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Power Quality Improvement of Grid Connected Wind Energy System having Balanced and Unbalanced Non-linear Loads

Veeraiah Kumbha, N. Sumathi, K. Siva Naga Raju

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 dimension. 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 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 linear non- linear loads.***

***Index Terms*—.International electro-technical commission (IEC), power quality, wind generating system (WGS).**

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, 2].

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 [3, 4].Among these, the distribution static compensator and the dynamic voltage restorer are most effective devices, both of them based on the VSC principle.

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 D-STATCOM include power factor correction, voltage regulation, load balancing and harmonic reduction. Comparing with the SVC, the D-STATCOM has quicker response time and compact structure. It is expected that the D-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 [3], so D-STATCOM and STATCOM adopt different control strategy.

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At present, the use of STATCOM is wide and its strategy is mature, while the introduction of D-STATCOM 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 DSTATCOM. A model of DSTATCOM is developed using MATLAB for investigating the transient analysis of distribution system underbalanced/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 DSTATCOM are presented and discussed to demonstrate power factor correction, harmonic elimination and load balancing capabilities of the DSTATCOM system [5-10].

II. DISTRIBUTION STATIC COMPENSATOR (D-STATCOM)

2.1 *Principle of DSTATCOM*

A D-STATCOM (Distribution Static Compensator), which is schematically depicted in Fig.1, consists of a two-level Voltage Source Converter (VSC), a dc energy storage device, a coupling transformer connected in shunt to the distribution network through a coupling transformer. The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages. These voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. Suitable adjustment of the phase and magnitude of the D-STATCOM output voltages allows effective control of active and reactive power exchanges between the DSTATCOM and the ac system. Such configuration allows the device to absorb or generate controllable active and reactive power.

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.

Here, such device is employed to provide continuous voltage regulation using an indirectly controlled converter.

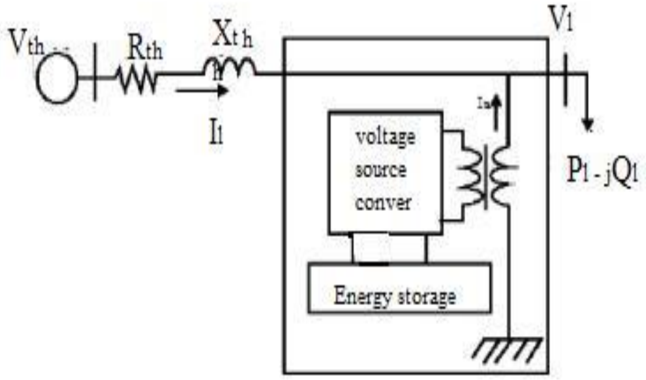

Figure.1 DSTATCOM

Fig. 1 the shunt injected current I_{sh} corrects the voltage sag by adjusting the voltage drop across the system impedance Z_{th}. The value of I_{sh} can be controlled by adjusting the output voltage of the converter. The shunt injected current I_{sh} can be written as,

$$I_{sh} = I_l - I_s = I_l - (V_{th} - V_l)/Z_{th} \qquad (1)$$

$I_{sh} /\_\eta = I_L /\_- \theta$

The complex power injection of the D-STATCOM can be expressed as,

$$S_{sh} = V_L I_{sh}^*$$

It may be mentioned that the effectiveness of the DSTATCOM in correcting voltage sag depends on the value of Zth or fault level of the load bus. When the shunt injected current Is his kept in quadrature with VL, he desired voltage correction can be achieved without injecting any active power into the system. On the other hand, when the value of I_{sh} is minimized, the same voltage correction can be achieved with minimum apparent power injection into the system.

2.2 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, D-STATCOM is also capable to generate or absorbs reactive power. If the output voltage of the VSC is greater than AC bus terminal voltages, D-STATCOM 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 DSTATCOM output voltages allows effectives control of active and reactive power exchanges between D-STATCOM 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].

2.3 Controller for DSTATCOM

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 DSTATCOM. 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. 2. The basic equations of control algorithm of DSTATCOM are as follows.

