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Enhancement of Power Quality in Grid Interconnection with Wind Generation based BESS under Different Loading Conditions

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Abstract:

The power arising out of the wind turbine when connected to a grid system concerning the power quality measurements, are: active power, reactive power, voltage sag, voltage swell, flicker, harmonics, and electrical behavior of switching operation. These are measured according to national/international guidelines. For this Static Compensator (STATCOM) with a battery energy storage system (BESS) at the point of common coupling to mitigate the power quality problems. The grid connected wind energy generation system for power quality improvement by using STATCOM-control scheme is simulated using SIMULINK in power system block set. So it is proposed to use Flexible AC Transmission System (FACTS) devices for the mitigation of power quality problems. The battery energy storage used to maintain constant real power from varying wind power. The generated power can be stored in the batteries at low power demand hours. The combination of battery storage with wind energy generation system will synthesize the output waveform by absorbing or injecting reactive power and enable the real power flow required by the load. The amount of energy consumed or given to the grid can be view through an online smart meter connected in the circuit. Using the online smart meter the utility can view the energy consumption of each system simultaneously. So the utility can coordinate all the system effectively.The FACTS Device (STATCOM) control scheme for the grid connected wind energy generation system to improve the power quality is simulated using MATLAB/SIMULINK.

Keywords:

Wind power, Distribution Network, Induction Generator, STATCOM, Reactive Power, Harmonics, and Power Quality.

I.INTRODUCTION:

Centralized power generation systems are facing the twin constraints of shortage of fossil fuel and the need to reduce emissions. Long transmission lines are one of the main causes for electrical power losses. Therefore, emphasis has increased on distributed generation (DG) networks with integration of renewable energy systems into the grid, which lead to energy efficiency and reduction in emissions. With the increase of the renewable energy penetration to the grid, power quality (PQ) of the medium to low voltage power transmission system is becoming a major area of interest. Most of the integration of renewable energy systems to the grid takes place with the aid of power electronics converters [1]. The main purpose of the power electronic converters is to integrate the DG to the grid in compliance with power quality standards. However, high frequency switching of inverters can inject additional harmonics to the systems, creating major PQ problems if not implemented properly. Custom Power Devices (CPD) like STATCOM (Shunt Active Power Filter), DVR (Series Active Power Filter) and UPQC (Combination of series and shunt Active Power Filter) are the latest development of interfacing devices between distribution supply (grid) and consumer appliances to overcome voltage/current disturbances and improve the power quality by compensating the reactive and harmonic power generated or absorbed by the load [2, 3]. Recently Active Conditioners such as STATCOM is usedto overcome these problems and also compensating the harmonics and suppressing the reactive power simultaneously due to fluctuating loads. To overcomes the above disadvantages; STATCOM is best suited for reactive power compensation and harmonic reduction. It is based on a controllable voltage source converter (VSC). In normal operating system we need a control circuit for the active power production. For reducing the disturbance we use a battery storage system.

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This compensates the disturbance generated by wind turbine. A STATCOM has been proposed for improving the power quality. This STATCOM technically manages the power level associated with the commercial wind turbines. This system produces a proper voltage level having power quality improvements. This system provides energy saving and uninterruptible power [5]. The wind energy system is used to charge the battery as and when the wind power is available. The voltage source inverter is controlled by using the current control mode.

The proposed system with battery storage has the following objectives:
• Unity power factor and power quality at point of common coupling bus.
• Real and reactive power support only from wind generator and batteries to load.
• Self operation in case of grid failure. The utility companies can view the current, voltage and power of each system simultaneously by using the online smart metes. The utility can measure power generation of each system simultaneously.

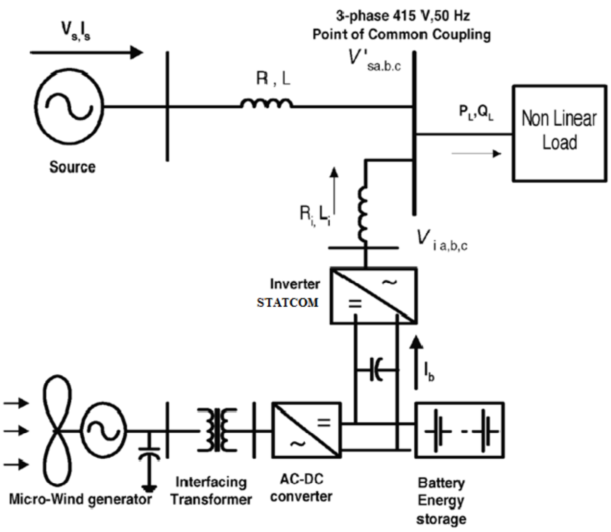

Fig.1 Scheme of wind generator with battery storage [6].

