POWER QUALITY ENHANCEMENT IN WIND & PV SOURCE BY MEANS OF STATIC COMPENSATOR (STATCOM)

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ABSTRACT

Power quality is one of major concerns in the present era. It has become important, especially, with the introduction of sophisticated devices, whose performance is very sensitive to the quality of power supply. Power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure of end use equipments. One of the major problems deal here is the harmonics reactive power compensation and power factor. 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. As a promising renewable alternative, the wind power is one of the significant source of generation. Reactive power compensation and harmonic reduction in a low voltage distribution networks for integration of wind power to the grid are the main issues addressed in this paper. 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 PV energy system to mitigate the power quality issues. The PV energy system 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.

Keywords— Photo Voltaic (PV) System, power quality, wind generating system (WGS), Statcom (Static Synchronous Compensator).

I. INTRODUCTION

The integration of wind power to grid introduces power quality issues, which mainly consist of voltage regulation and reactive power compensation. Induction machines are mostly used as generators in wind power based generations. Induction generators draw reactive power from the grid to which they are connected. Therefore, the integration of wind power to power system networks is one of the main concerns of the power system engineers. The addition of wind power into the electric grid affect's the power quality [I].During the last few years, power electronic technology plays an important role in distributed generation and integration of wind energy generation into the electric grid [2]. A non-linear load on a power system is typically a rectifier (such as used in a power supply), or some kind of arc discharge device such as a fluorescent lamp, electric welding machine, or arc furnace. Because current in these systems is interrupted by a switching action, the current contains frequency components that are multiples of the power system frequency. It changes the shape of the current waveform from a sine wave to some other form and also create harmonic currents in addition to the original (fundamental frequency) AC current. The most used unit tocompensate 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). By control of the voltage source converter output voltage in relation to the grid voltage, the voltage source converter will appear as a generator or absorber of reactive power [6].Fig I shows the block diagram of grid connected system. In this 3-phase separately excited induction generator feeding non linear load has been presented. A STATCOM is connected at the point of common coupling with this system in order to compensate the reactive power requirements of induction generator as well as load and also to reduce the harmonics produced by the non linear load.

Voltage sags or dip is caused by a fault in the utility system, a fault within the customer's facility or a large increase of the load current, like starting a motor or transformer energizing [2,3].Voltage sags are one of the most occurring power quality problems. For an industry voltage sags occur more often and cause severe problems and economical losses. Utilities often focus on disturbances from end-user equipment as the main power quality problems [5]

Voltage dips are one of the most occurring power quality problems. Off course, for an industry an outage is worse, than a voltage dip, but voltage dips occur more often and cause severe problems and economical losses. Utilities often focus on disturbances from end-user equipment as the main power quality problems. This is correct for many disturbances, flicker, harmonics, etc., but voltage dips mainly have their origin in the higher voltage levels. Faults due to lightning, is one of the most common causes to voltage dips on overhead lines. If the economical losses due to voltage dips are significant, mitigation actions can be profitable for the customer and even in some cases for the utility. Since there is no standard solution which will work for every site, each mitigation action must be carefully planned and evaluated

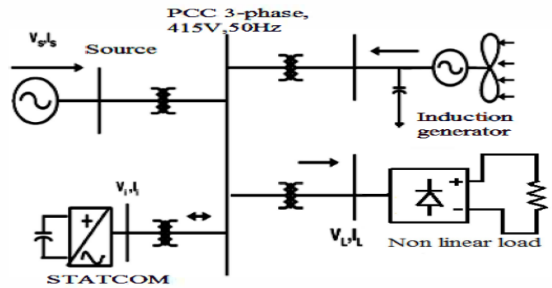

Fig.1 Schematic diagram of grid connected wind energy system

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STATCOM is often used in transmission system. When it is used in distribution system, it is called D-STATCOM（STATCOM in Distribution system). D-STATCOM is a key FACTS controller and it utilizes power electronics to solve many power quality problems commonly faced by distribution systems. Potential applications of STATCOM include power factor correction, voltage regulation, load balancing and harmonic reduction. Comparing with the SVC, the STATCOM has quicker response time and compact structure. It is expected that the STATCOM will replace the roles of SVC in nearly future D-STATCOM and STATCOM are different in both structure and function, while the choice of control strategy is related to the main-circuit structure and main function of compensators [8], so D-STATCOM and STATCOM adopt different control strategy.

