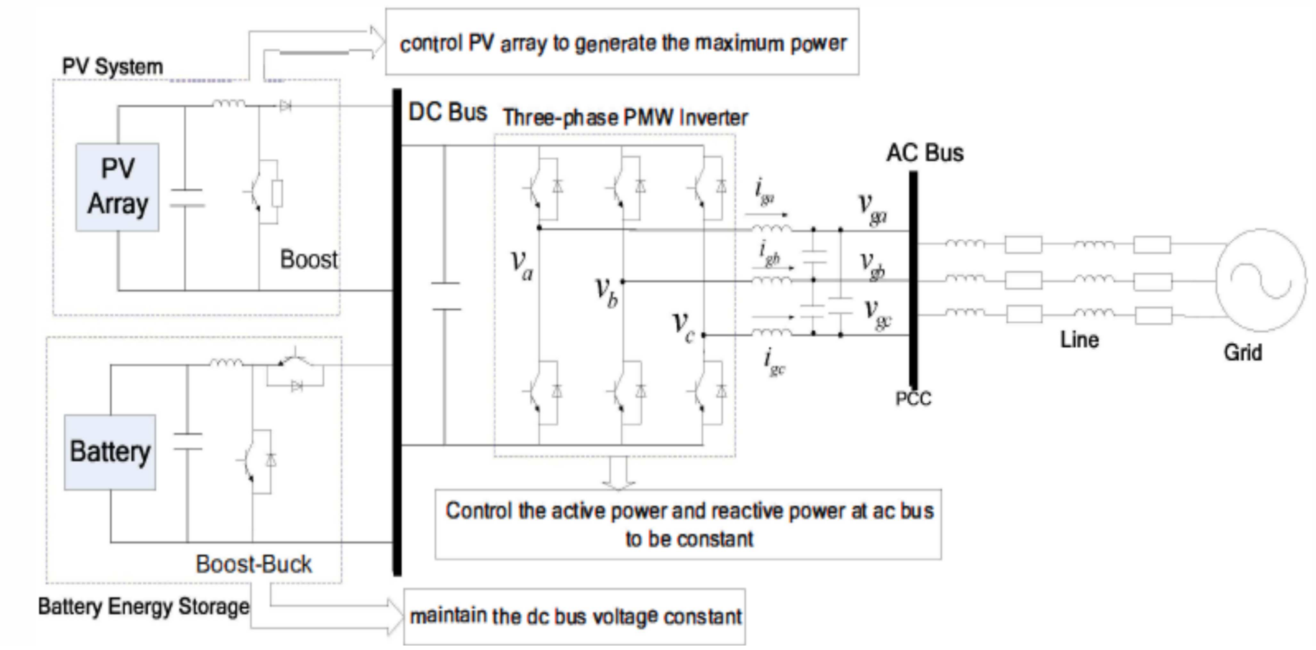

Fig. 2. *Block diagram for Grid conncted PV system.*

3.1. Boost Circuit and Its Control

For two-stage PV generation system, boost chopper circuit is always used as the DC/DC converter. Since the output voltage of PV cell is low, the use of boost circuit will enable low-voltage PV array to be used, as a result, the total cost will be reduced. A capacitor is generally connected between PV array and the boost circuit, which is used to reduce high frequency harmonics. Figure 3(a)is the configuration of the boost circuit and its control system.

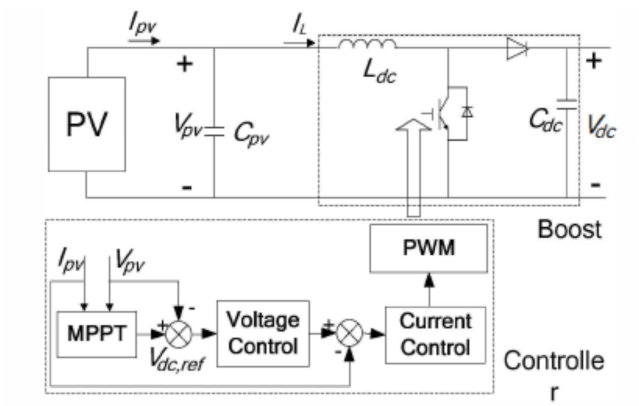

Fig. 3 (a). *Boost circuit of PV system.*

Fig.3(b) shows the Battery energy storage system (BESS).Battery energy storage system (BESS) is composed of a battery bank, a bi-directional DC/DC converter and control system [10]. The system should be able to operating in two directions: the battery can be charged to store the extra energy and also can discharge the energy to loads[4].

The utility grid is considered as a backup source and the battery bank serves as a short-duration power source to meet the load demands which cannot be fully met by the PV system, particularly during fluctuations of the solar or transient periods.