The most used unit to compensate for reactive power in the power systems are either synchronous condensers or shunt capacitors, the latter either with mechanical switches or with thyristor switch, as in Static VAR Compensator (SVC).The disadvantage of using shunt Capacitor is that the reactive power supplied is proportional to the square of the voltage. Consequently, the reactive power supplied from the capacitors decreases rapidly when the voltage decreases [3] .

To overcomes the above disadvantages; STATCOM is best suited for reactive power compensation and harmonic reduction. It is based on a controllable voltage source converter (VSC). The paper study demonstrates the power quality problem due to installation of wind turbine with the grid. 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. The battery energy storage is integrated to sustain the real power source under fluctuating wind power. The STATCOM control scheme for the grid connected wind energy generation system for power quality improvement is simulated using MATLAB/SIMULINK.

II. STATIC SYNCHRONOUS COMPENSATOR (STATCOM):

The STATCOM is a shunt-connected reactive-power compensation device that is capable of generating and/or absorbing reactive power and in which the output can be varied to control the specific parameters of an electric power system. It is in general a solid-state switching converter capable of generating or absorbing independently controllable real and reactive power at its output terminals when it is fed from an energy source or energy-storage device at its input terminals. Specifically, the STATCOM, which is a voltage-source converter which when fed from a given input of dc voltage, produces a set of 3-phase ac-output voltages, each in phase with and coupled to the corresponding ac system voltage through a relatively small reactance (which is provided by either an interface reactor or the leakage inductance of a coupling transformer). The dc voltage is provided by an energy-storage capacitor.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. A STATCOM can improve power-system Performance like:

1. The dynamic voltage control in transmission and distribution systems,
2. The power-oscillation damping in power- transmission systems,
3. The transient stability,
4. The voltage flicker control, and
5. The control of not only reactive power but also (if needed) active power in the connected line, requiring a dc energy source.

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A STATCOM is analogous to an ideal synchronous machine, which generates a balanced set of three sinusoidal voltages at the fundamental frequency with controllable amplitude and phase angle. This ideal machine has no inertia, is practically instantaneous, does not significantly alter the existing system impedance, and can internally generate reactive (both Capacitive and inductive) power.

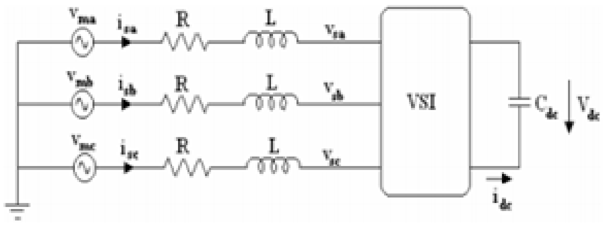

Fig. 2. Equivalent circuit of STATCOM

Fig.2. shows the equivalent circuit of the STATCOM connected to the power system. The reactive power supplied by the STATCOM is either inductive or capacitive depending upon the relative magnitude of fundamental component of vs with respect to vm. If |v m| > |vs|, the VSI draws reactive power from the ac bus whereas if |v m| < |vs|, it supplies reactive power to the ac system.

III POWER QUALITY ISSUES:

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 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. The rapid switching gives a large reduction in lower order harmonic current com- pared to the line commutated converter, but the output current will have high frequency current and can be easily filter out. 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 (1).

$$V_{THD} = \sqrt{\sum_{h=2}^{40} \frac{V_n^2}{V_1} 100} \quad (1)$$

Where Vn is the nth harmonic voltage and V1 is the fundamental frequency (50) Hz. The THD limit for 132 KV is <3 %.THD of current ITHD is given as in (2)

$$I_{THD} = \sqrt{\sum \frac{I_n}{I_1} 100} \quad (2)$$

Where In is the nth harmonic current and I1 is the fundamental frequency (50) Hz. The THD of current and limit for 132 KV is <2.5%.

C.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. The interactions between wind turbine and power system network are important aspect of wind generation system. When wind turbine is equipped with an induction generator and fixed capacitor are used for reactive compensation then the 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 stabilize the grid. The suggested control technique is capable of controlling reactive power to zero value at point of common connection (PCC).

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.

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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. The induction generators are widely used, due to theadvantage of cost effectiveness, robustness, ruggedness, simplicity and requirement of no brush and commutators.However; induction generators require reactive power for magnetization.

When the generated active power of an induction generator is varied due to wind, absorbed reactive power and terminal voltage of an induction generator can be significantly affected. During the operation induction generator draws reactive power from the grid for its magnetization. Non linear load distorts the grid current waveform and also increase the harmonic component.