At present, the use of STATCOM is wide and its strategy is mature, while the introduction is seldom reported. Many control techniques are reported such as instantaneous reactive power theory (Akagi et al., 1984), power balance theory, etc. In this paper, an indirect current control technique (Singh et al., 2000a,b) is employed to obtain gating signals for the Insulated Gate Bipolar Transistor (IGBT) devices used in current controlled voltage source inverter (CC-VSI) working as a STATCOM. A model of STATCOM is developed using MATLAB for investigating the transient analysis of distribution system under balanced/unbalanced linear and non-linear three-phase and single-phase loads (diode rectifier with R and R-C load). Simulation results during steady-state and transient operating conditions of the STATCOM are presented and discussed to demonstrate power factor correction, harmonic elimination and load balancing capabilities of the STATCOM system [5-10].

A possible solution to overcome the above mentioned drawback is to use the STATCOM as a power interface between the renewable energy sources and the AC bus of the microgrids as shown in Fig. 2. The STATCOM has proved to be an important alternative to compensate current and voltage disturbances in power distribution systems [2], [3]. Different STATCOM topologies have been presented in the technical literature [4], but most of them are not adapted for microgrids applications.

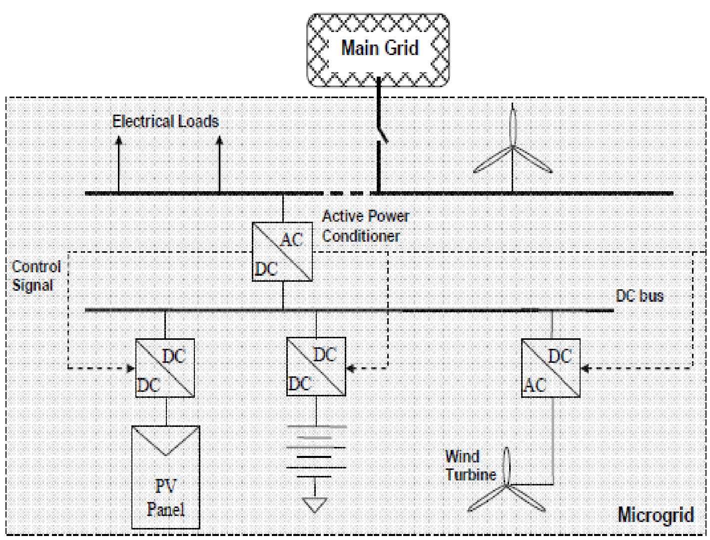


Fig.2. Stacom for micro grid application

II. STATIC COMPENSATOR (DSTATCOM)

A. Principle of STATCOM

Generally, four-wire APCs have been conceived using fourleg converters [5]. This topology has proved better controllability [6] than the classical three-leg four-wire converter but the latter is preferred because of its lower number of power semiconductor devices. In this paper, it is shown that using an adequate control strategy, even with a simple three-leg four-wire system, it is possible to mitigate disturbances like voltage unbalance. The topology of the investigated APC and its interconnection with the microgrid is presented in Fig. 3.

It consists of a three-leg four-wire voltage source inverter. In this type of applications, the VSI operates as a current controlled voltage source. In order to provide the neutral point, two capacitors are used to split the DC-link voltage and tie the neutral point to the mid-point of the two capacitors.

