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A NOVEL METHOD OF STATIC COMPENSATION BASED SCHEME FOR IMPROVEMENT OF POWER QUALITY IN RENEWABLE ENERGY APPLICATIONS

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Abstract: Renewable energy source is adopted for the electric power generation, because of its valuable need. Among them wind based generation and PV cells is the motivated sources for power production. In wind based power generation the wind turbines are used for generation purpose. Mostly the wind energy system is directly integrated with the power system for power supply. In case of direct integration, there arises a complexity for maintaining power quality. The power quality factors like voltage sag, voltage sag, swells, flickers, harmonics etc. In order to maintain the power quality in power system while the usage of wind energy system, an external circuit is adopted. In this paper, we presents The performance of the wind turbine and PV cells 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. 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 paper study demonstrates the power quality problem due to installation of wind turbine with the grid and also applied to renewable application of PV CELLS.

Key words: Wind Energy System Distribution Static Compensator (DSTATCOM) Proportional Integral Derivative (PID) Controller Artificial Neural Network (ANN) Power Quality.

(I)INRODUCTION

Now a days energy demand is increasing rapidly, due to the growth in population and economic development in the world leading to increase in environmental impact on conventional plants. Hence renewable energy resources must be employed in order to meet the energy demand and have communal development and prolong growth. In recent years, among the other renewable energy sources, wind energy is gaining ever increasing attention as a clean, safe and economical resource. Thus to exploit wind power effectively its grid connection is necessary so as to realize its potential to significantly mitigate present day problems like energy demand along with atmospheric pollution. But amalgamation of wind power to grid introduces power quality issues, which predominantly consist of voltage regulation and reactive power compensation. The power quality is a crucial customer-focused measure and is of prominent importance to the wind turbine. The main power quality issues are voltage, current and frequency that results in mal-operation of customer end equipments. Wind turbine produces a continuously variable output power during its normal operation because of wind variation, effect of tower shadow, wind shear, turbulence. Voltage sag, swell ,flickers, harmonics etc. are the power quality issues which are more harmful to wind generation, transmission and distribution network i.e. for grid. In wind power based generation, mostly induction generators are used because of its cost effectiveness and robustness. Induction generators draw reactive power from the grid for magnetization to which they are connected. The active power generated by induction generated is varied due to fluctuating nature of wind and this variation can prominently affect the absorbed reactive power and terminal voltage of induction generator. Integration of wind energy into grid affects the power quality of system. The devices used for mitigation of power quality problems are known as Customer Power Devices (CPDs). The generalized compensating devices are: Dynamic Voltage Regulator (DVR), Static VAR Compensator (SVC), Static Synchronous Compensator (STATCOM), and Unified Power Quality Conditioner (UPQC). Among all these devices performance of STATCOM with battery energy storage system (BESS) is very good and user friendly to mitigate the power quality issues.

• Support the reactive power to wind turbine and non-linear load from STATCOM .

• For fast dynamic response controller is implemented in STATCOM

• Minimize the THD percentage at the PCC waveform

2 Literature Survey:

1. Y.H Song and A. Johns to explain the concept of Flexible ac Transmission Systems (FACTS).
2. N.G. Hingorani and Gyugyi to describe the concepts and technology of Flexible AC Transmission Systems.
3. L. gyugyi , C.D. Schauder , S.L. Willims , T.R Rietman, D.R Togerson and A.Edris , to propose a new concept of the unified power flow controller a new approach to power transmission control.
4. A-A Edris to explain the proposed terms and definitions for flexible ac transmission system.
5. K.K Sen to address the static Synchronous series Compensator.

3 Objective of the Project:

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.

4 Problem of formation:

Injection of the wind power into an electric grid affects the power quality. In this proposed scheme STATIC COMPENSATOR (STATCOM) is connected at a point of common coupling with a battery energy storage system (BESS) to mitigate the power quality issues. 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; 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.Moreover, much research confirms several advantages of STATCOM. These advantages compared to other shunt compensators include: Size, weight, and cost reduction. • Equality of lagging and leading output. • Precise and continuous reactive power control with fast response. Possible active harmonic filter capability.