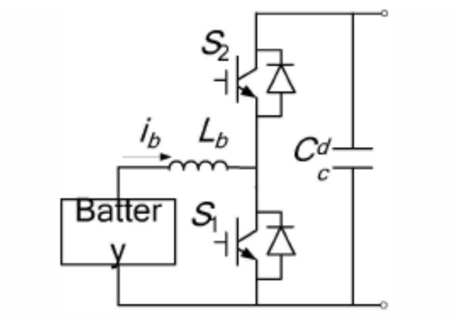

Fig. 3 (b). *BESS for PV arry.*

The primary objective of the battery converter is to maintain the common dc link voltage constant. Tn this way, no matter the battery is charging or discharging, the voltage of the dc bus can be stable and thus the ripple in the capacitor voltage is much less. When charging, switch Sf is activated and the converter works as a boost circuit. otherwise. Whendischarging, switch S2 is activated and the converter works as a buck circuit.

3.2. Control of Grid-Connected Inverter

PV array and the battery are connected to the ac grid via a common DC/AC inverter.Fig 4 Shows the control block diagram for the inverter. The inverter is used in current control method with PWM switching mechanism to make the inductance current track the sinusoidal reference current command closely and obtain a low THD injected current. The control strategy mainly consists of two cascaded loops, namely a fast internal current loop and an external voltage loop. The proposed multi-level control scheme is based on the concept of instantaneous power on the synchronous-rotating dq reference frame.

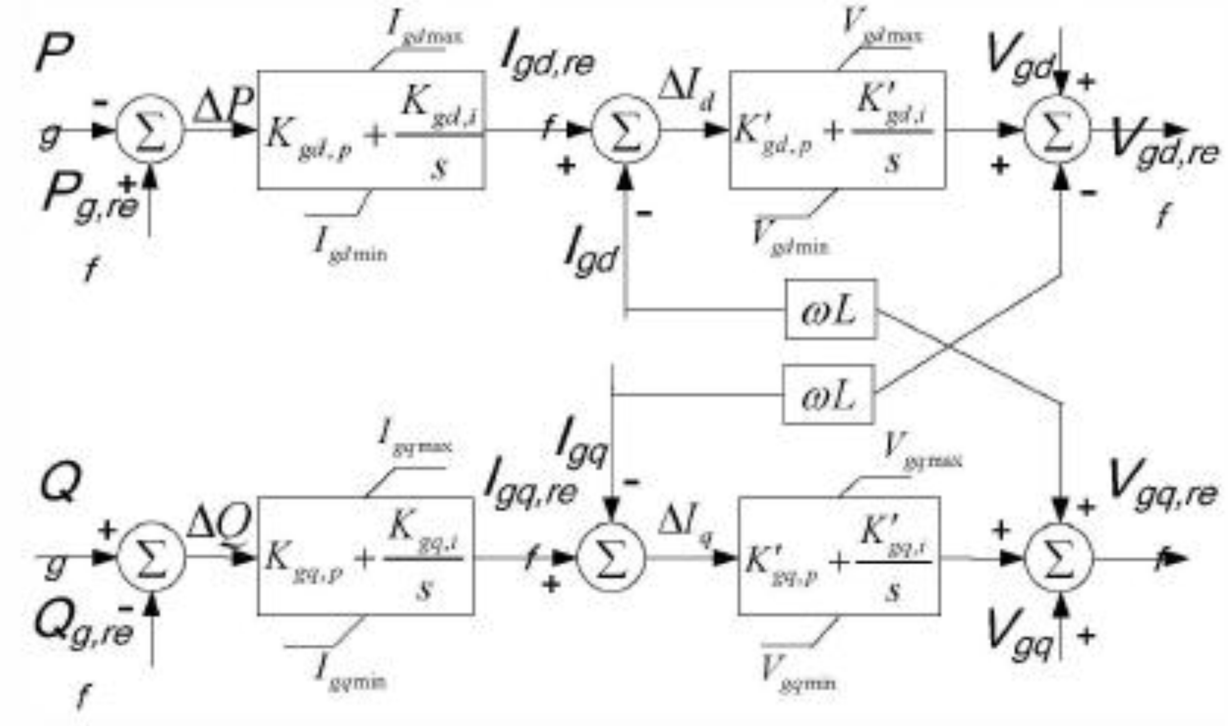

Fig. 4. *Control circuit block diagram of PV connected Inverter.*

3.3. Grid Connected Solar Energy System with Shunt APF

Renewable energy source (RES) integrated at distribution level is termed as distributed generation (DG). The utility is concerned due to the high penetration level of intermittent RES in distribution systems as it may pose a threat to network in terms of stability, voltage regulation and power-quality (PQ) issues. Therefore, the DG systems are required to comply with strict technical and regulatory frameworks to ensure safe, reliable and efficient operation of overall network. With the advancement in power electronics and digital control technology, the DG systems can now be actively controlled to enhance the system operation with improved PQ at PCC[3]. However, the extensive use of power electronics based equipment and non-linear loads at PCC generate harmonic currents, which may deteriorate the quality of power.