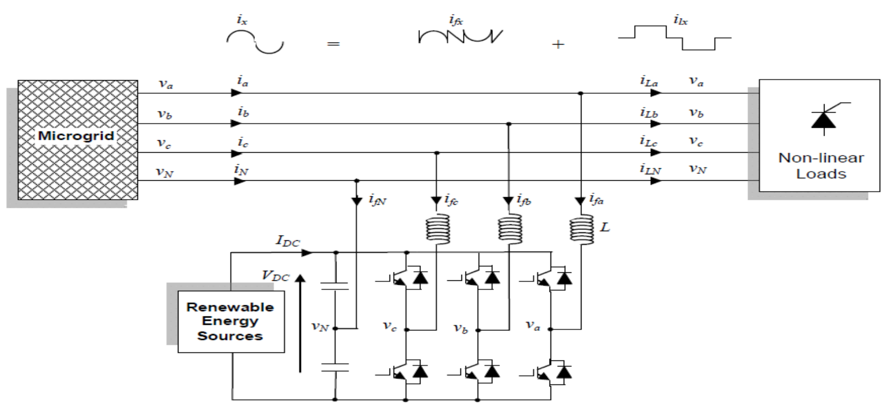


FIG. 3 STATCOM MAIN CIRCUIT

This topology allows the current to flow in both directions through the switches and the capacitors, causing voltage deviation between the DC capacitors. The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes:

1. Voltage regulation and compensation of reactive power;
2. Correction of power factor; and
3. Elimination of current harmonics

B. Voltage Source Converter (VSC

A voltage-source converter is a power electronic device that connected in shunt or parallel to the system. It can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. The VSC used to either completely replace the voltage or to inject the ‘missing voltage’. The ‘missing voltage’ is the difference between the nominal voltage and the actual. It also converts the DC voltage across storage devices into a set of three phase AC output voltages [8, 9]. In addition, APC is also capable to generate or absorbs reactive power. If the output voltage of the VSC is greater than AC bus terminal voltages, APC 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 coupled with the AC system through the reactance of coupling transformers. Suitable adjustment of the phase and magnitude of the APC output voltages allows effectives control of active and reactive power exchanges between APC 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 [10].

C. Controller for STATCOM

The three-phase reference source currents are computed using three-phase AC voltages (*v*ta, *v*tb and *v*tc) and DC bus voltage (*V*dc) of STATCOM. These reference supply currents consist of two components, one in-phase (*I*spdr) and another in quadrature (*I*spqr) with the supply voltages. The control scheme is represented in Fig. 4. The basic equations of control algorithm of STATCOM are as follows.

D. Computation of In-Phase Components of Reference Supply Current

The instantaneous values of in-phase component of reference supply currents (*I*spdr) is computed using one PI controller over the average value of DC bus voltage of the DSTATCOM (*v*dc) and reference DC voltage (*v*dcr) as

$$I_{spdr} = I_{spdr(n-1)} + K_{pd}\{V_{de(n)} - V_{de(n-1)}\} + K_{id}V_{de(n)}$$

where Vde(*n*) Vdcc-Vdc*n*) denotes the error in Vdcc and average value of Vdc *Kpd* and *Kid* are proportional and integral gains of the DC bus voltage PI controller. The output of this PI controller (*I*spdr) is taken as amplitude of in-phase component of the reference supply currents. Three-phase in-phase components of the reference supply currents (*i*sadr, *i*sbdr and *i*scdr) are computed using the in-phase unit current vectors (*u*a, *u*b and *u*c) derived from the AC terminal voltages (*v*tan, *v*tbn and *v*tcn), respectively.

$$U_a = V_{ta}/V_{tm} \quad U_b = V_{tb}/V_{tm} \quad U_c = V_{tc}/V_{tm}$$

where *V*tm is amplitude of the supply voltage and it is computed as

$$V_{tm} = \sqrt{[(2/3)(V_{tan}^2 + V_{tbn}^2 + V_{tcn}^2)]}$$

The instantaneous values of in-phase component of reference supply currents (*i*sadr, *i*sbdr and *i*scdr) are computed as

$$I_{sadr} = I_{spds}U_a \quad I_{sbdr} = I_{spdr}U_b \quad I_{scdr} = I_{spdr}U_c$$

E. Computation of quadrature components of reference supply current

The amplitude of quadrature component of reference supply currents is computed using a second PI controller over the amplitude of supply voltage (*v*tm) and its reference value (*v*tmr)

$$I_{spqr(n)} = I_{spqr(n-1)} + K_{pq}\{V_{ac(n)} - V_{ac(n-1)}\} + K_{iq}V_{ac(n)}$$

Where Vac = Vtmc Vmc(n) denotes the error in Vtmc and computed value *Vtmn* from Equation (3) and Kpq and Kiq are the proportional and integral gains of the second PI controller.