2.3.1*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

$$I_{spdr} = I_{spdr(n-1)} + K_{pd}\{V_{de(n)} - V_{de(n-1)}\} + K_{id}V_{de(n)} \qquad (2)$$

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Where $V_{de(n)}$ = Vdcc-Vdcn) 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.

$$U_a = V_{ta}/V_{tm}\ U_b = V_{tb}/V_{tm}\ U_c = V_{tc}/V_{tm} \qquad (3)$$

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

$$V_{tm} = \sqrt{[(2/3)(V_{tan}^2 + V_{tbn}^2 + V_{tcn}^2)]} \qquad (4)$$

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

$$I_{sadr} = I_{spds} U_a I_{sbdr} = I_{spdr} U_b I_{scdr} = I_{spdr} U_c \qquad (5)$$

2.3.1*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})

$$I\_spqr(n) = I\_spqr(n-1) + K\_pq\ \{V\_ac(n) - V\_ac(n-1)\} + K\_iq\ V\_ac(n) \qquad (6)$$

Where V_{ac} = V_{tmc} $V_{mc(n)}$ denotes the error in V_{tmc} and computed value V_{tmn} from Equation (3) and K_{pq} and K_{iq} are the proportional and integral gains of the second PI controller.

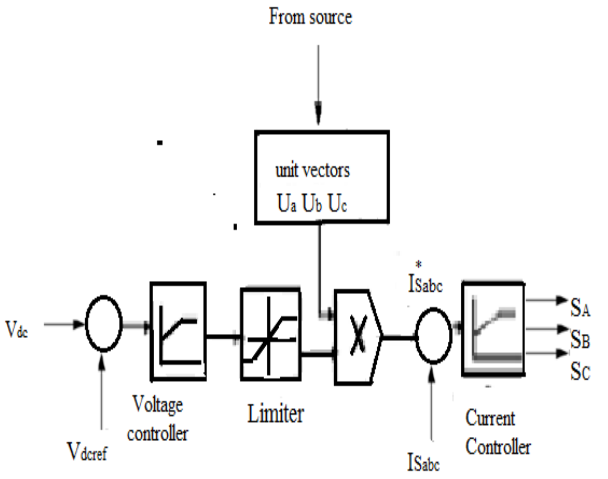
$$W_a = \{-U_b + U_c\}/\{\sqrt{3}\} \qquad (7)$$

$$W_b = \{U_a\sqrt{3} + U_b - U_c\}/\{2\sqrt{3}\} \qquad (8)$$

$$W_c = \{-U_a\sqrt{3} + U_b - U_c\}/\{2\sqrt{3}\} \qquad (9)$$

Three-phase quadrature components of the reference supply currents (i_{sadr},i_{sbdr} and i_{scdr}) are computed using the output of second PI controller (*I*spqr) and quadrature unit current vectors (w_a , w_b and w_c) as

$$i_{saqr} = I_{spqr} W_a, i_{sbqr} = I_{spqr} W_b, i_{scqr} = I_{spqr} W_c, \qquad (10)$$