3.4. Control Circuit for the Four Leg VSI

A dq-based current reference generator scheme is used to obtain the active power filter current reference signals. Four leg VSI Schematic Diagram is shown in Fig. 5. The current reference signals are obtained from the corresponding load currents as shown in Fig 6. The dq-based scheme operated in a rotating reference frame. Therefore, the measured currents must be multiplied by the sin ωtand cos ωt signals. By using *dq* transformation, the *d* current component is synchronized with the corresponding phase-to-neutral system voltage and the *q* current components are phase-shifted by 90°. The sin ωt and cosωt synchronized reference signals are obtained from a Synchronous Reference Frame (SRF) PLL. The SRF-PLL generates a pure sinusoidal waveform even when the system voltage is severely distorted.

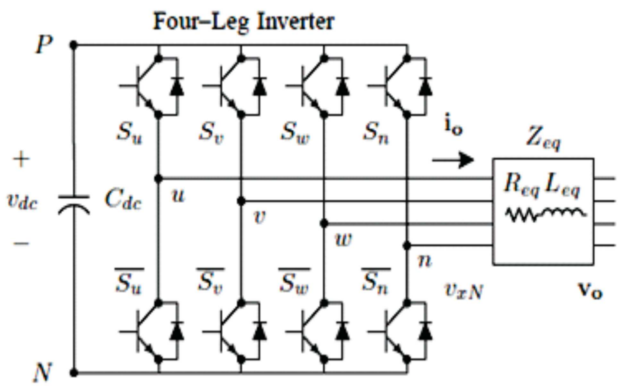

Fig. 5. *Four leg VSI Schematic Diagram.*

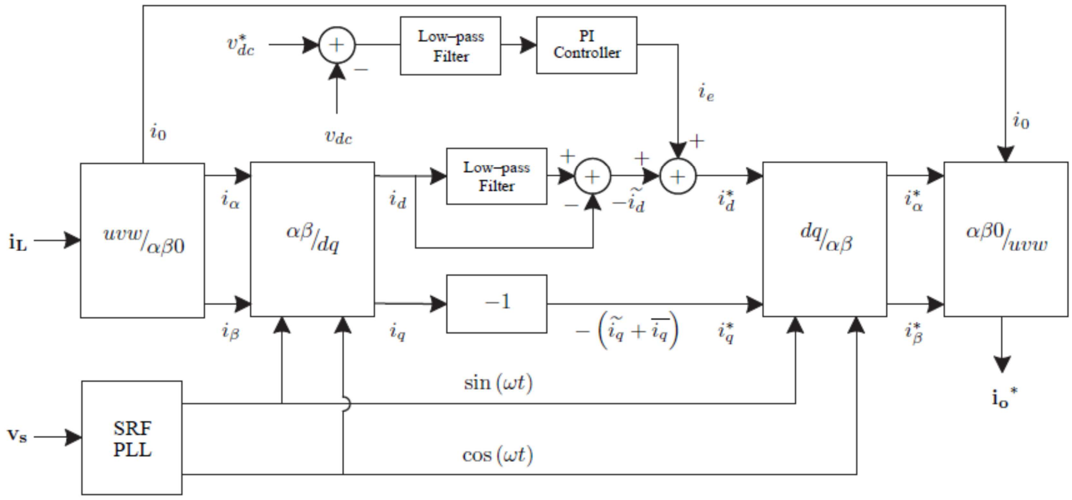

Fig. 6. *Block Diagram for control circuit of four Leg based VSI.*

3.5. Simulation Results of PV Based System

A simulation model for the three-phase four-leg PWM converter with the source voltage of 55V, System frequency of 50 Hz, dc capacitor of 2200μF and filter inductor of 5.0 mH with a sampling time of 20 micro seconds has been developed using MATLAB-Simulink. The objective is to verify the current harmonic compensation effectiveness of the proposed control scheme under different operating conditions. A six pulse rectifier was used as a non-linear load.

In the simulated results shown in Figures 7-16, the active filter starts to compensate at t =0.2. At this time, the active power filter injects an output current i to compensate oucurrent harmonic components, current unbalanced, and neutral current simultaneously. During compensation, the system currents (is) show sinusoidal waveform, with low total harmonic distortion. At t =0.4, a three-phase balanced load step change is generated from 0.6 to 1.0 p.u. The compensated system currents remain sinusoidal despite the change in the load current magnitude. Finally, at t=0.6, a single-phase load step change is introduced in phase u from 1.0 to 1.3 p.u., which is equivalent to an 11% current imbalance. As expected on the load side, a neutralcurrent flow through the neutral conductor (iLn), but on the source side, no neutral current is observed (isn). Simulated results show that the proposed control scheme effectively eliminates unbalanced currents. Additionally, Results show that the dc-voltage remains stable throughout the whole active power filter operation.