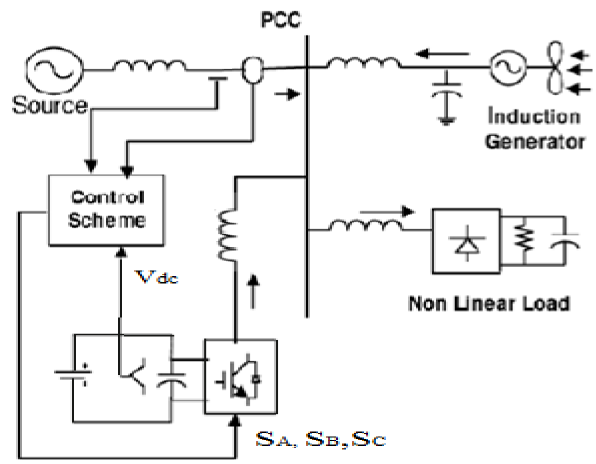
$$W_a = \{-U_b + U_C\}/\{\sqrt{3}\}$$

$$W_b = \{U_a\sqrt{3} + U_b - U_c\}/\{2\sqrt{3}\}$$

$W_c = \{-U_a\sqrt{3} + U_b - U_c\}/\{2\sqrt{3}\}$

Three-phase quadrature components of the reference supply currents (*i*saqr, *i*sbqr and *i*scqr) are computed using the output of second PI controller (*I*spqr) and quadrature unit current vectors (*w*a, *w*b and *w*c) as

$i_{saqr} = I_{spqr}W_a, i_{sbqr} = I_{spqr}W_b, i_{scqr} = I_{spqr}W_c,$



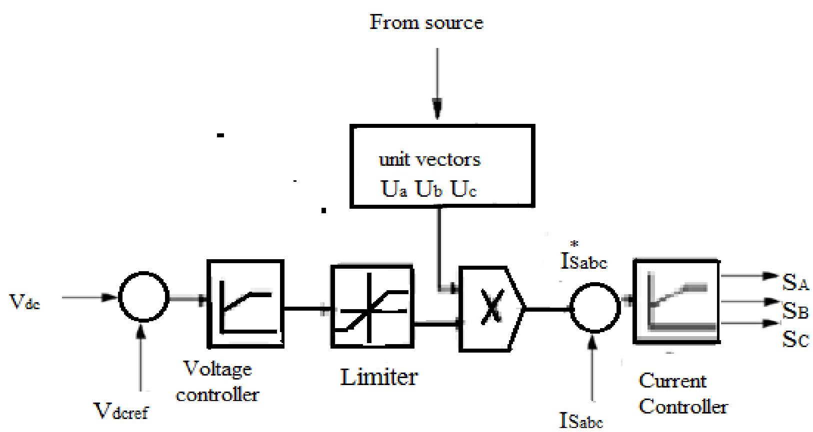


Fig. 4. Control method for STATCOM

F. Computation of total reference supply currents

Three-phase instantaneous reference supply currents (*i*sar, *i*sbr and *i*scr) are computed by adding in-phase (*i*sadr, *i*sbdr and *i*scdr) and quadrature components of supply currents (*i*saqr, *i*sbqr and *i*scqr) as

$i_{sar} = i_{sadr} + i_{saqr}, \quad i_{sbr} = i_{sbdr} + i_{sbqr}, \quad i_{scr} = i_{scdr} + i_{scqr}$

A hysteresis pulse width modulated (PWM) current controller is employed over the reference (*i*sar, *i*sbr and *i*scr) and sensed supply currents (*i*sa, *i*sb and *i*sc) to generate gating pulses for IGBTs of STATCOM

G. PV Mathematical Model

A Photovoltaic (PV) system directly converts sunlight into electricity. The basic device of a PV system is the PV cell. Cells may be grouped to form panels or arrays. The voltage and current available at the terminals of a PV device may directly feed small loads such as lighting systems and DC motors. [7] A photovoltaic cell is basically a semiconductor diode whose *p–n* junction is exposed to light. Photovoltaic cells are made of several types of semiconductors using different manufacturing processes. The incidence of light on the cell generates charge carriers that originate an electric current if the cell is short circuited.