Due to this, grid current is not in phase with the grid voltage and its wave shape is also different from sine wave which is shown in fig 4. Hence the power factor is not unity. Reactive power requirement of induction generatorand load is supplied by the grid.

IV.REFERENCE CURRENT GENERATION FOR STATCOM:

Reference current for the STATCOM is generated based on instantaneous reactive power theory [7][10]. A STATCOM injects the compensation current which is a sum of reactive component current of IG, non-linear load and harmonic component current of non-linear load. P-Q theory gives a generalized definition of instantaneous reactive power, which is valid for sinusoidal or non sinusoidal, balanced or unbalanced, three-phase power systems with or without zero sequence currents and/or voltages.

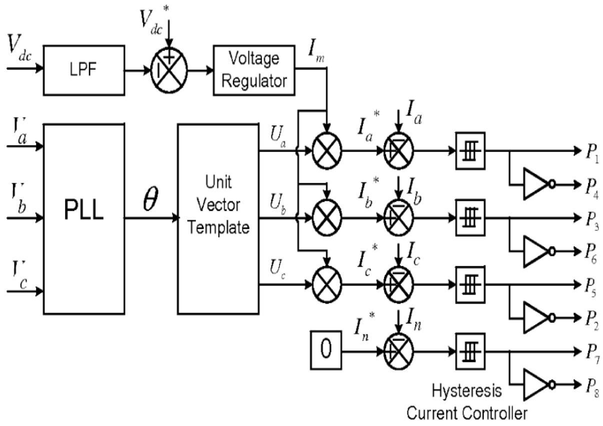

Fig. 3. Block diagram representation of grid-interfacing inverter control.

The control diagram of grid- interfacing inverter for a 3-phase 3-wire system is shown in Fig. 3. While performing the power management operation, the inverter is actively controlled in such a way that it always draws/ supplies fundamental active power from/ to the grid. If the load connected to the PCC is non-linear or unbalanced or the combination of both, the given control approach also compensates the harmonics, unbalance, and neutral current. The duty ratio of inverter switches are varied in a power cycle such that the combination of load and inverter injected power appears as balanced resistive load to the grid. The regulation of dc-link voltage carries the information regarding the exchange of active power in between renewable source and grid. Thus the output of dc-link voltage regulator results in an active current (Im). The multiplication of active current component (Im). With unity grid voltage vector templates (Ua,Ub, and Uc) generates the reference grid currents . The grid synchronizing angle (θ) obtained from phase locked loop (PLL) is used to generate unity vector template as [9]–[11]

$$U_a = \text{Sin}(\theta) \quad (3)$$

$$U_b = \text{Sin}(\theta - \frac{2\pi}{3}) \quad (4)$$

$$U_c = \text{Sin}(\theta + \frac{2\pi}{3}) \quad (5)$$

The actual dc-link voltage (Vdc) is sensed and passed through a first-order low pass filter (LPF) to eliminate the presence of switching ripples on the dc-link voltage and in the generated reference current signals.

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The difference of this filtered dc-link voltage and reference dc-link voltage (V*dc) is given to a discrete- PI regulator to maintain a constant dc-link voltage under varying generation and load conditions. The dc-link voltage error Vdcerr (n) at nth sampling instant is given as:

$$V_{\mathrm{dcerr}(n)} = V^*_{\mathrm{dc}(n)} - V_{\mathrm{dc}(n)}. \quad (6)$$

The output of discrete-PI regulator at th sampling instant is expressed as

$$I_{m(n)} = I_{m(n-1)} + K_{PV_{dc}}(V_{\mathrm{dcerr}(n)} - V_{\mathrm{dcerr}(n-1)}) + K_{IV_{dc}} V_{\mathrm{dcerr}(n)} \quad (7)$$

Where $K_{PVdc} = 10$ and $K_{IVdc} = 0.05$ are proportional and integral gains of dc-voltage regulator. The instantaneous values of reference three phase grid currents are computed as

$$I_a^* = I_m \cdot U_a \quad (8)$$

$$I_b^* = I_m \cdot U_b \quad (9)$$

$$I_c^* = I_m \cdot U_c. \quad (10)$$

The neutral current, present if any, due to the loads connected to the neutral conductor should be compensated by forth leg of grid-interfacing inverter and thus should not be drawn from the grid. In other words, the reference current for the grid neutral current is considered as zero and can be expressed as

$$I_n^* = 0. \quad (11)$$

The reference grid currents (I*a, I*b,I*c and I*n) are compared with actual grid currents (Ia, Ib,Ic and In) to compute the current errors as