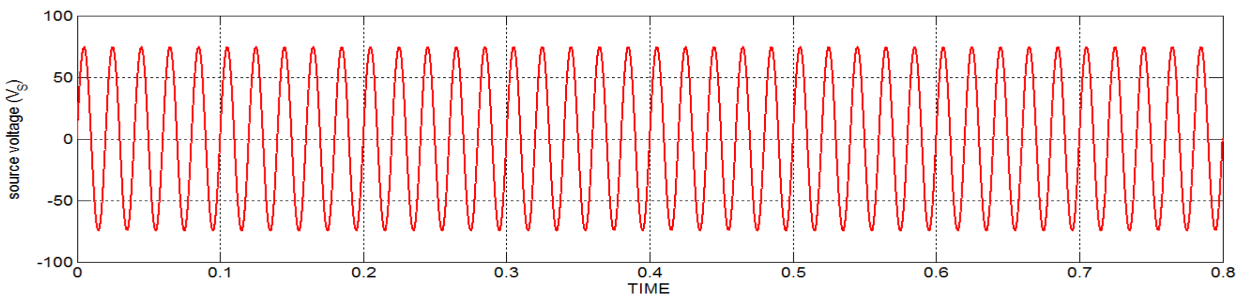

Fig. 7(a). *Phase to neutral Source voltages.*

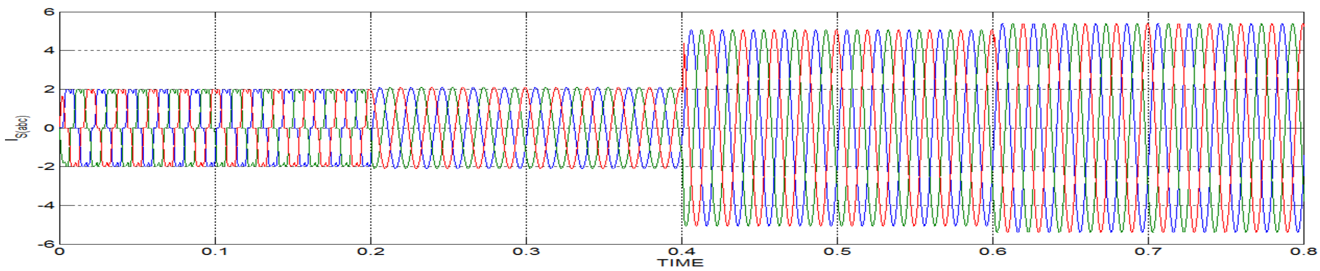

Fig. 7(b). *Source Currents.*

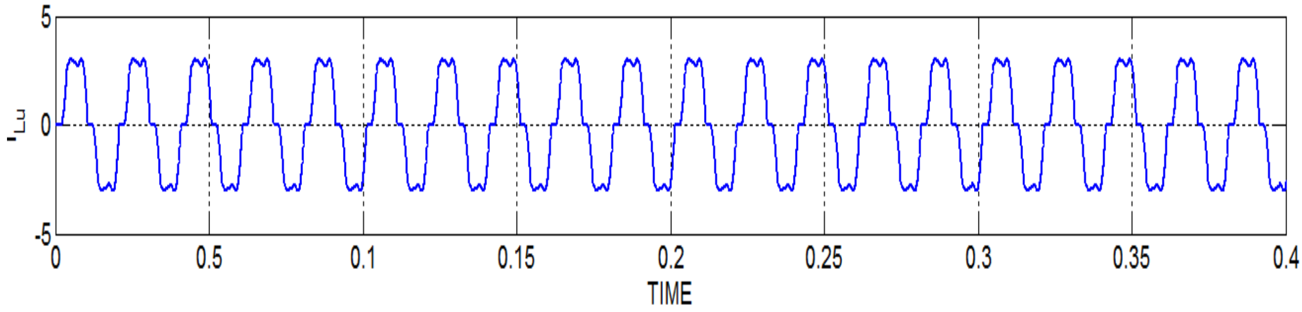

Fig. 8. *Load current at 0<t<0.4sec.*

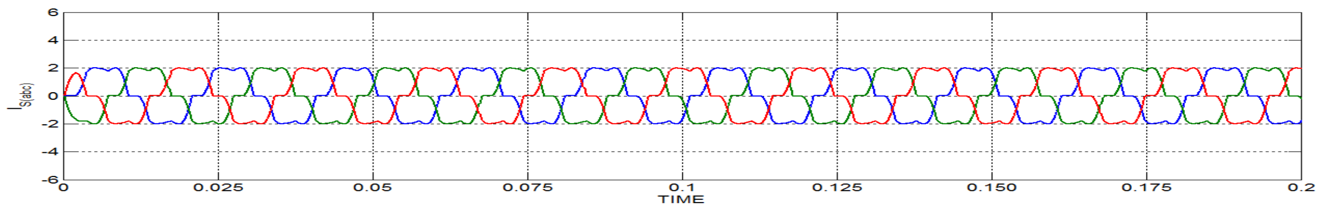

Fig. 9. *Source current at 0<t<0.2 Sec.*

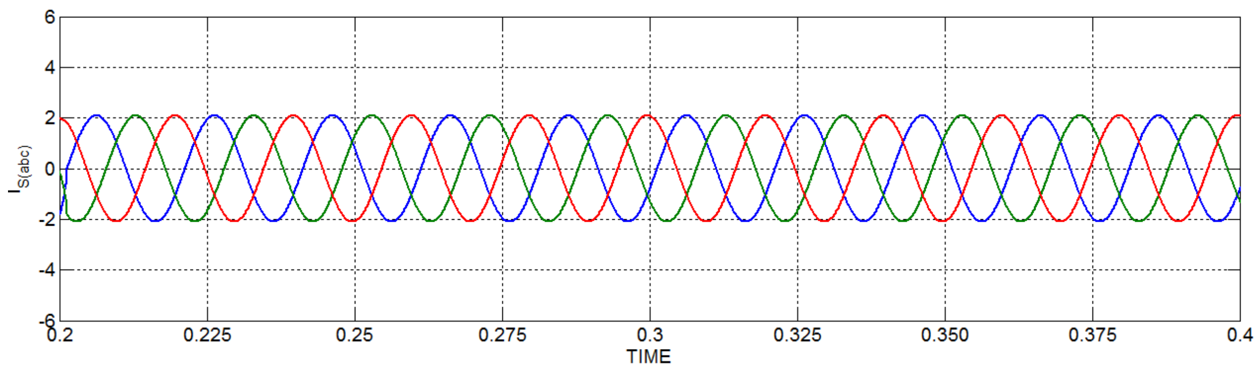

Fig. 10. *Source current at 0.2 <t<0.4sec.*

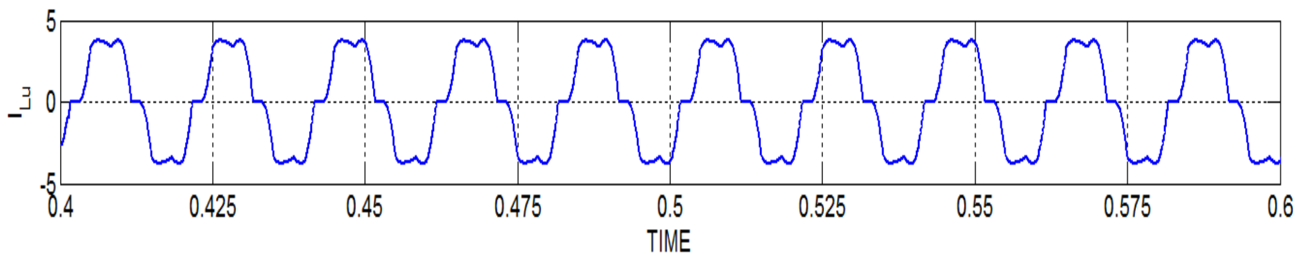