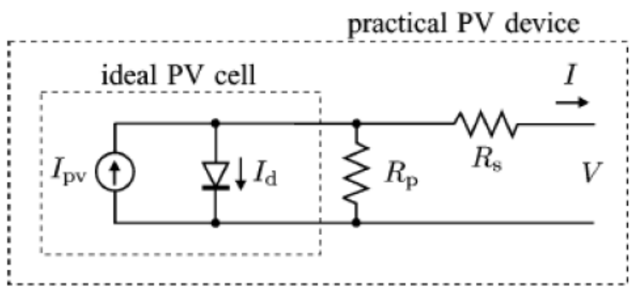


Fig. 5 Equivalent Circuit of a PV Device including theResistances

The equivalent circuit of PV cell is shown in above diagram the PV cell is represented by a parallel with diode. Rs and Rp represent se resistance respectively. The output current and cell are represented by I and V.

The net cell current I is composed of the light- generated current Ipv and the diode current Id

$$\mathrm{I = Ipv - Id} \qquad (1)$$

Where

A.Id =Io expqV/akT

B.Io = leakage current of the diode

C. q= electron charge

D. k = Boltzmann constant

E.T= temperature of pn junction

F.a= diode ideality constant

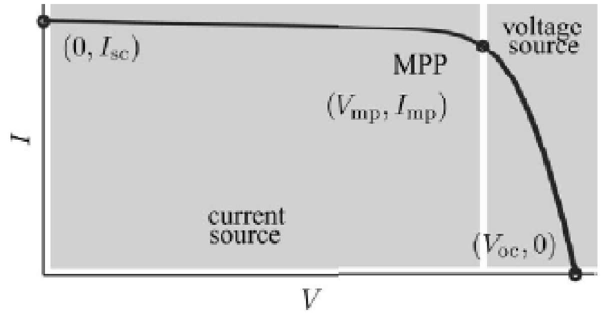
The basic equation (1) of the pv cell does not represent the *I-V* characteristic of a practical PV array. Practical arrays are composed of several connected PV cells and the observation of the characteristic at the terminals of the PV array requires the inclusion of additional parameters to the basic equation.

$$\mathrm{I = Ipv - \left[exp\left(V + \frac{RsI}{Vta}\right) - 1\right] - \frac{V + RsI}{Rp}} \qquad (2)$$

Where

$$\mathrm{Vt = NskT/q}$$

Is the thermal voltage of the array with Ns cells connected in series. Cells connected in series provide greater output voltages. The I-V characteristic of a practical PV cell with maximum power point (MPP), Short circuit current (Isc) and Open circuit voltage (Voc) is shown in fig. 6. The MPP represents the point at which maximum power is obtained.



Vmp and Imp are voltage and current at MPP respectively. The output from PV cell is not the same throughout the day; it varies with varying temperature and insolation (amount of radiation). Hence with varying temperature and insolation maximum power should be tracked so as to achieve the efficient operation of PV system.