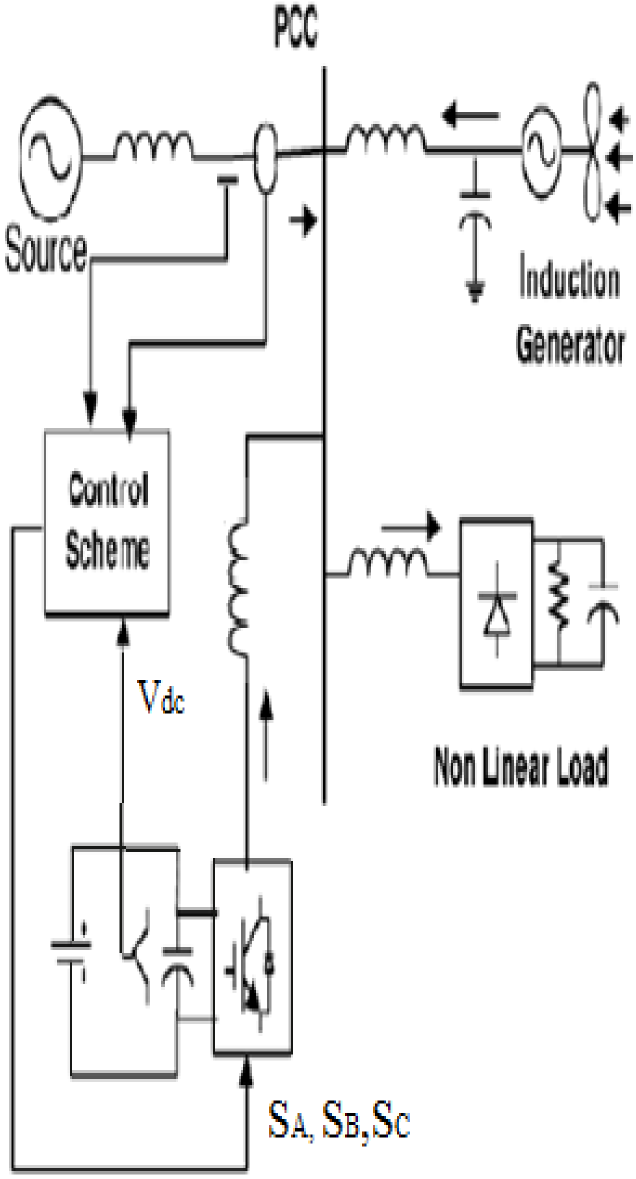


Figure. 2 System operational scheme in grid system

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2.3 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_{sadr,}$$i_{sbdr}$ and i_{scdr}) as

$$i_{sar} = i_{sadr} + i_{saqr}, i_{sbr} = i_{sbdr} + i_{sbqr}, \;\; i_{scr} = i_{scdr} + i_{scqr} \qquad (11)$$

A hysteresis pulse width modulated (PWM) current controller is employed over the reference ($i_{sadr,}$$i_{sbdr}$ and i_{scdr}) and sensed supply currents (i_{sa}, i_{sb} and i_{sc}) to generate gating pulses for IGBTs of DSTATCOM

III. MATLAB/SIMULINK MODELING OF DSTATCOM

3.1 Modeling of Power Circuit

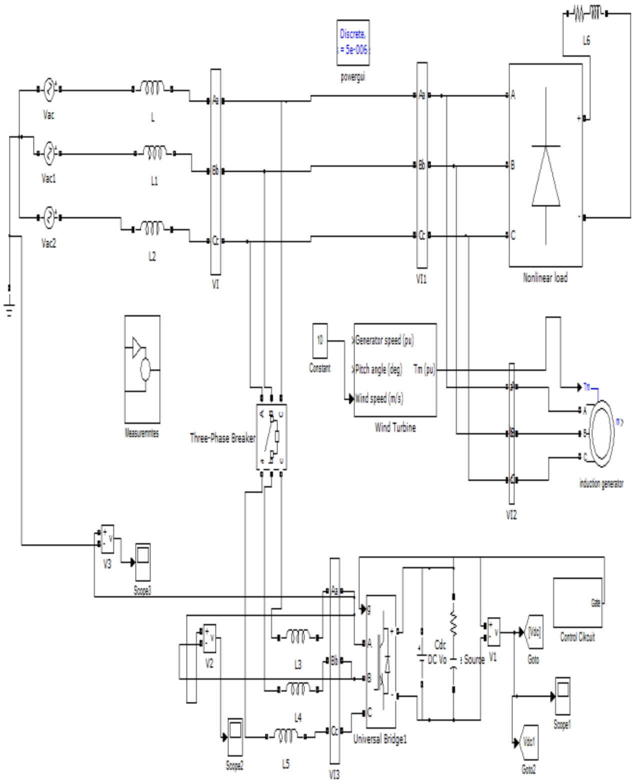

Figure. 3 Matlab/Simulink Model of DSTATCOM

Fig. 3 shows the complete MATLAB model of DSTATCOM along with control circuit. The power circuit as well as control system are modelled using Power System Blackest and Simulink. The grid source is represented by three-phase AC source. Three-phase AC loads are connected at the load end. DSTATCOM 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 DSTATCOM system is carried out for linear and non-linear loads. The linear load on the system is modelled using the block three-phase parallel R-L load connected in delta configuration. 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. 4 shows the control algorithm of DSTATCOM 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 DSTATCOM 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.

