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Power Quality Improvement of Grid Connected Wind Energy System by Statcom for Balanced and Unbalanced Linear and Nonlinear Loads

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Abstract- A Power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure or a mis-operation of end user equipments. Utility distribution networks, sensitive industrial loads and critical commercial operations suffer from various types of outages and service interruptions which can cost significant financial losses. With the restructuring of power systems and with shifting trend towards distributed and dispersed generation, the issue of power quality is going to take newer dimensions. Injection of the wind power into an electric grid affects the power quality. The performance of the wind turbine and thereby power quality are determined on the basis of measurements and the norms followed according to the guideline specified in International Electro-technical Commission standard, IEC-61400. The influence of the wind turbine in the grid system concerning the power quality measurements are-the active power, reactive power, variation of voltage, flicker, harmonics, and electrical behavior of switching operation and these are measured according to national/international guidelines. The 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 in power system block set. Finally the proposed scheme is applied for both balanced and unbalanced non linear loads.

Keywords—Power Quality, Wind Generating System (WGS), STATCOM, BESS, International electro-technical commission (IEC) standard.

I. INTRODUCTION

One of the most common power quality problems today is voltage dips. A voltage dip is a short time (10 ms to 1 minute) event during which a reduction in r.m.s voltage magnitude occurs. It is often set only by two parameters, depth/magnitude and duration. The voltage dip magnitude is ranged from 10% to 90% of nominal voltage (which corresponds to 90% to 10% remaining voltage) and with a duration from half a cycle to 1 min. In a three-phase system a voltage dip is by nature a three-phase phenomenon, which affects both the phase-to-ground and phase-to-phase voltages. A voltage 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. Typical faults are single-phase or multiple-phase short circuits, which leads to high currents. The high current results in a voltage drop over the network impedance. At the fault location the voltage in the faulted phases drops close to zero, whereas in the non-faulted phases it remains more or less unchanged. [1]

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. There are different ways to mitigate voltage dips, swell and interruptions in transmission and distribution systems. At present, a wide range of very flexible controllers, which capitalize on newly available power electronics components, are emerging for custom power applications.[5, 6] Among these, the distribution static compensator and the dynamic voltage restorer are most effective devices, both of them based on the VSC principle.

The power quality issues can be viewed with respect to the wind generation, transmission and distribution network, such as voltage sag, swells, flickers, harmonics etc. However the wind generator introduces disturbances into the distribution network. One of the simple methods of running a wind generating system is to use the induction generator connected directly to the grid system. The induction generator has inherent advantages of cost effectiveness and robustness. 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. A proper control scheme in wind energy generation system is required under normal operating condition to allow the proper control over the active power production. In the event of increasing grid disturbance, a battery energy storage system for wind energy generating system is generally required to compensate the fluctuation generated by wind turbine.[3] 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.

Today in wind turbine generating system pulse controlled inverters are used. Due to the improvement in switching techniques, the voltage and current at the point of common connection can be made in sinusoidal form and at unity power factor so as to improve the power quality at PCC.

II. STATIC COMPENSATOR (STATCOM)

2.1 Principle of STATCOM

A STATCOM is in principle a voltage source converter (VSC) connected via an inductance to a grid. The concept has been known for many years and is described in detail Figure 1 shows an example of a STATCOM connected to a grid; Figure 2 shows the simplified single line diagram.The inductance can represent a reactor or a transformer. Reactive power can be altered by modifying the voltage amplitude of the VSC.

The phasor diagram in Figure 3 helps to understand the principle of the STATCOM. For this purpose, a transformer with a turns-ratio of 1:1 or a reactor is assumed. In addition, constant grid voltage is assumed. Therefore, the grid voltage vector U_{Grid} remains at a constant value. If the value of the compensator voltage vector U_{Comp} is higher than the grid voltage vector, the vector of the voltage drop across the inductance X_T is in the same direction as the compensator voltage vector. Therefore the compensator current I_{Grid} flows in positive direction as per the definition in Figure 2. In this situation, the STATCOM acts like a capacitor. . If the value of the compensator voltage vector U_{Comp} is lower than the grid voltage vector, the vector of the voltage drop across the inductance X_T is in the opposite direction compared to the compensator voltage vector. Therefore the compensator current I_{Grid} flows in negative direction as per the definition in Figure 2. In this situation, the STATCOM acts like an inductor.