III. MATAB/SIMULINK MODELING OF STATCOM

3.1 Modeling of Power Circuit

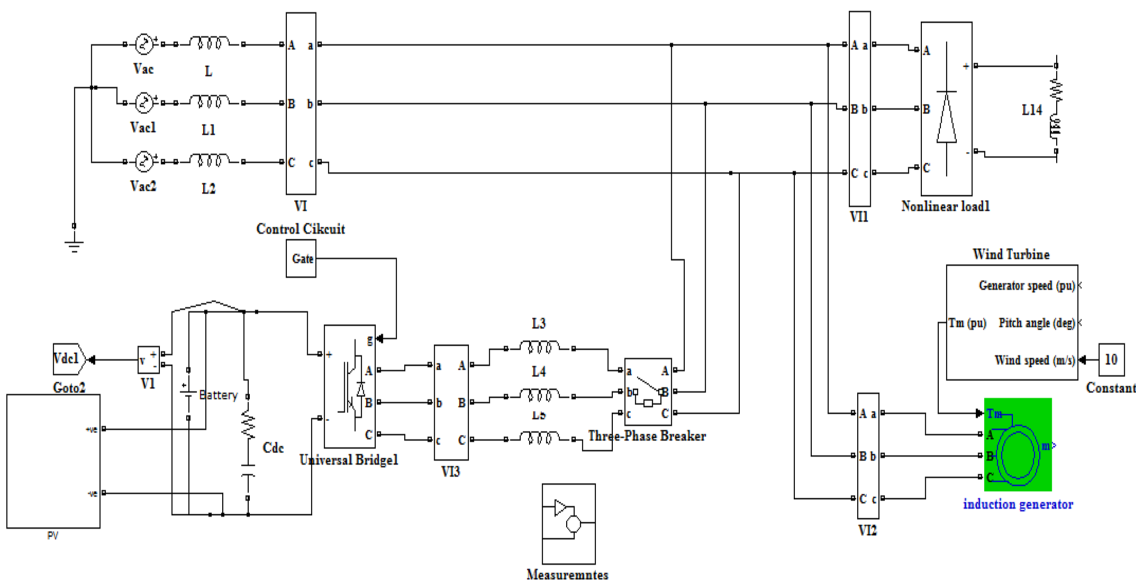


Fig.7. Matlab/Simulink Model of STATCOM Power Circuit with RES

Fig. 7. Shows the complete MATLAB model of STATCOM along with control circuit and Distributed generation system. The power circuit as well as control system are modelled using Power System Blockset 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. The non-linear load on the system is modelled using R and R-C circuits connected at output of the diode rectifier. Provision is made to connect loads in parallel so

that the effect of sudden load addition and removal is studied. The feeder connected from the three-phase source to load is modelled using appropriate values of resistive and inductive components.

3.1 Modeling of Control Circuit

Fig. 8 shows the control algorithm of STATCOM with two PI controllers. One PI controller regulates the DC link voltage while the second PI controller regulates the terminal voltage at PCC. The in-phase components of STATCOM reference currents are responsible for power factor correction of load and the quadrature components of supply reference currents are to regulate the AC system voltage at PCC.