$$I_{\mathrm{aerr}} = I_a^* - I_a \quad (12)$$

$$I_{\mathrm{berr}} = I_b^* - I_b \quad (13)$$

$$I_{\mathrm{cerr}} = I_c^* - I_c \quad (14)$$

$$I_{\mathrm{nerr}} = I_n^* - I_n. \quad (15)$$

These current errors are given to hysteresis current controller. The hysteresis controller then generates the switching pulses (P_1 *to* P_8) for the gate drives of grid-interfacing inverter. The average model of 4-leg inverter can be obtained by the following state space equations

$$\frac{dI_{\mathrm{Inva}}}{dt} = \frac{(V_{\mathrm{Inva}} - V_a)}{L_{\mathrm{sh}}} \quad (16)$$

$$\frac{dI_{\mathrm{Invb}}}{dt} = \frac{(V_{\mathrm{Invb}} - V_b)}{L_{\mathrm{sh}}} \quad (17)$$

$$\frac{dI_{\mathrm{Invc}}}{dt} = \frac{(V_{\mathrm{Invc}} - V_c)}{L_{\mathrm{sh}}} \quad (18)$$

$$\frac{dI_{\mathrm{Invn}}}{dt} = \frac{(V_{\mathrm{Invn}} - V_n)}{L_{\mathrm{sh}}} \quad (19)$$

$$\frac{dV_{\mathrm{dc}}}{dt} = \frac{(I_{\mathrm{Invad}} + I_{\mathrm{Invbd}} + I_{\mathrm{Invcd}} + I_{\mathrm{Invnd}})}{C_{\mathrm{dc}}} \quad (20)$$

Where V_{Inva}, V_{Invb}, V_{Invc} and V_{Invn} are the three-phase ac switching voltages generated on the output terminal of inverter. These inverter output voltages can be modeled in terms of instantaneous dc bus voltage and switching pulses of the inverter as

$$V_{\mathrm{Inva}} = \frac{(P_1 - P_4)}{2} V_{\mathrm{dc}} \quad (21)$$

$$V_{\mathrm{Inva}} = \frac{(P_3 - P_6)}{2} V_{\mathrm{dc}} \quad (22)$$

$$V_{\mathrm{Inva}} = \frac{(P_5 - P_2)}{2} V_{\mathrm{dc}} \quad (23)$$

$$V_{\mathrm{Inva}} = \frac{(P_7 - P_8)}{2} V_{\mathrm{dc}} \quad (24)$$

Similarly the charging currents VInvad, VInvbd, VInvcd and Vinvnd on dc bus due to the each leg of inverter can be expressed as

$$I_{\mathrm{Invad}} = I_{\mathrm{Inva}}(P_1 - P_4) \quad (25)$$

$$I_{\mathrm{Invbd}} = I_{\mathrm{Invb}}(P_3 - P_6) \quad (26)$$

$$I_{\mathrm{Invcd}} = I_{\mathrm{Invc}}(P_5 - P_2) \quad (27)$$

$$I_{\mathrm{Invad}} = I_{\mathrm{Inva}}(P_7 - P_8) \quad (28)$$

The switching pattern of each IGBT inside inverter can be formulated on the basis of error between actual and reference current of inverter, which can be explained as: If IInva < (I*Inva-hb), then upper switch S1will be OFF (P1 =0) and lower switch S4 will be ON (P4=1) in the phase "a" leg of inverter. If IInva > (I*Inva-hb), then upper switch S1 will be ON (P1 =1) and lower switch S4 will be OFF (P4=0) in the phase "a" leg of inverter Where hb is the width of hysteresis band. On the same principle, the switching pulses for the other remaining three legs can be derived.

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V. HYSTERESIS CONTROLLER:

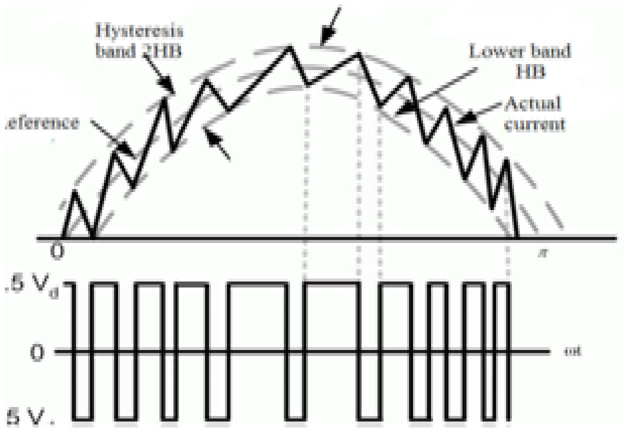

Fig.4. Hysteresis current Modulation

With the hysteresis control, limit bands are set on either side of a signal representing the desired output waveform [6]. The inverter switches are operated as the generated signals within limits. The control circuit generates the sine reference signal wave of desired magnitude and frequency, and it is compared with the actual signal.