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

a). International Electro Technical Commission Guidelines: The guidelines are provided for measurement of power quality of wind turbine. The International standards are developed by the working group of Technical Committee-88 of the International Electro-technical Commission (IEC), IEC standard 61400-21, describes the procedure for determining the power quality characteristics of the wind turbine. The standard norms are specified.

1. IEC 61400-21: Wind turbine generating system, part-21. Measurement and Assessment of power quality characteristic of grid connected wind turbine.

2. IEC 61400-13: Wind Turbine measuring procedure in determining the power behavior.

3. IEC 61400-3-7: Assessment of emission limits for fluctuating load IEC 61400-12: Wind Turbine performance. The data sheet with electrical characteristic of wind turbine provides the base for the utility assessment regarding a grid connection.

b) 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 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. The IEC 61500-5-15 specifies a flicker.

c) 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-61500-36 guideline. The rapid switching gives a large reduction in lower order harmonic current compared to the line commutated converter, but the output current will have high frequency current and can be easily filter-out.

d) 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.

e) Self Excitation of Wind Turbine Generating System: The self-excitation of wind turbine generating system (WTGS) with an asynchronous generator takes place after disconnection of wind turbine generating system (WTGS) with local load. The risk of self-excitation arises especially when WTGS is equipped with compensating capacitor. The capacitor connected to induction generator provides reactive power compensation. However the voltage and frequency are determined by the balancing of the system. The disadvantages of self-excitation are the safety aspect and balance between real and reactive power.

f) Consequences of the Issues: The voltage variation, flicker, harmonics causes the malfunction of equipment's namely microprocessor based control system, programmable logic controller adjustable speed drives, flickering of light and screen. It may leads to tripping of contractors, tripping of protection devices, stoppage of sensitive equipment's like personal computer, programmable logic control system and may stop the process and even can damage of sensitive equipment's. Thus it degrades the power quality in the grid.The risk of self-excitation arises especially when WTGS is equipped with compensating capacitor. The rapid switching gives a large reduction in lower order harmonic current compared to the line commutated converter, but the output current will have high frequency current and can be easily filter-out.

6. GRID COORDINATION RULE

The American Wind Energy Association (AWEA) led the effort in the United States for adoption of the grid code for the interconnection of the wind plants to the utility system. The first grid code was focused on the distribution level, after the blackout in the United State in August 2003. The United State wind energy industry took a stand in developing its own grid code for contributing to a stable grid operation. The rules for realization of grid operation of wind generating system at the distribution network are defined as-per IEC-61400-21. The grid quality characteristics and limits are given for references that the customer and the utility grid may expect. According to Energy-Economic Law, the operator of transmission grid is responsible for the organization and operation of interconnected system.

a) Voltage Rise (u): Voltage rise at the point of common coupling can be approximated as a function of maximum apparent power of the turbine, the grid impedances R and X at the point of common coupling and the phase angle given in eq. (1)

$$\Delta u = S_{\max}(R\cos\phi - X\sin\phi)/U^2 \quad (1)$$

Where Φ-phase difference, U-is the nominal voltage of grid. The Limiting voltage rise value is <2%

b) **Voltage Dips (d):** The voltage dips is due to startup of wind turbine and it causes a sudden reduction of voltage. It is the relative %voltage change due to switching operation of wind turbine. The decrease of nominal voltage change is given in (2).

$$d = K_u \frac{S_n}{S_K} \quad (2)$$

Where d is relative voltage change, rated apparent power, short circuit apparent power, and sudden voltage reduction factor. The acceptable voltage dips limiting value is ≤3%.

c) Flicker: The measurements are made for maximum number of specified switching operation of wind turbine with 10-min period and 2-h period are specified, as given in eq. 6.3

$$P_{lt} = C(\Psi_K)\frac{S_n}{S_K} \quad (3)$$

Where P_{1t} long term flickers. $C(\Psi_K)$. Flicker coefficient calculated from Rayleigh distribution of the wind speed. The Limiting Value for flicker coefficient is about, for average time of 2 h.

d) Harmonics: The harmonic distortion is assessed for variable speed turbine with a electronic power converter at the point of common connection [9]. The total harmonic voltage distortion of voltage is given as in (4):

$$V_{THD} = \sqrt{\sum_{h=2}^{40} \frac{V_n^2}{V_1} 100} \quad (4)$$

Where V_n is the nth harmonic voltage.