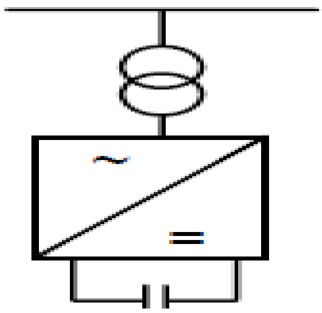


Figure 1: STATCOM, a VSC connected to a grid

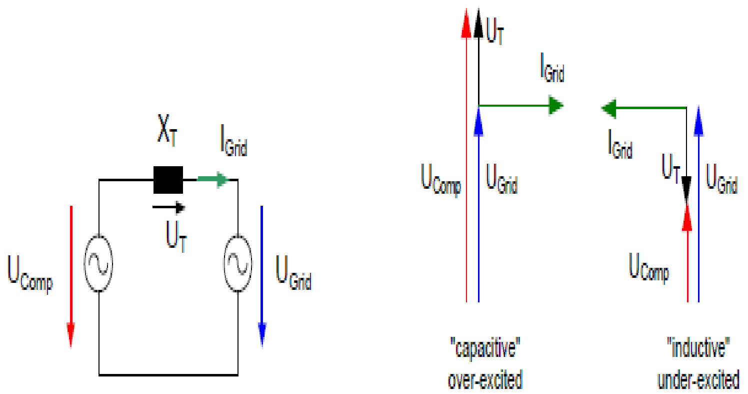


Figure 2 & 3: Single line diagram of a STATCOM and vector diagram for capacitive and inductive STATCOM operation

Since in all situations the current I_{Grid} is phase shifted by 90° compared the grid voltage U_{Grid} .the STATCOM power is purely reactive.

2.2 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

2.3 Controller for STATCOM

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 Fig2.The control algorithm needs the measurements of several variables such as three-phase source current, DC voltage, inverter current with the help of sensor. The current control block, receives an input of reference current and actual current are subtracted so as to activate the operation of STATCOM in current control mode.

In three-phase balance system, the RMS voltage source amplitude is calculated at the sampling frequency from the source phase voltage (Vsa, Vsb, Vsc) and is expressed, as sample template, sampled peak voltage(1)

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

The in-phase unit vectors are obtained from AC source—phase voltage and the RMS value of unit vector (Usa, Usb, Usc) as shown in bellow(2)

$$U_{sa} = \frac{V_{sa}}{V_{sm}}, U_{sb} = \frac{V_{sb}}{V_{sm}}, U_{sc} = \frac{V_{sc}}{V_{sm}} \qquad (2)$$

The in-phase generated reference currents are derived using in-phase unit voltage template as bellow (3)

$$i_{sa}^{*} = I.U_{sa}, i_{sb}^{*} = I.U_{sb}, i_{sc}^{*} = I.U_{sc} \qquad (3)$$

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

2.4 Bang-Bang Current Controller

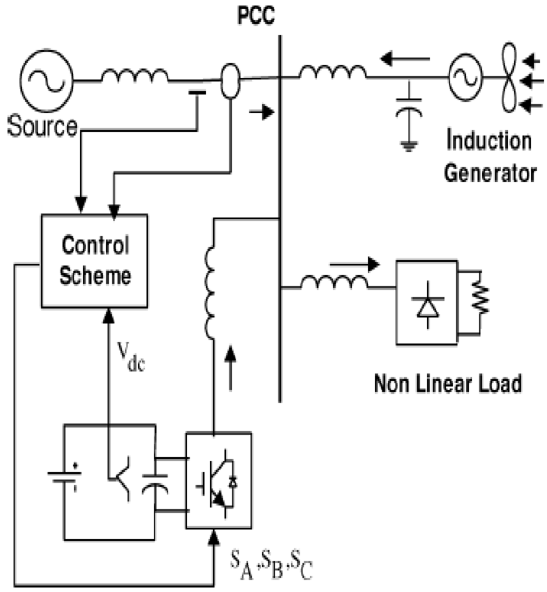
Bang-Bang current controller is implemented in the current control scheme. The reference current is generated as in (2) and actual current are detected by current sensors and are subtracted for obtaining a current error for a hysteresis based bang-bang controller. Thus the ON/OFF switching signals for IGBT of STATCOM are derived from hysteresis controller.[12]