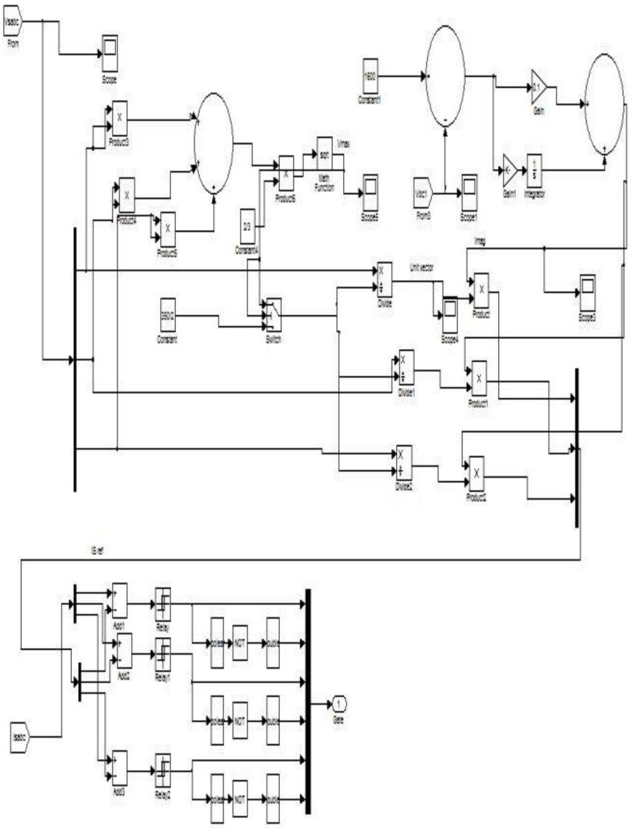

Figure. 4 Control Circuit

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 ($i_{sadr,}$ i_{sbdr} and i_{scdr}) are obtained by adding the in-phase supply reference currents ($i_{sadr,}$ i_{sbdr} and i_{scdr}) and quadrature supply reference currents ($i_{sadr,}$$i_{sbdr}$ and i_{scdr}). Once the reference supply currents are generated, a carrier less hysteresis PWM controller is employed over the sensed supply currents (i_{sa}, i_{sb} and i_{sc}) and instantaneous reference currents (i_{sadr} ,i_{sbdr} and i_{scdr}) to generate gating pulses to the IGBTs of DSTATCOM.

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The controller controls the DSTATCOM 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 DSTATCOM.

IV. SIMULATION RESULTS

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

4.1 Case one

Performance of DSTATCOM 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}), 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}), DSTATCOM currents (i_{ca}, i_{cb} and i_{cc}) and DC link voltage (V_{dc}).

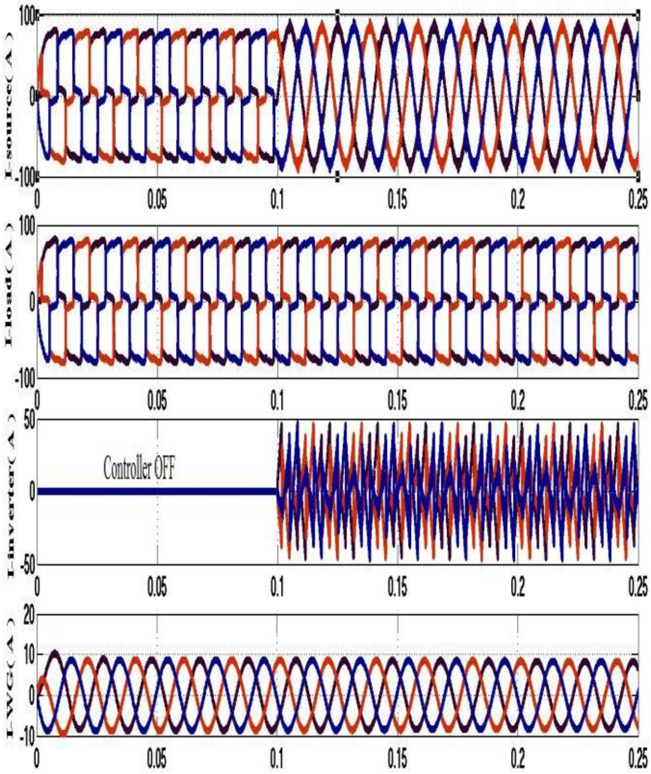

Figure. 5 Simulation results for Balanced Non Linear Load
(a) Source current. (b) Load current. (c) Inverter injected current. (d) wind generator (induction generator) current.

Fig. 5 shows the source current, load current and compensator current and induction generator currents plots respectively. Here compensator is turned on at 0.1 seconds.