V_1 is the fundamental frequency (60) Hz.

The THD limit for 132 KV is <3 %

THD of current is given as in (6)

$$I_{THD} = \sqrt{\sum \frac{I_n}{I_1} 100} \quad (5)$$

Where, I_n is the nth harmonic current, I_1 is the fundamental frequency (50) Hz.

The THD of current and limit for 132 KV is <2.5%.

e) Grid Frequency: The grid frequency in India is specified in the range of 47.6–51.6 Hz, for wind farm connection. The wind farm shall able to withstand change in frequency up to 0.5 Hz/s.

7. 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. 7. 1. The grid connected system in Fig 7.1, consists of wind energy generation system and battery energy storage system with STATCOM.

a) 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 eq.6.

$$P_{\text{wind}} = \frac{1}{2}\rho A V_{\text{wind}}^3 \tag{6}$$

Where *p* (kg/m) is the air density and A(m_2) is the area swept out by turbine blade, V_{wind} is the wind speed in m_{tr}/s. It is not possible to extract all kinetic energy of wind, thus it extract a fraction of power in wind, called power coefficient C_p of the wind turbine, and is given in eq.7.

$$P_{\text{mech}} = C_p P_{\text{wind}} \tag{7}$$

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 eq.8.

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

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

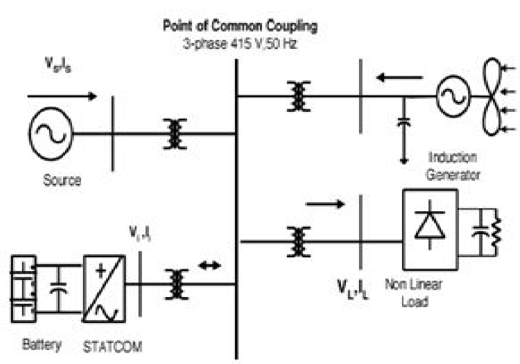

Fig 1 Grid connected system for power quality improvement.

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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. 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) 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.

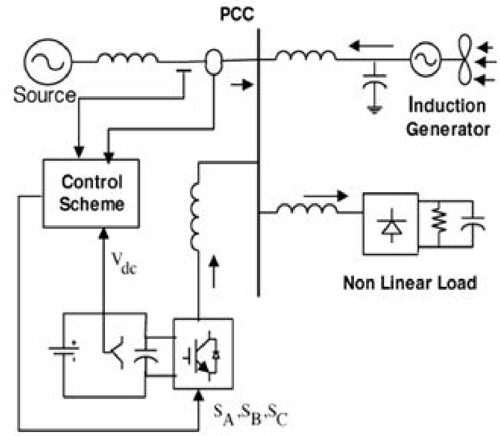

Fig 2 system operational scheme in grid connected system.

d) 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.

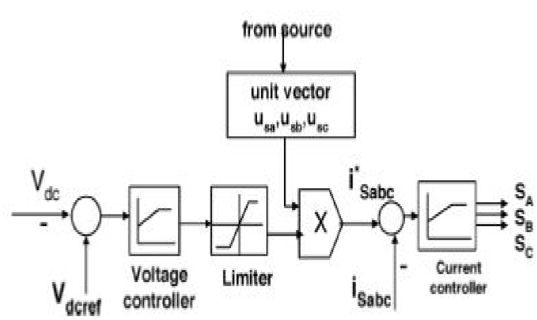

Fig 3 Control system scheme.

The control algorithm needs the measurements of several variables such as three-phase source current i_{sabc}, DC voltage

V_{dc} , inverter current i_{sabc} with the help of sensor. The current control block, receives an input of reference current i_{sabc}* and actual current i_{sabc} are subtracted so as to activate the operation of STATCOM in current control mode.

(i) Grid Synchronization

In three-phase balance system, the RMS voltage source amplitude is calculated at the sampling frequency from the source phase voltage (V_{sa} V_{sb} V_{sc}) and is expressed, as sample template *Vsm*, sampled peak voltage, as in eq. 7.4.