Fig. 11. *Load current due to step change 0.4 <t<0.6 sec.*

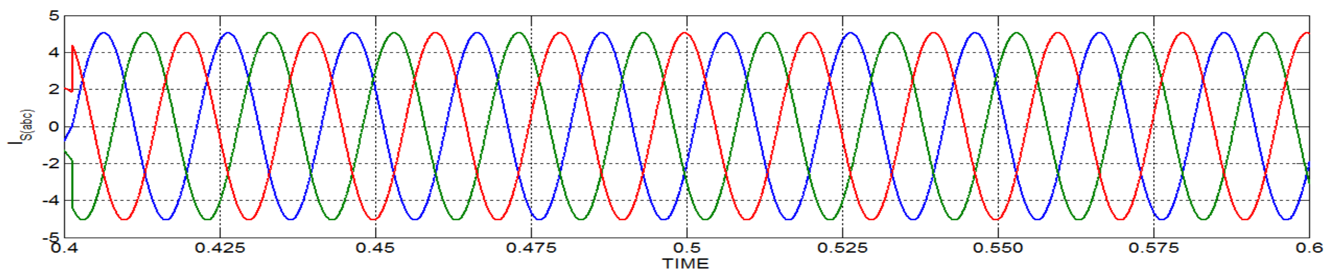

Fig. 12. *Compensated load current 0.4<t<0.6 sec.*

4. Grid Connected Wind Energy System

The three main components for energy conversion in WT are rotor, gear box and generator. The rotor converts the fluctuating wind energy into mechanical energy and is thus the driving component in the conversion system. The block diagram for wind energy system with grid connection is shown in Fig 13.