As the signal exceeds a prescribed hysteresis band, the upper switch in the half bridge is turned OFF and the lower switch is turned ON. As the signal crosses the lower limit, the lower switch is turned OFF and the upper switch is turned ON. The actual signal wave is thus forced to track the sine reference wave within the hysteresis band limits.

VI. MATLAB MODELEING AND SIMULATION RESULTS :

Fig.5 Matlab/Simulink Model of proposed power circuit, along with control circuit. The power circuit as well as control system are modeled using Power System Block set and Simulink. The grid source is represented by three-phase AC source. Three-phase AC loads are connected at the load end. STATCOM is connected in shunt and it consists of PWM voltage source inverter circuit and a DC capacitor connected at its DC bus.

An IGBT-based PWM inverter is implemented using Universal bridge block from Power Electronics subset of PSB. Snubber circuits are connected in parallel with each IGBT for protection. Simulation of STATCOM system is carried out for linear and non-linear loads.

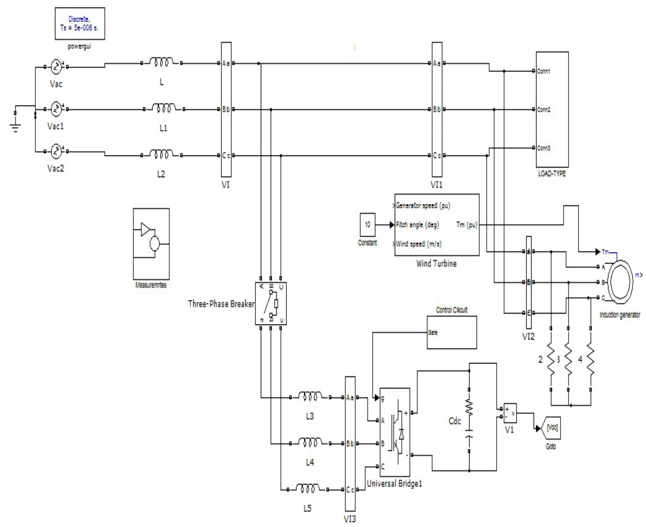

Fig.5 Matlab/Simulink of Proposed Statcom-Power Circuit

Here simulation is carried out at different load conditions,
1) Balanced Linear Load Condition,
2) Un-Balanced Linear Load Condition.
3) Balanced Non-Linear Load Condition
4) Un-Balanced Non-Linear Load Condition.
5) Variable Load Condition.

Case 1: Balanced Linear Load Condition

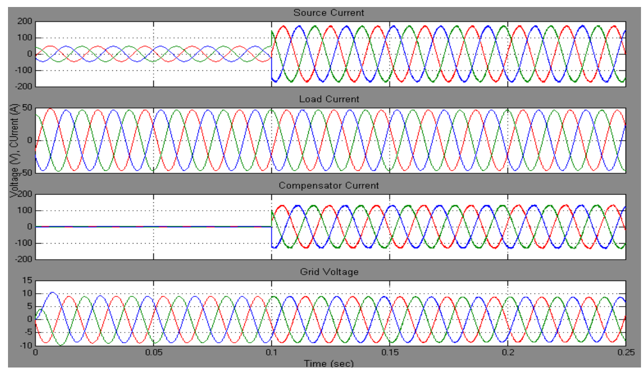

Fig.6. Simulation results for Balanced Linear Load (a) Source current. (b) Load current. (c) Compensator current. (d) Grid Voltage

Fig. 6 shows the source current, load current and compensator current & induction generator currents plots respectively. Here compensator is turned on at 0.1 seconds, for controlling active & reactive power.

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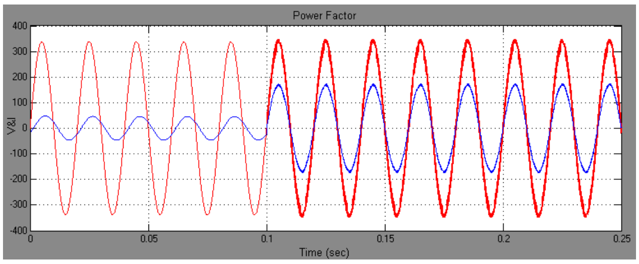

Fig.7 Simulation Results Power Factor For Balanced Linear Load

Fig. 7 shows the power factor it is clear from the figure after compensation power factor is unity.