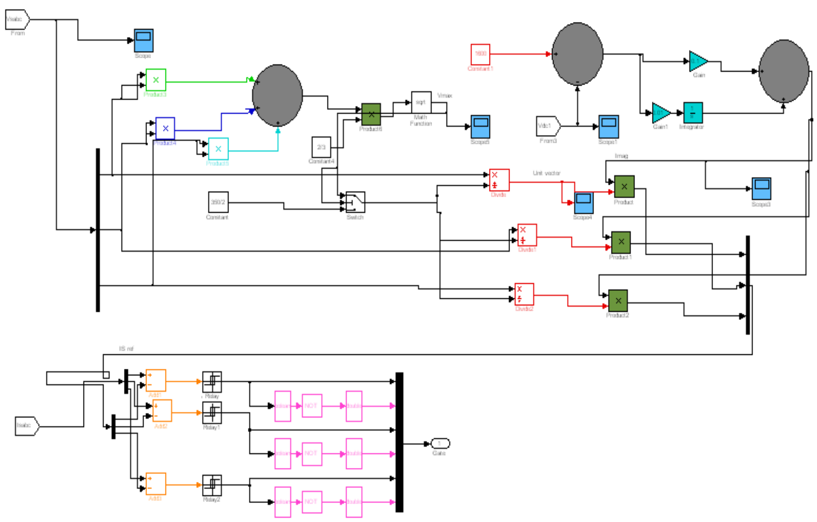


Fig. 8. Control Circuit

The output of PI controller over the DC bus voltage (*I*spdr) is considered as the amplitude of the in-phase component of supply reference currents and the output of PI controller over AC terminal voltage (*I*spqr) is considered as the amplitude of the quadrature component of supply reference currents. The instantaneous reference currents (*i*sar, *i*sbr and *i*scr) are obtained by adding the in-phase supply reference currents (*i*sadr, *i*sbdr and *i*scdr) and quadrature supply reference currents (*i*saqr, *i*sbqr and *i*scqr). Once the reference supply currents are generated, a carrierless hysteresis PWM controller is employed over the sensed supply currents (*i*sa, *i*sb and *i*sc) and instantaneous reference currents (*i*sar, *i*sbr and *i*scr) to generate gating pulses to the IGBTs of STATCOM. The controller controls the STATCOM currents to maintain supply currents in a band around the desired reference current values. The hysteresis controller generates appropriate switching pulses sixIGBTs of the VSI working as STATCOM.

IV . SIMULATION RESULTS

Here Simulation results are presented for two cases. In case one load is balanced non linear with Battery Energy Storage System (BESS) case two load is balanced non linear with PV energy system for regulating the voltage.

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Case 1: Balanced non linear with Battery Energy Storage System (BESS):

Performance of STATCOM connected to a weak supply system for power factor correction and load balancing. The variation of performance variables such as supply voltages (*v*sa, *v*sb and *v*sc), terminal voltages at PCC (*v*ta, *v*tb and *v*tc), supply currents (*i*sa, *i*sb and *i*sc), load currents (*i*la, *i*lb and *i*lc), STATCOM currents (*i*ca, *i*cb and *i*cc) and DC link voltage (*V*dc) are shown below.

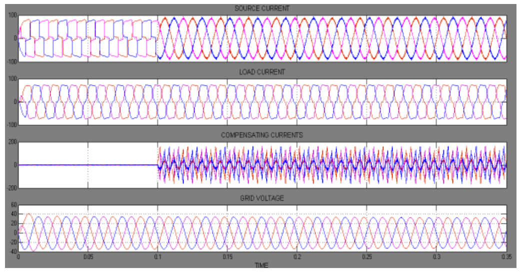

Fig.9. Simulation results for Balanced Non Linear Load with BESS (a) Source current. (b) Load current. (c) Inverter injected current. (d) grid voltage.

Fig. 9 shows the source current, load current and compensator current and grid voltage plots respectively. Here compensator is turned on at 0.1 seconds.

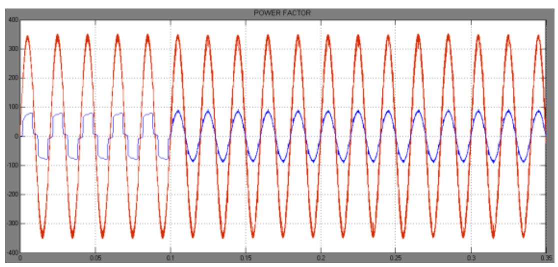

Fig.10. Simulation results power factor for Non linear Load

Fig. 10 shows the power factor it is clear from the figure after compensation power factor is unity.