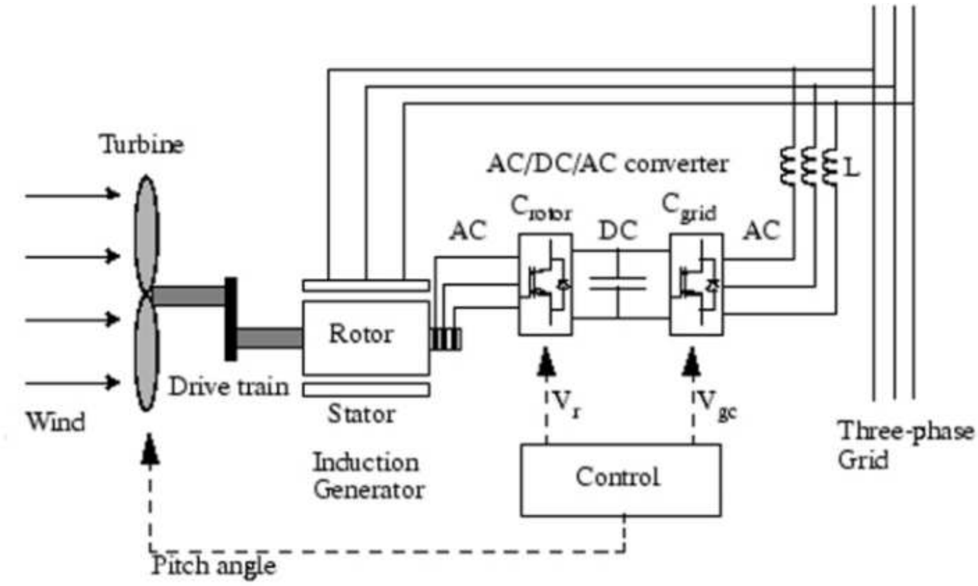

Fig. 13. *Schematic diagram of Gidconncted wind turbine.*

At the point of common coupling (PCC) betweenthe single WT or the wind farm and the grid a circuitbreaker for the disconnection of the whole windfarm or of the WT must exist. In general this circuitbreaker is located at the medium voltage systeminside a substation, where also the electricity meterfor the settlement purposes is installed. This usuallyhas its own voltage and current transformers. The medium voltage connection to the grid can beperformed as a radial feeder or as a ring feeder,depending on the individual conditions of theexisting supply system.

4.1. Classification of Induction Generators for Wind Turbines

Induction generators can be classified by different ways as rotorconstruction, excitation process, and prime movers.

4.1.1. Classification on the Basis of Their Rotor Construction

- Squirrel cage induction generator
- Wound rotor induction generator

4.1.2. Classification on the Basis of Their Excitement Process

- Grid connected induction generator
- Self-excited induction generator

4.1.3. Classification on the Basis of Prime Movers Used, and Their Locations

- Fixed speed concept using a multistage gearbox
- Limited Variable speed concept using a multistage Gearbox
- Variable speed concept with a partial scale power Converter
- Variable speed direct drive concept with a full-scalepower converter

4.2. Grid Connected Wind Energy System with STATCOM Control

The wind energy generating system is connected with grid having the nonlinear load. 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 three phase injected current into the grid from STATCOM will cancel out the distortion caused by the non-linear load and wind generator.

The Fig.14shows the complete simulation diagram for the grid connected wind energy conversion system using hybrid fuzzy controller. Here the grid voltage 415 volts and frequency 50 Hz is maintained continuously and a nonlinear load is connected to it and it is represented by the subsystem. A constant speed (10 m/s) wind turbine, with asynchronous generator is connected to the grid.

Induction generator is connected to the distribution network; it requires an external reactive source connected to its stator winding to provide an output voltage control. This reactive support is given by the STATCOM since STATCOM operates in two different modes. One is voltage regulation and the other is VAR control mode. In voltage regulation mode the STATCOM regulates at its connection point by controlling the amount of reactive power that is absorbed from or injecting into the power system through VSC.

When the system voltage is high the STATCOM will absorb the reactive power (inductive behavior). When the system voltage is low the STATCOM will generate and inject reactive power into the system. That's how it will give reactive support to the induction generator for its excitation.