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

$$i_{sa} < \left(i_{sa}^{*} - HB\right) \rightarrow S_A = 0$$

$$i_{sa} > \left(i_{sa}^{*} - HB\right) \rightarrow S_A = 1$$

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



System operational scheme in grid system

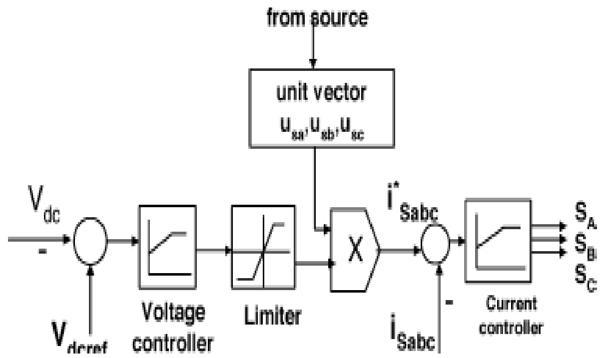


Figure. 2 Control methods for STATCOM

2.5 Modeling of Control Circuit

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 Fig2.The control algorithm needs the measurements of several variables such as three-phase source current, DC voltage, inverter current with the help of sensor. The current control block, receives an input of reference current and actual current are subtracted so as to activate the operation of STATCOM in current control mode Once the reference supply currents are generated, a carrier less hysteresis PWM controller is employed over the sensed supply currents and instantaneous reference currents 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 for six IGBTs of the VSI working as STATCOM

2.6 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 bellow

$$P_{wind} = \frac{1}{2}\rho A V_{wind}{}^{3} \qquad (4)$$

Be aware that the density of air decreases with temperature and altitude and that the major factor in power generation is wind velocity. A 20% increase in the wind velocity - increases the power generated with 73%It is not possible to extract all kinetic energy of wind, thus it extract a fraction of power in wind, called power coefficient *Cp* of the wind turbine, and is given in bellow

$$P_{mech} = C_p P_{wind} \qquad (5)$$

$$C_p(\lambda,\upsilon) = c_1\left(c_2\frac{1}{\Lambda} - c_3\upsilon - c_4\upsilon^x - c_5\right)e^{\left(\frac{-c_6}{\Lambda}\right)} \qquad (6)$$

$$\lambda = \frac{\omega\eta R}{v}$$

Where,

$$\frac{1}{\Lambda} = \frac{1}{\lambda+0.08\upsilon} - \frac{0.0035}{1+\upsilon^3} \qquad (7)$$

Where, Pm is the mechanical power developed in watts, ρ is density of air (kg/m^3), V is wind speed (m/s), C_p is power coefficient, υ is pitch angle, λ is tip speed ratio, η is gear ratio and A is the area swept by the rotor. ω is the angular velocity (rpm), R is the turbine rotor radius (m) and $c_1 - c_6$,x are constants. The variation of power coefficient C_p with a variation of υ, λ is nonlinear in nature. It can be estimated by the relation the mechanical power produce by wind turbine is given in bellow

$$P_{mech} = \frac{1}{2}\rho\pi R^2 {V_{wind}}^3 C_p \qquad (8)$$

Where C_p 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 λ and pitch angle θ.