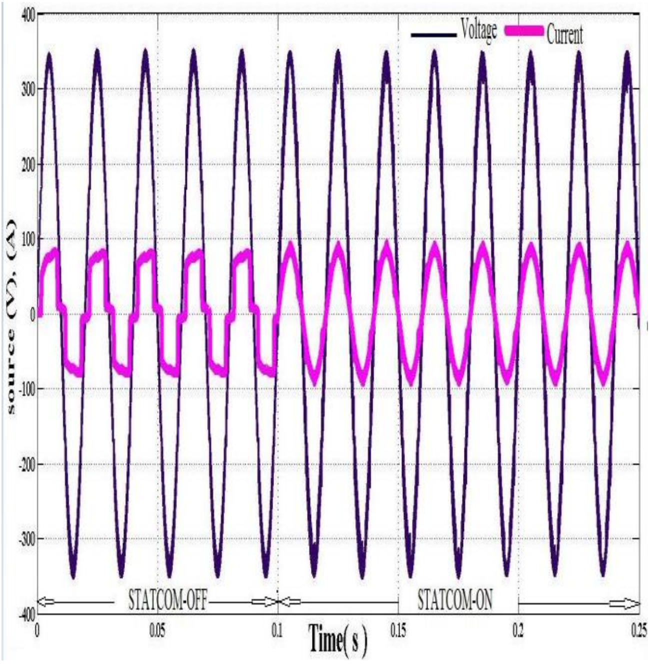

Figure. 6 Simulation results power factor for Non linear

Fig. 6show the power factor it is clear from the figure after compensation power factor is unity.

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 DSTATCOM for supply voltages (*v*sabc), supply currents (*i*sabc), load currents (*i*la, *i*lb and *i*lc), DSTATCOM currents (*i*ca, *i*cb and *i*cc) along with DC link voltage (*V*dc) and its reference value (*V*dcr) at rectifier nonlinear load.

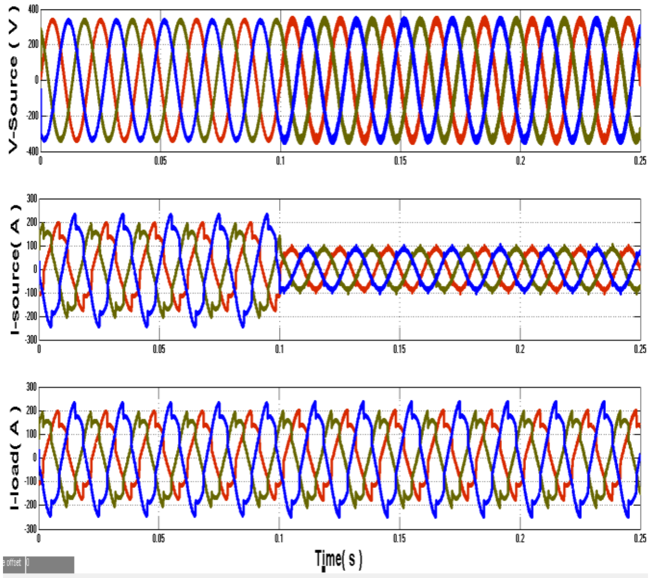

Figure. 7 Simulation results Non- Linear Unbalanced Load

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

4.3 Case three

Performance of DSTATCOM connected to a weak supply system is shown in Fig.8 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}), 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}), DSTATCOM currents (i_{ca}, i_{cb} and i_{cc}) and DC link voltage (V_{dc}).

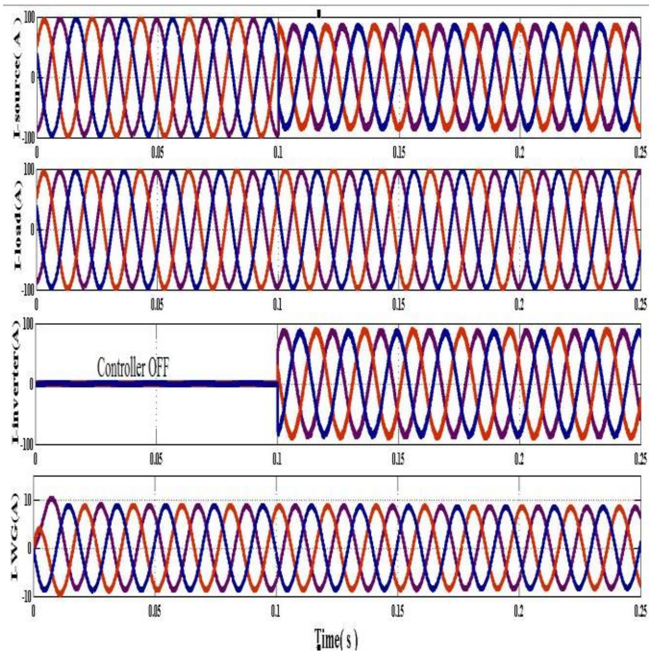

Figure. 8 Simulation results for Balanced Linear Load (a) Source current. (b) Load current. (c) Inverter injected current.(d) wind generator (induction generator) current.