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

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

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

$$i_{Sa}^* = I.u_{Sa}, \quad i_{Sb}^* = I.u_{Sb}, \quad i_{Sc}^* = I.u_{Sc} \quad (10)$$

The in-phase generated reference currents are derived using in-phase unit voltage template as, in eq.10

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.

(ii) Bang-Bang Current Controller

Bang-Bang current controller is implemented in the current control scheme. The reference current is generated as in eq.7.5 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.

The switching function Sa for phase 'a' is expressed as below.

$$\begin{aligned} i_{sa} &< (i_{sa}^* - HB) \rightarrow S_A = 0 \\ i_{sa} &> (i_{sa}^* - HB) \rightarrow S_A = 1 \end{aligned} \quad (11)$$

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

8. PHOTOVOLTAIC TECHNOLOGY

A PV array consists of a number of PV modules, mounted in the same plane and electrically connected to give the required electrical output for the application. The PV array can be of any size from a few hundred watts to hundreds of kilowatts, although the larger systems are often divided into several electrically independent sub arrays each feeding into their own power conditioning system.Photovoltaic's is the field of technology and research related to the

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devices which directly convert sunlight into electricity using semiconductors that exhibit the photovoltaic effect. Photovoltaic effect involves the creation of voltage in a material upon exposure to electromagnetic radiation.The photovoltaic effect was first noted by a French physicist, Edmund Becquerel, in 1839, who found that certain materials would produce small amounts of electric current when exposed to light. In 1905, Albert Einstein described the nature of light and the photoelectric effect on which photovoltaic technology is based, for which he later won a Nobel prize in physics. The first photovoltaic module was built by Bell Laboratories in 1954. It was billed as a solar battery and was mostly just a curiosity as it was too expensive to gain widespread use. In the 1960s, the space industry began to make the first serious use of the technology to provide power aboard spacecraft. Through the space programs, the technology advanced, its reliability was established, and the cost began to decline. During the energy crisis in the 1970s, photovoltaic technology gained recognition as a source of power for non-space applications.The solar cell is the elementary building block of the photovoltaic technology. Solar cells are made of semiconductor materials, such as silicon. One of the properties of semiconductors that makes them most useful is that their conductivity may easily be modified by introducing impurities into their crystal lattice. For instance, in the fabrication of a photovoltaic solar cell, silicon, which has four valence electrons, is treated to increase its conductivity. On one side of the cell, the impurities, which are phosphorus atoms with five valence electrons (n-donor), donate weakly bound valence electrons to the silicon material, creating excess negative charge carriers.

On the other side, atoms of boron with three valence electrons (p-donor) create a greater affinity than silicon to attract electrons. Because the p-type silicon is in intimate contact with the n-type silicon a p-n junction is established and a diffusion of electrons occurs from the region of high electron concentration (the n-type side) into the region of low electron concentration (p-type side). When the electrons diffuse across the p-n junction, they recombine with holes on the p-type side. However, the diffusion of carriers does not occur indefinitely, because the imbalance of charge immediately on either sides of the junction originates an electric field. This electric field forms a diode that promotes current to flow in only one direction.Ohmic metal-semiconductor contacts are made to both the n-type and p-type sides of the solar cell, and the electrodes are ready to be connected to an external load. When photons of light fall on the cell, they transfer their energy to the charge carriers. The electric field across the junction separates photo-generated positive charge carriers (holes) from their negative counterpart (electrons). In this way an electrical current is extracted once the circuit is closed on an external load.

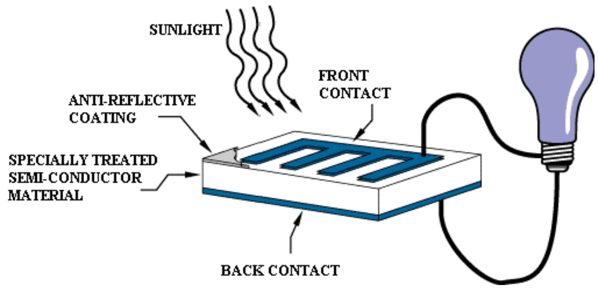

Fig: 4. photovoltaic system

(B) PV CELL MODEL

The equivalent circuit of a PV cell is shown in Fig.4.3. It includes a current source, a diode, a series resistance and a shunt resistance.