III. MATAB/SIMULINK MODELING OF STATCOM

3.1 Modeling of Power Circuit

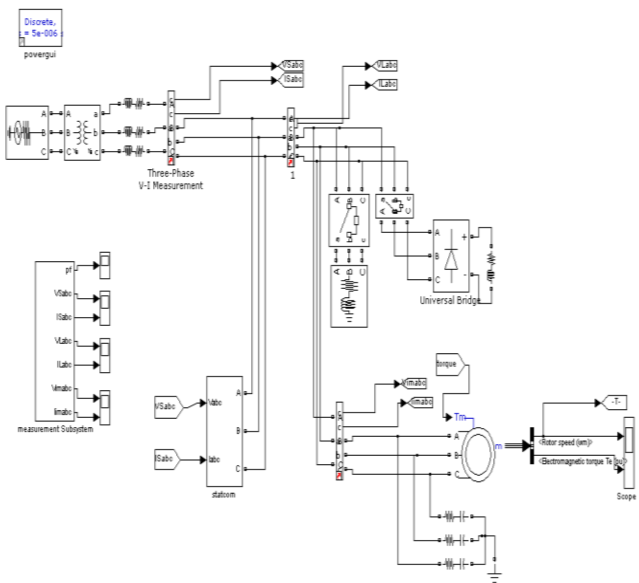


Figure. 3 Mat lab/Simulink Model

Fig.3 shows the complete MATLAB model of STATCOM 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. The linear load on the system is modeled using the block three-phase parallel R-L load connected in delta configuration. The non-linear load on the system is modeled 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 modeled using appropriate values of resistive and inductive components.

IV. SIMULATION RESULTS

Here Simulation results are presented for two cases. In case one load is balanced non linear and in case two unbalanced non linear load is considered.

4.1 Case one

Performance of STATCOM connected to a weak supply system is shown in Fig.5 for power factor correction and load balancing. This figure shows variation of performance variables such as supply voltages (v_{sa}, v_{sb} and v_{sc}), supply currents (i_{sa}, i_{sb} and i_{sc}), load currents (il_a, il_b and il_c).