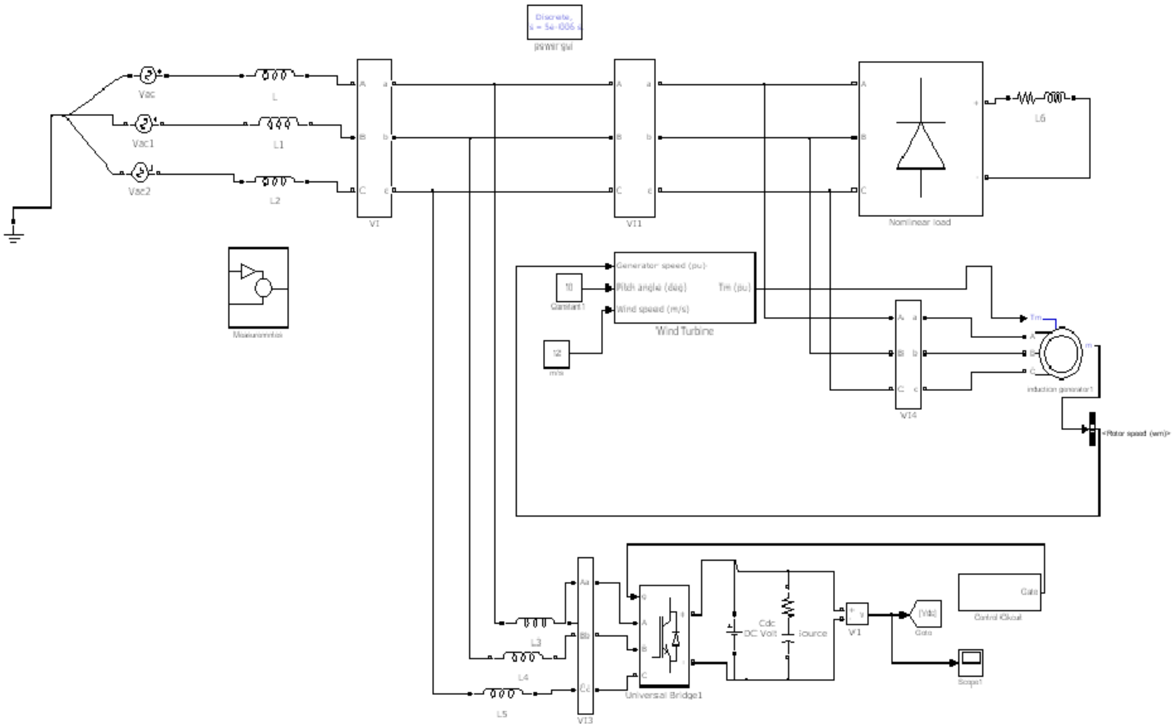

Fig. 14. Simulation diagram for grid connected Wind turbine with STATCOM Control.

To control the distortions caused by the nonlinear load and wind turbine a battery energy storage system with STATCOM is also connected at the point of common coupling. 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.

4.3. Simulation Results of Wind System

The wind energy generating system is connected with grid having the nonlinear load. Itis 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 three phase injected current into the grid from STATCOM will cancel out the distortion caused by the nonlinear load and wind generator. Fig. 15(a) shows the source current waveform of the test system without STATCOM and the Fig. 15 (b) shows the corresponding FFT analysis waveform. From FFT analysis, it is observed that the Total Harmonic Distortion (THD) of the source current waveform of the test system without STATCOM is 27.21%.

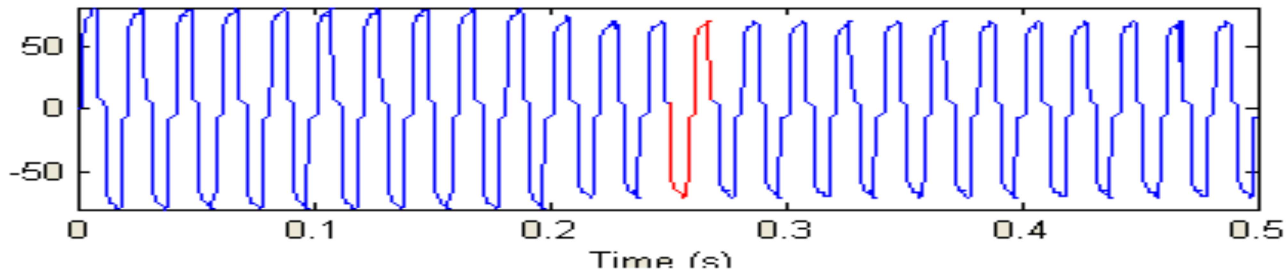

Fig. 15(a). Source current wave form with out STATCOM.