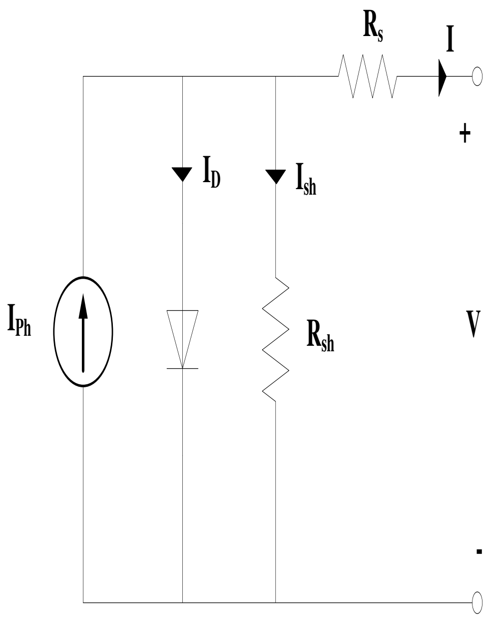

Fig 5. PV cell equivalent circuit.

In view of that, the current to the load can be given as:

$$I = I_{ph} - I_s(\exp\frac{q(V+R_sI)}{NKT}) -1) - \frac{(V+R_sI)}{R_{sh}} \quad (12)$$

In this equation, $I_{ph}$is the photocurrent, $I_s$is the reverse saturation current of the diode, q is the electron charge, V is the voltage across the diode, K is the Boltzmann's constant, T is the junction temperature, N is the ideality factor of the diode, and $R_s$and $R_{sh}$are the series and shunt resistors of the cell, respectively. As a result, the complete physical behavior of the PV cell is in relation with I_{ph}, I_s, $R_s$and $R_{sh}$from one hand and with two environmental parameters as the temperature and the solar radiation from the other hand.

9.SIMULATION BLOCK DIAGRAM WITHOUT STATCOM

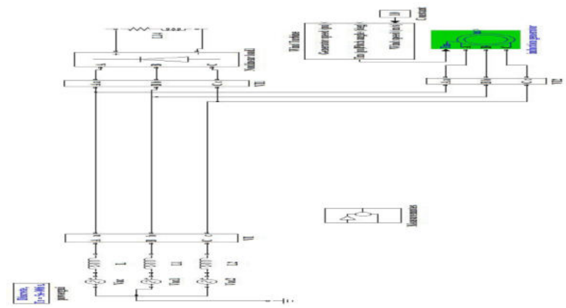

Fig6 Simulation block diagram without STATCOM.

SINGLE PHASE CURRENT WAVEFORMS (WITHOUT STATCOM)

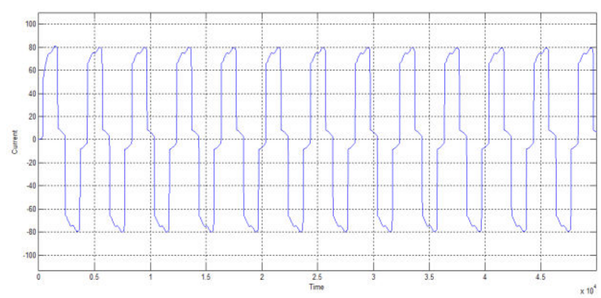

Fig:7 1-ϕ Source current waveform without STATCOM.

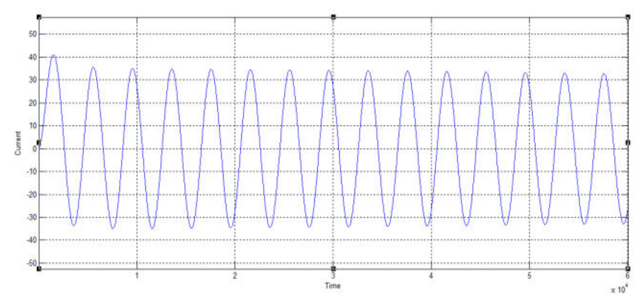

Fig: 8 1-ϕ Generator current waveform without STATCOM.