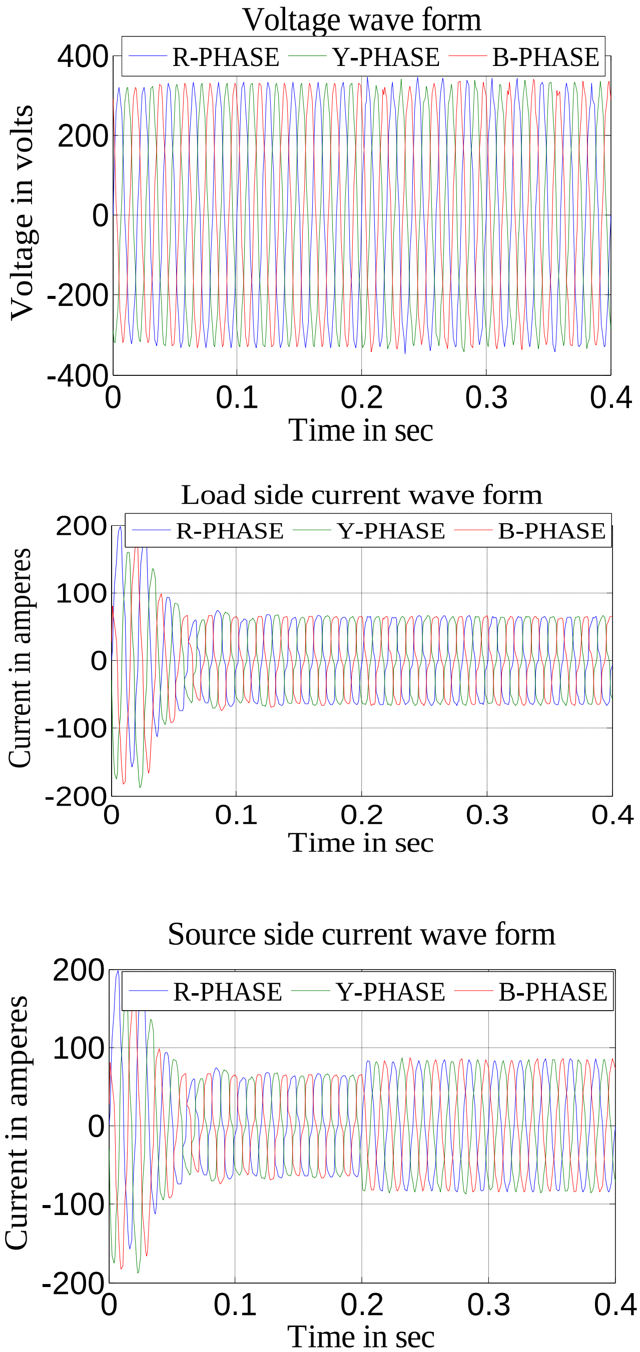


Figure. 5 Simulation results for Balanced Non Linear Load

Fig. 5 shows the source current, load current and compensator current and induction generator currents plots respectively. Here compensator is turned on at 0.2 seconds. Fig. 6 show the power factor it is clear from the figure after compensation power factor is unity

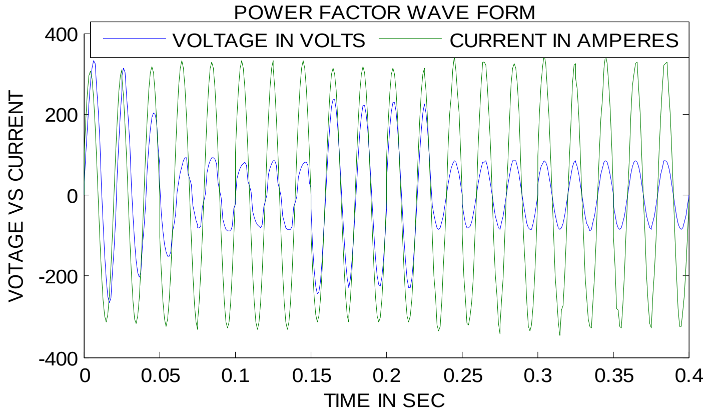


Figure. 6 Simulation results power factor for linear and non linear Loads

4.2 Case two

Un Balanced three-phase non-linear load is represented by three-phase uncontrolled diode bridge rectifier with pure resistive load at its DC bus. Fig. 7 shows the transient responses of distribution system with STATCOM for supply voltages (vs_{abc}), load currents (il_a, il_b and il_c), supply currents (is_{abc}).