Case 2: Un-Balanced Linear Load Condition

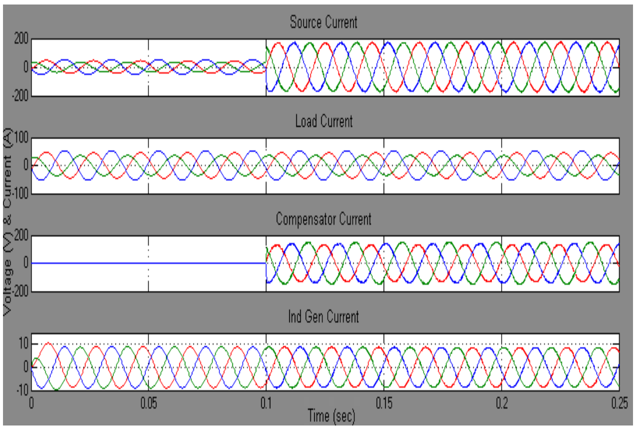

Fig. 8 Simulation results of Linear Unbalanced Load (a) Source Current (b) Load Current (c) Compensator Current (d) Wind Generator (Induction Generator) Current.

Fig. 8 shows the Simulation results of Linear Unbalanced Load, source current, load current, compensator current & induction generator currents respectively. Here, the compensator is turned on at 0.1 seconds, for controlling unbalanced condition coming from unbalanced load.

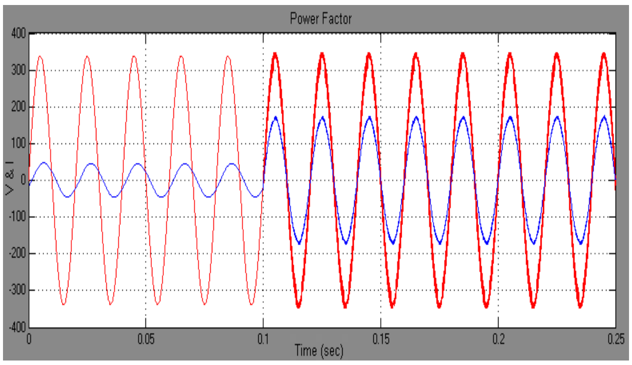

Fig.9 Simulation Results Power Factor For Linear Un-Balanced Load

Fig. 9 shows the power factor it is clear from the figure after compensation power factor is unity.

Case 3: Balanced Non-Linear Load Condition

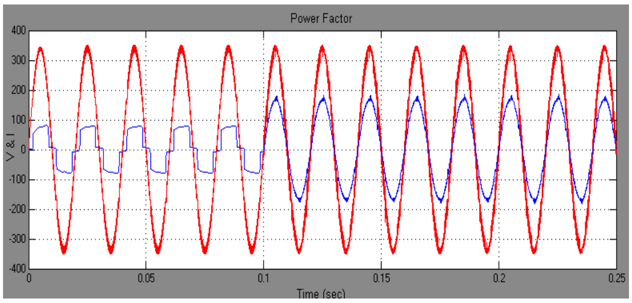

Fig.10 Simulation Results Power Factor For Balanced Non- Linear Load

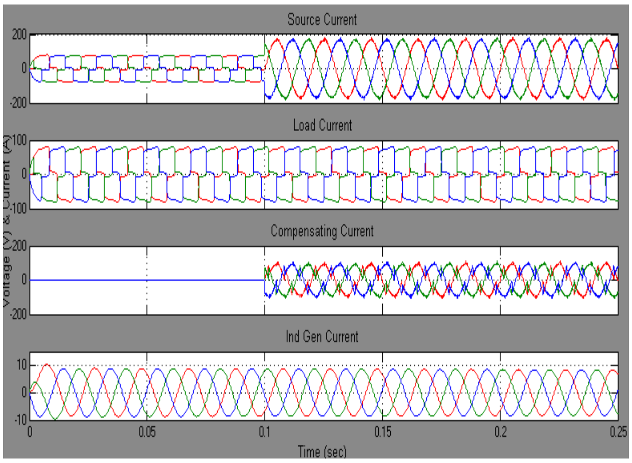

Fig.11 Simulation results for Balanced Non Linear Load (a) Source current. (b) Load current. (c) Compensator Current.(d) Wind Generator (Induction Generator) Current.

Fig. 11 shows the source current, load current and compensator current and induction generator currents plots respectively. Here compensator is turned on at 0.1 seconds, before we get some harmonics coming from non-linear load, then distorts our parameters and get sinusoidal when compensator is in on.