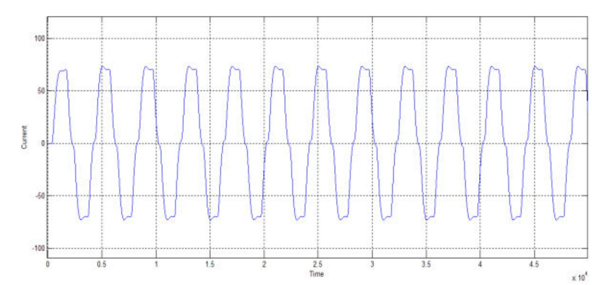

Fig: 9 1-ϕ Load current waveform without STATCOM.

THREE PHASE CURRENT WAVE FORMS WITHOUT STATCOM

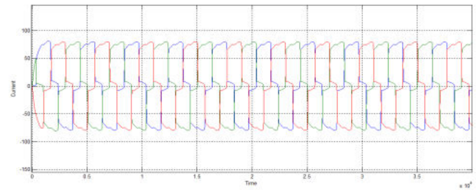

Fig: 10 3-ϕ Source current waveform without STATCOM.

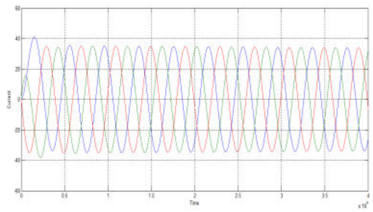

Fig: 11 3-ϕ Generator current waveform without STATCOM.

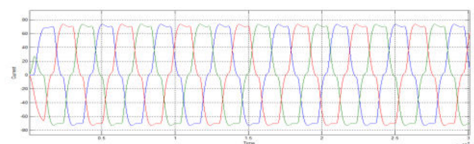

Fig: 12 3-ϕ Load current waveform without STATCOM.

THD ANALYSIS OF SOURCE CURRENT WITHOUT STATCOM

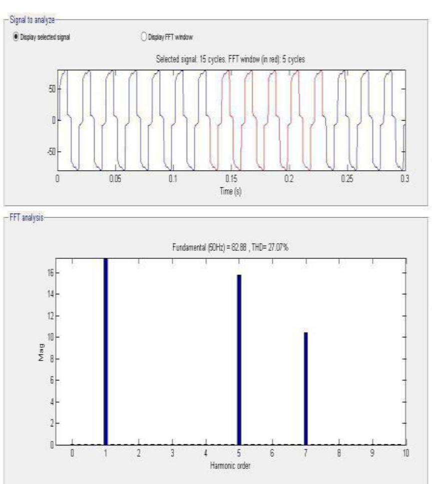

Fig: 13 THD analysis of source current without STATCOM.

Total Harmonic Distortion: 27.07 %.

SIMULATION BLOCK DIAGRAM WITH STATCOM

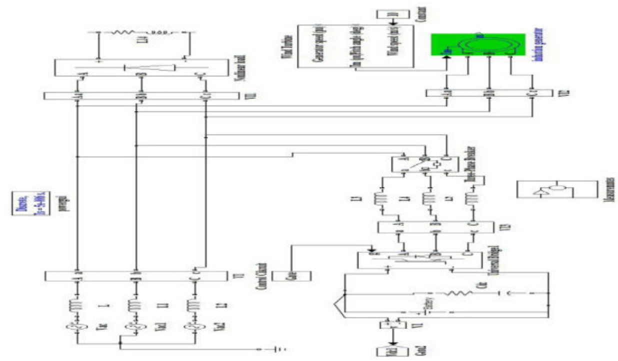

Fig 14 Simulation block diagram with STATCOM.

SINGLE PHASE CURRENT WAVE FORMS WITH STATCOM

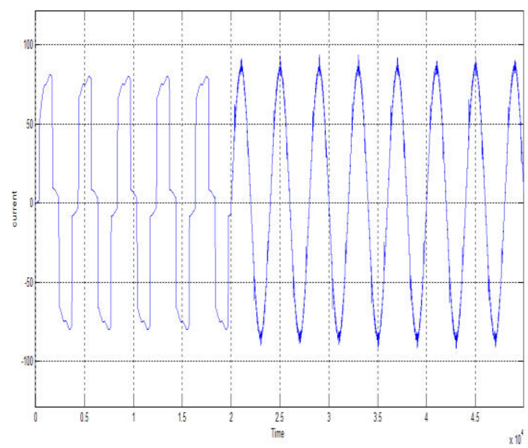

Fig: 15 1-ϕ Source current waveform with STATCOM.