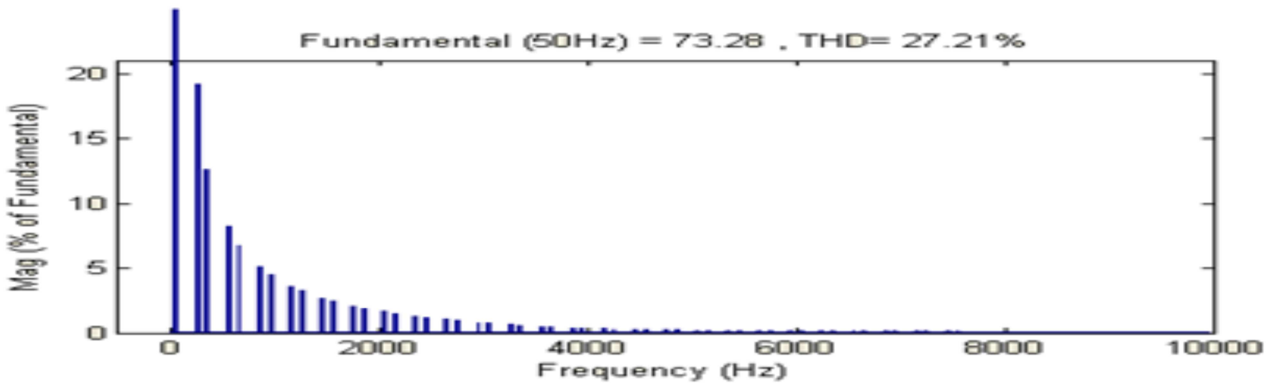

Fig. 15(b). *FFT analysis of source currnt wave form.*

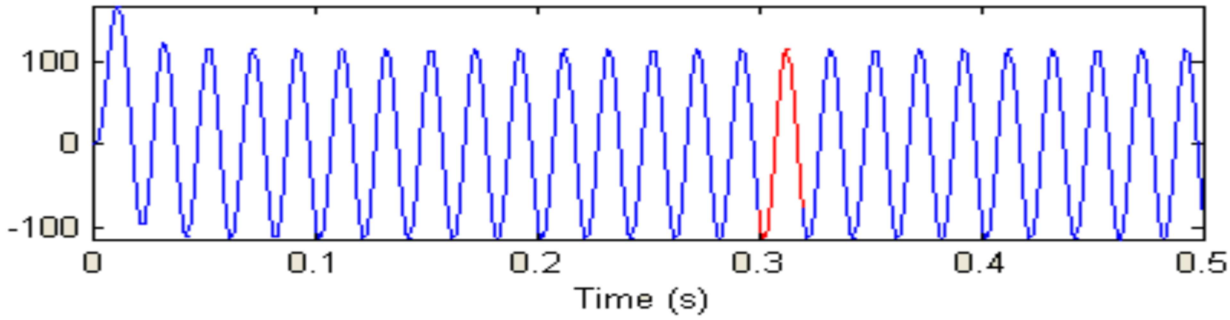

Fig. 16(a). *Source current wave form with STATCOM Compensation.*

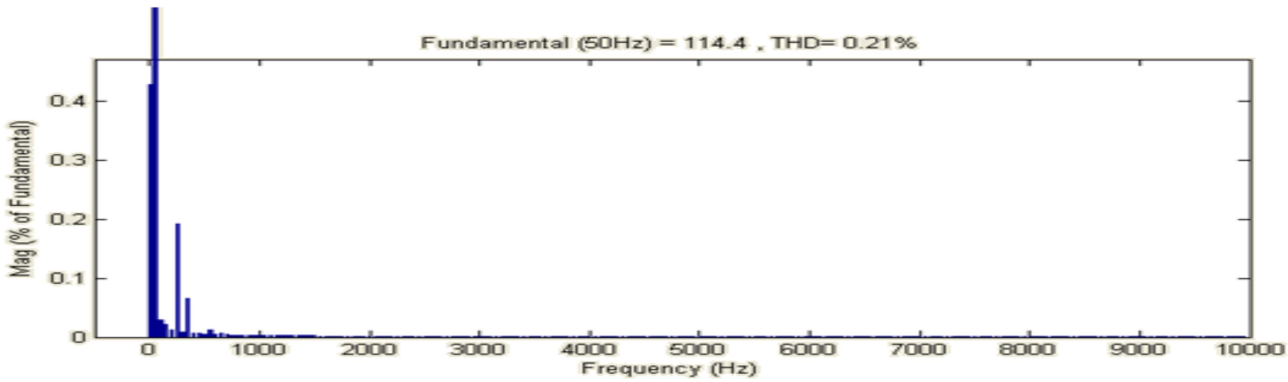

Fig. 16(b). *THD for the source current wave form with STATCOM.*

Fig. 16(a) shows the source current waveform of the test system with Hybrid F uzzy Logic Controller based STATCOM and the Fig. 16(b) shows the corresponding FFT analysis waveform. From FFT analysis, it is observed that the THD of the source current waveform of the test system with Hybrid FLC based STATCOM is 0.21 %. Thus, it is observed that there is a further reduction in the THD value of the source current waveform.

5. Conclusions

End user appliances are becoming more sensitive to the power quality condition. This Case presents a technical review of causes of Power quality Problems associated with renewable based distribution generation system (wind energy, solar energy). Simulation study has done on PV based grid connected system with four leg VSI to enhance the power quality. It has been shown that the grid interfacing inverter can be effectively utilized for power conditioning without affecting its normal operating of real power transfer. A hybrid fuzzy logic controller based STATCOM is presented for grid connected Wind Energy Generating System. The proposed Hybrid FLC based The proposed Hybrid FLC based STATCOM have improved the power quality of source current significantly by reducing the THD from 27.21% to 0.21%.

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