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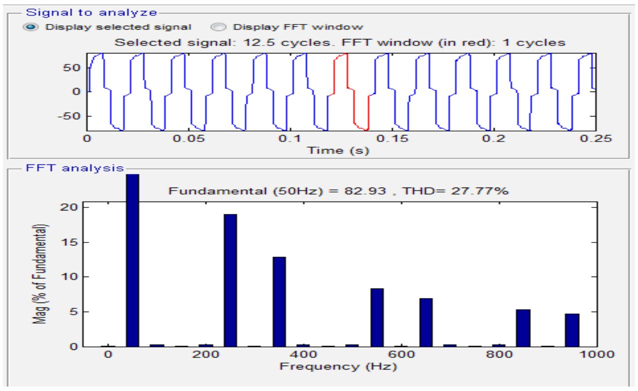

Fig. 12 FFT Analysis of Phase-A Source Current for Balanced Non-Linear Load

Fig.12 shows the FFT Analysis of Phase-A Source Current for Balanced Non-Linear Load, here we get 27.77%.

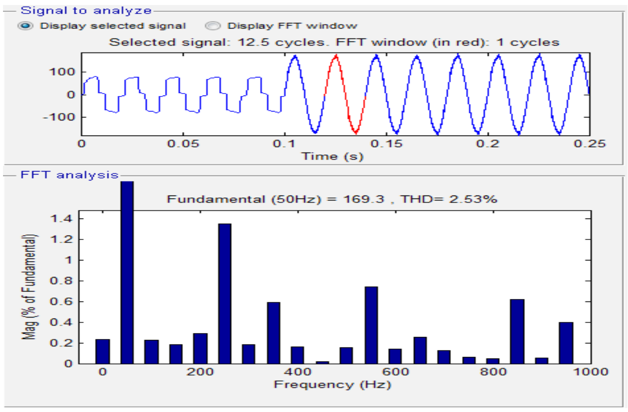

Fig. 13 FFT Analysis of Phase-A Source Current for Balanced Non-Linear Load.

Case 4: Un-Balanced Non-Linear Load Condition:

Fig.13 shows the FFT Analysis of Phase-A Source Current for Balanced Non-Linear Load, here we get 2.53%.

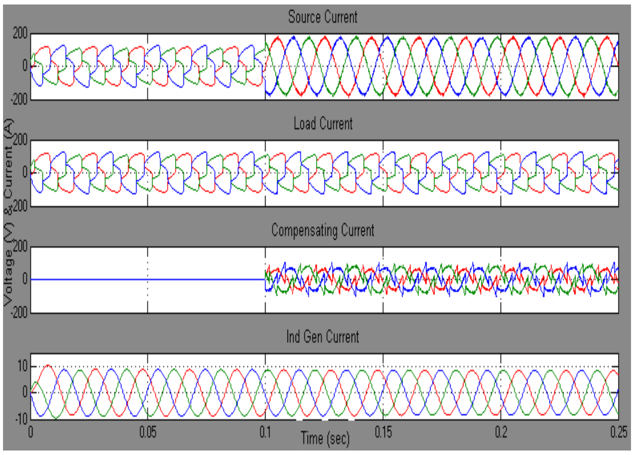

Fig. 14 Simulation results of Non-Linear Unbalanced Load (a) Source Current (b) Load Current (c) Compensating Current (d) Wind Generator (Induction Generator) Current.

Fig. 14 shows the Simulation results of Non-Linear Unbalanced Load, source current, load current and compensator current and induction generator currents respectively. Here compensator is turned on at 0.1 seconds, for controlling unbalanced condition coming from unbalanced load.

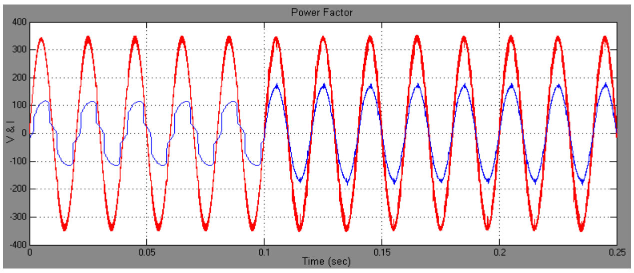

Fig.15 Simulation Results Power Factor For Un-Balanced Non- Linear Load

Fig. 15 shows the power factor it is clear from the figure after compensation power factor is unity.