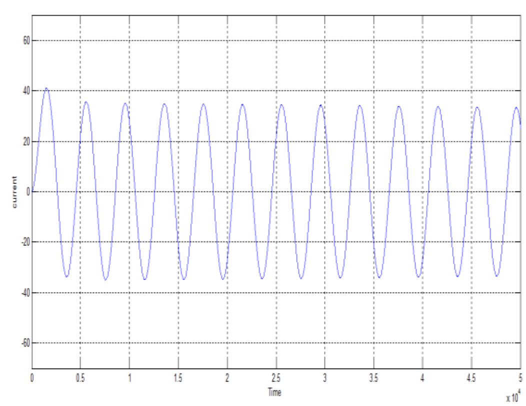

Fig: 16 1-ϕ Generator current waveform with STATCOM.

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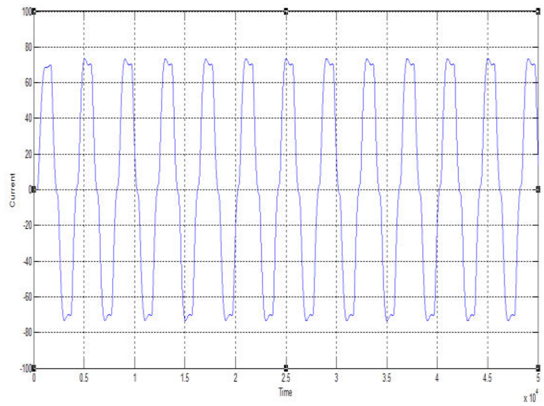

Fig: 17 1-ϕ Load current waveform with STATCOM.

THREE PHASE CURRENT WAVE FORMS WITH STATCOM

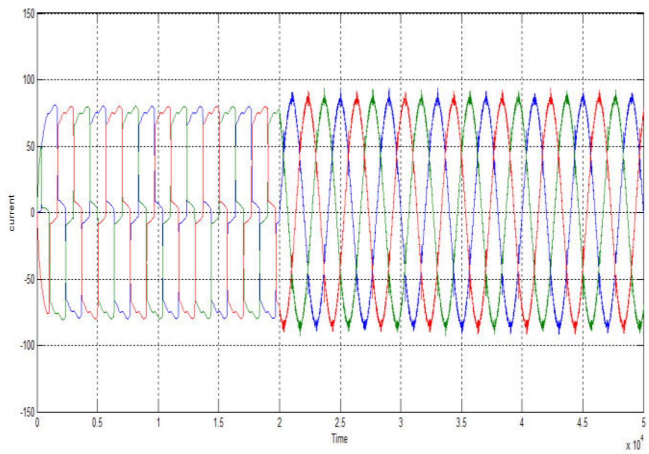

Fig: 18 3-ϕ Source current waveform with STATCOM.

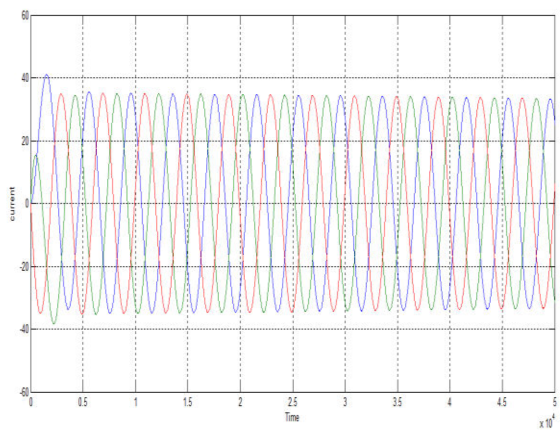

Fig: 19 3-ϕ Generator current waveform with STATCOM.