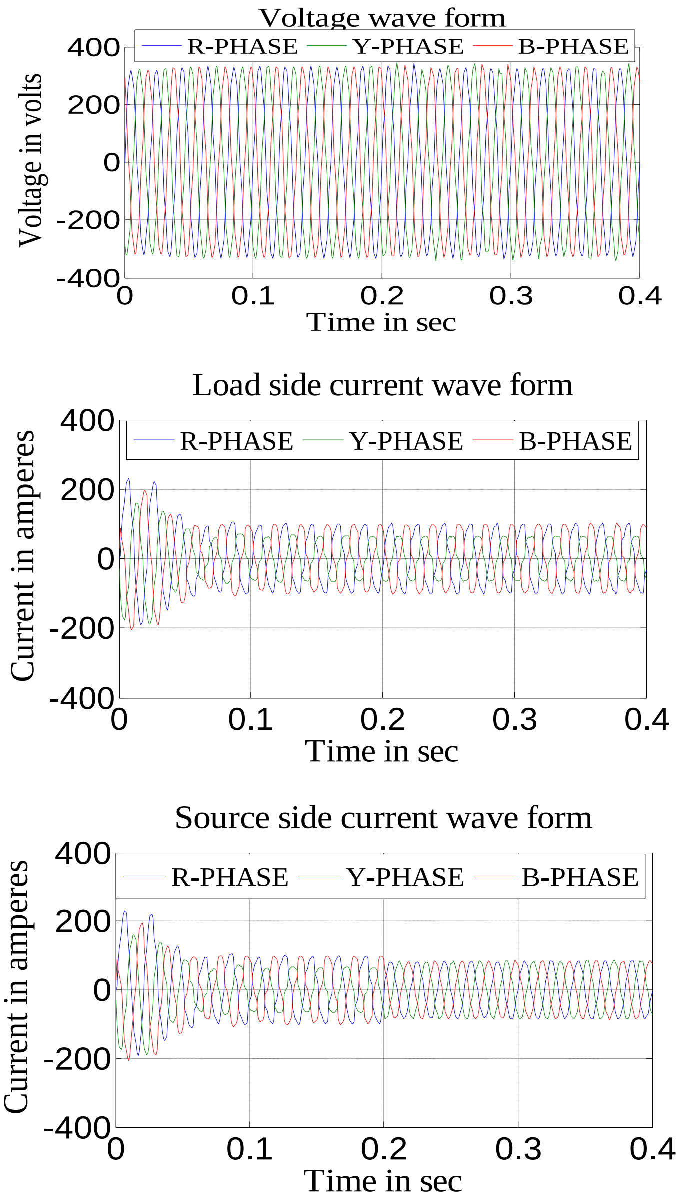


Figure. 7: Simulation results Non- Linear Unbalanced Load

Fig.7 & 8 shows the unbalanced non linear load and linear load case. From the figure it is clear that even though load is unbalanced source currents are balanced and sinusoidal.

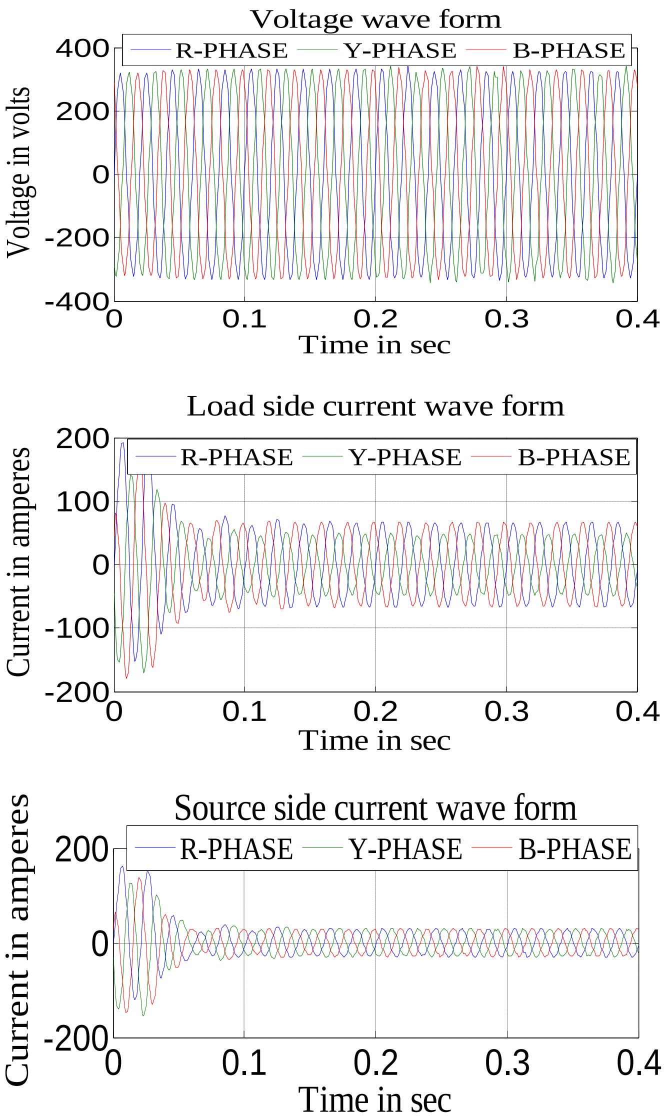


Figure. 8: Simulation results Linear Unbalanced Load

V. CONCLUSION

STATCOM system is an efficient mean for mitigation of PQ disturbances introduced to the grid. 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. 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. Rectifier-based non-linear loads generated harmonics are eliminated by STATCOM. When single-phase rectifier loads are connected, STATCOM currents balance these unbalanced load currents.

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