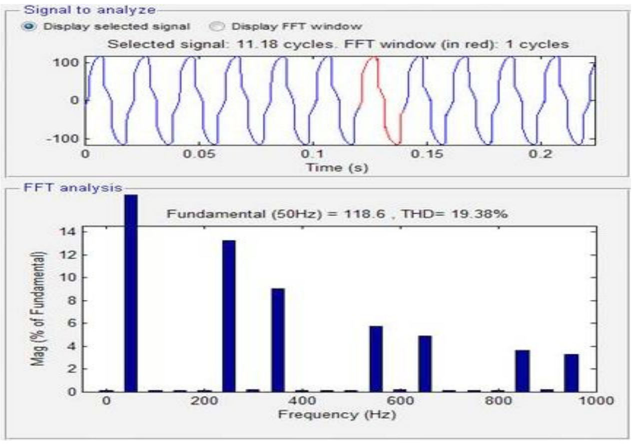

Fig.16 FFT Analysis of Phase-A Source Current for Un-Balanced Non-Linear Load

Fig.16 shows the FFT Analysis of Phase-A Source Current for Un-Balanced Non-Linear Load, here we get 19.38%.

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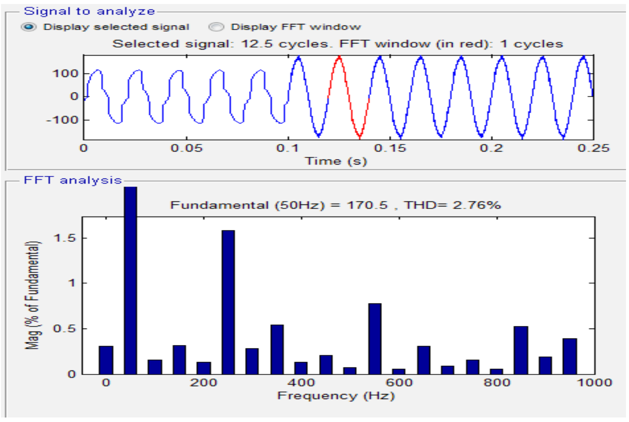

Fig. 17 FFT Analysis of Phase-A Source Current for Un-Balanced Non-Linear Load

Fig.17 shows the FFT Analysis of Phase-A Source Current for Un-Balanced Non-Linear Load, here we get 2.76%.

Case 5: Variable Load Condition

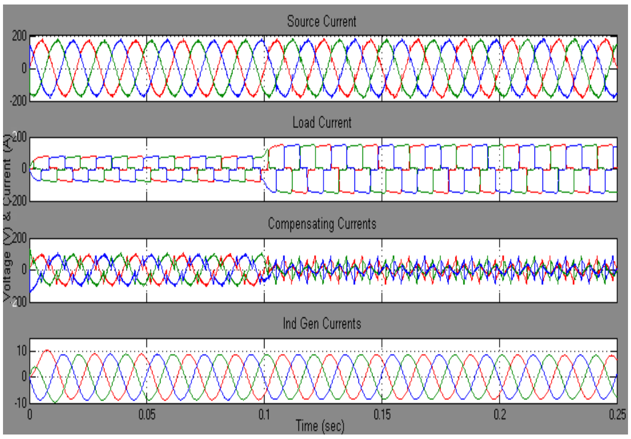

Fig. 18 Simulation results of Variable Load (a) Source Current (b) Load Current (c) Compensating Current (d) Wind Generator (Induction Generator) Current.

Fig. 18 shows the Simulation results of Variable Load, source current, load current and compensator current and induction generator currents.

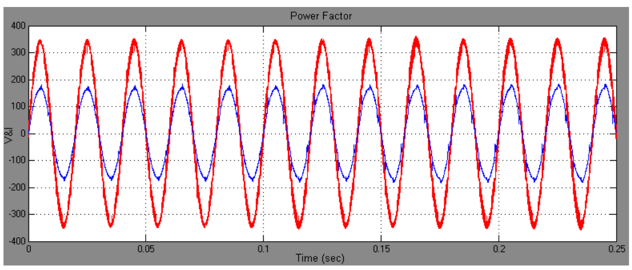

Fig.19 Simulation Results Power Factor For Variable Load Condition

Fig. 19 shows the power factor it is clear from the figure after compensation power factor is unity.

V. CONCLUSION:

Here the STATCOM-based HCC control scheme for power quality improvement in grid connected wind generating system and with several load conditions are presented. 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 in MATLAB/SIMULINK for maintaining the power quality is simulated. It has a capability to cancel out the harmonic parts of the grid current. It 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 power quality in the transmission line. This paper analysed a control of three phase grid interfacing inverter improve the quality of power at PCC for a 3 phase 3 wire system applied to various load conditions, here we preferred balanced as well as unbalanced load conditions with linear & non-linear load. This also makes real power flow at instantaneous demand of the load. Rapid injection or absorption of reactive/real power flow in the power system can be made possible through battery energy storage and static compensator. Battery energy storage provides rapid response and enhances the performance under the fluctuation of wind turbine output and improves the voltage stability of the system.

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