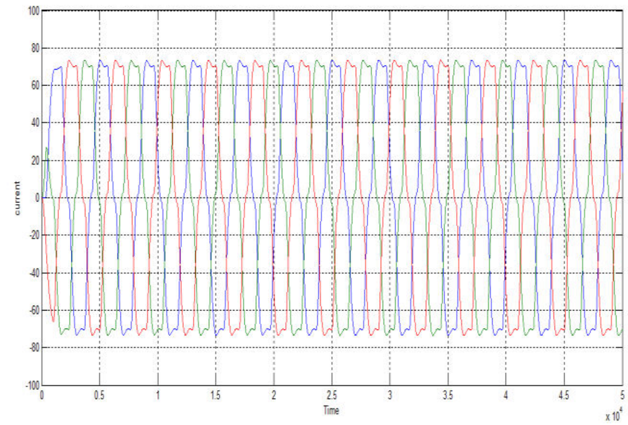

Fig: 20 3-ϕ Load current waveform with STATCOM.

THD ANALYSIS OF SOURCE CURRENT WITH STATCOM

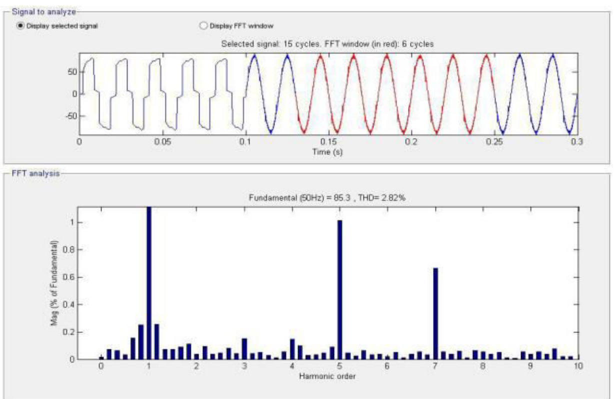

Fig: 21 THD analysis of source current with STATCOM.

Total Harmonic Distortion: 2.82%

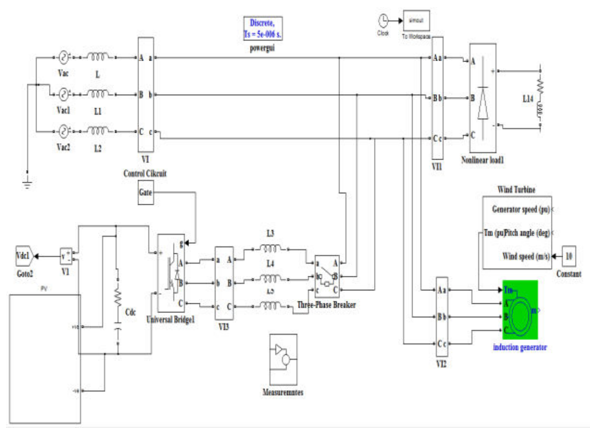

Fig 22 Simulation block diagram STATCOM with PV CELL.

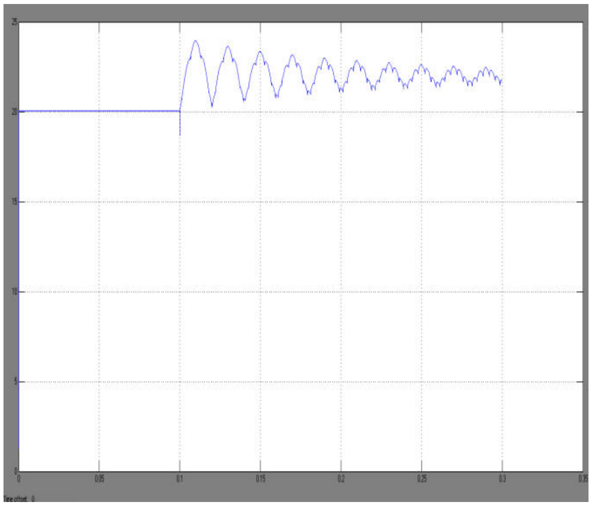

Fig: 23 PV Voltage waveform with STATCOM.

10. CONCLUSION

The project presents the STATCOM-based control scheme for power quality improvement in grid connected wind generating system and with non-linear 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 pv cell STATCOM with BESS have shown the outstanding performance. Thus the proposed scheme in the grid connected system fulfills the power quality.

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