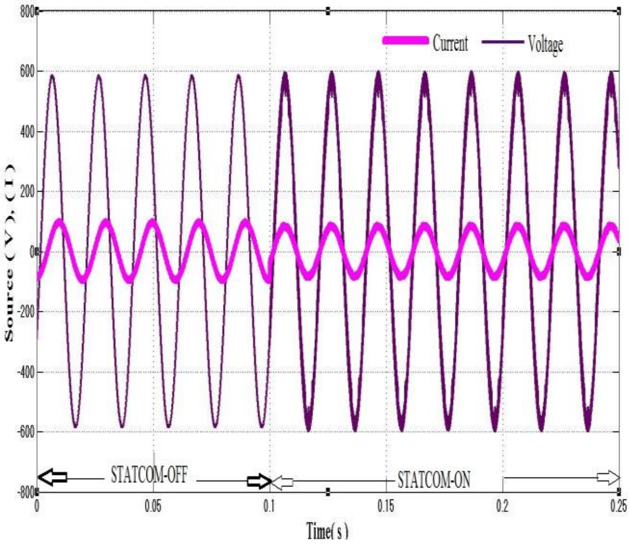

Figure. 9 Simulation results power factor for linear

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

4.4 Case four

Un Balanced three-phase 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 DSTATCOM for supply voltages (v_{sabc}), supply currents (i_{sabc}), load currents (i_{la}, i_{lb} and i_{lc}), inverter current (I_{ina}, I_{inb}, I_{inc}) DSTATCOM currents (i_{ca}, i_{cb} and i_{cc}) along with DC link voltage (V_{dc}) and its reference value (V_{dcr}) at rectifier linear load.

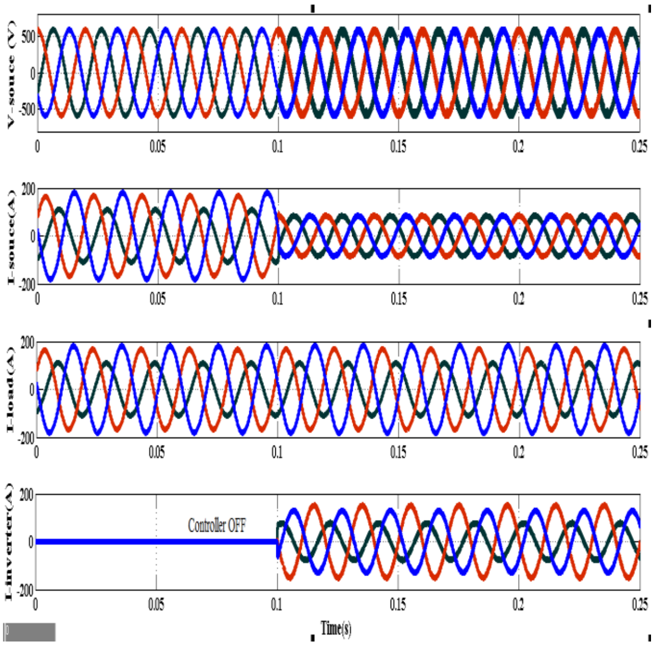

Figure.10 Simulation results for unbalanced linear load

V. CONCLUSION

DSTATCOM system is an efficient mean for mitigation of PQ disturbances introduced to the grid by DERs. DSTATCOM 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 DSTATCOM system has been found to be satisfactory for improving the power quality at the consumer premises. DSTATCOM 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 DSTATCOM has an inherent property to provide a self-supporting DC bus of DSTATCOM. It has been found that the DSTATCOM system reduces THD in the supply currents for non-linear loads.

Rectifier-based non-linear loads generated harmonics are eliminated by DSTATCOM. When single-phase rectifier loads are connected, DSTATCOM currents balance these unbalanced load currents.

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