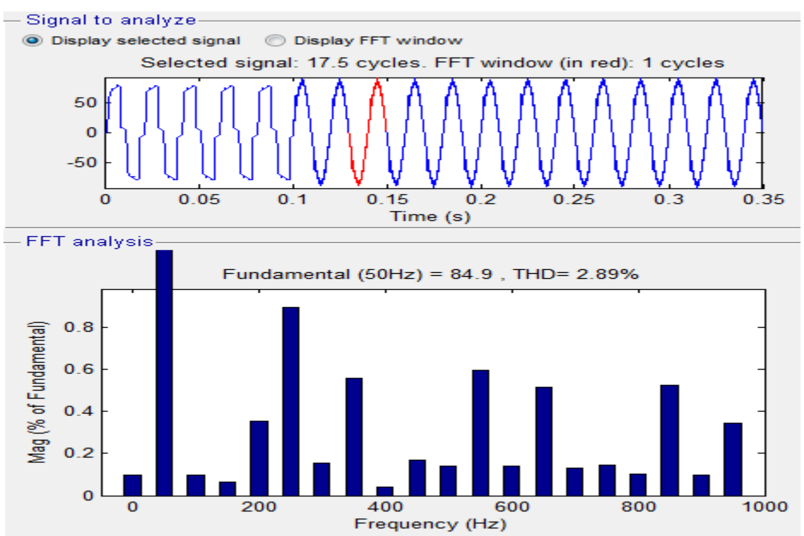

Fig.11 FFT Analysis of Phase A Source Current

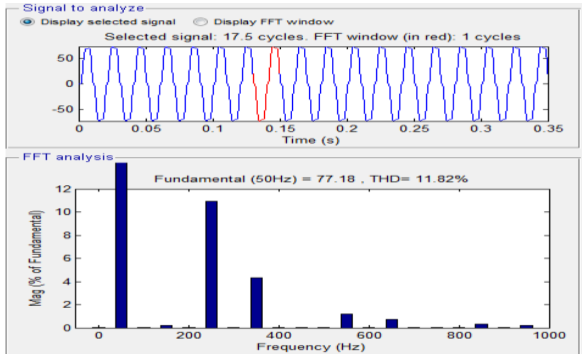

Fig. 12 FFT Analysis of Phase A Load Current

Fig.11, 12 shows the FFT Analysis of Source Current & Load Current with Balanced Non-Linear Load with BESS.

Case 2: Balanced non linear with PV Energy System:

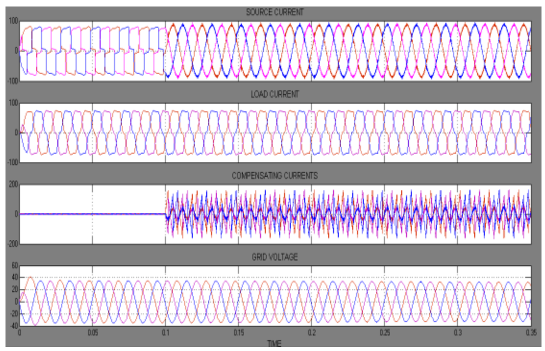

Fig.13. Simulation results for Balanced Non Linear Load with PV Energy System (a) Source current. (b) Load current. (c) Inverter injected current.(d) grid voltage.

Fig. 13 shows the source current, load current and compensator current and grid voltage plots respectively. Here compensator is turned on at 0.1 seconds with PV interfaced to compensate the active power as well as reactive power in the power system network to balance the system parameters

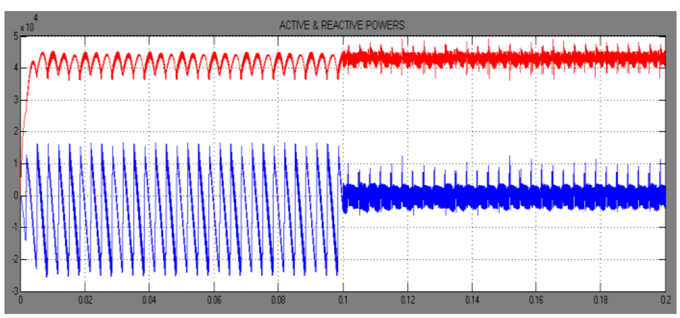

Fig. 14 Active & Reactive Power

Fig.14 shows the Active & Reactive Power of System, as before 0.1 sec our compensator is in off condition that's why power are changed to different values, whenever compensator turn on, we get constant power to maintain system in balance condition

V.CONCLUSION

STATCOM system is an efficient mean for mitigation of PQ disturbances introduced to the grid by DERs. STATCOM compensator is a flexible device which can operate in current control mode for compensating voltage variation, unbalance and reactive power and in voltage control mode as a voltage stabilizer. The latter feature enables its application for compensation of dips coming from the supplying network. The simulation results show that the performance of STATCOM system has been found to be satisfactory for improving the power quality at the consumer premises. STATCOM control algorithm is flexible and it has been observed to be capable of correcting power factor to unity, eliminate harmonics in supply currents and provide load balancing. It is also able to regulate voltage at PCC by using interfaced PV system. The control algorithm of STATCOM has an inherent property to provide a self-supporting DC bus of STATCOM. It has been found that the STATCOM system reduces THD in the supply currents for non-linear loads within limits provided by IEEE.

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