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Improvement of Power Quality by Using Facts Controllers

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Abstract- Implementation of intelligence controller by using speed as feedback for significantly improving the dynamic performance of D-Statcom and voltage sag/swell conditions of the DVR, the comparative analysis of several control strategies fed D-Statcom for power quality improvement features is presented. Due to the sensitivity of consumers on power quality and also advancement in power electronics may attain the power quality concerns. D-Statcom technology is the most efficient way to compensate reactive power and cancel out low order harmonics generated by nonlinear loads. An D-Statcom is a device that is connected in parallel to and cancels the reactive and harmonic currents from the group of nonlinear loads so that the resulting total current drawn from the ac main is sinusoidal and also The Dynamic Voltage Restorer (DVR) is fast, flexible and efficient solution to voltage sag problem. The DVR is a power electronic based device that provides three-phase controllable voltage source with impedance circuit, whose voltage vector (magnitude and angle) adds to the source voltage during sag event, to restore the load voltage to pre-sag conditions. The DVR can restore the load voltage within few milliseconds. This paper discussed abc to dq0 base new control algorithm to generate the pulse. The simulation results are obtained through MATLAB/SIMULINK software.
***Key words- Power Quality, Voltage sags /swells, DVR,* D-Statcom.**

I.INTRODUCTION

There are different ways to improve power quality problems in transmission and distribution systems. Among these, the D-STATCOM is one of the most effective devices. A new PWM-based control scheme has been implemented to control the electronic valves in the D-STATCOM. The D-STATCOM has additional capability to sustain reactive current at low voltage, and can be developed as a voltage and frequency support by replacing capacitors with batteries as energy storage [6-7].

Advances in semiconductor device technology have fuelled a revolution in power electronics over the past decade, and there are indications that this trend will continue. However these power equipments which include adjustable-speed motor drives (ASDs), electronic power supplies, direct current (DC) motor drives, battery chargers, electronic ballasts are responsible for the rise in related PQ problems. These nonlinear loads are constructed by nonlinear devices, in which the current is not proportional to the applied voltage Conventional passive filters are the earliest solution to mitigate the harmonics currents drawn by the non-linear loads, but due to its heavy in size and resonance with the impedance [3], its applications have becomes very limited in use.

One of the power electronic solutions to the voltage regulation is the use of a Dynamic Voltage Restorer (DVR). DVRs are a class of custom power devices for providing reliable distribution power quality. They employ a series of voltage boost technology using solid state switches for compensating voltage sags/swells. The DVR applications are mainly for sensitive loads that may be drastically affected by fluctuations in system voltage. Power Quality problems encompass a wide range of disturbances such as voltage sags/swells, flicker, harmonics distortion, impulse transient, and interruptions.

- Voltage sag :

Voltage sags can occur at any instant of time, with amplitudes ranging from 10 – 90% and a duration lasting for half a cycle to one minute.

- Voltage swell:

Voltage swell is defined as an increase in rms voltage or current at the power frequency for durations from 0.5 cycles to 1 min.

- Harmonics:

The fundamental frequency of the AC electric power distribution system is 50 Hz. A harmonic frequency is any sinusoidal frequency, which is a multiple of the fundamental frequency. Harmonic frequencies can be even or odd multiples of the sinusoidal fundamental frequency.

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II. REVIEW ON FACTS DEFINITIONS

FACTS are a group of static equipments and devices used for the AC T&D of electrical energy. A power electronic based system and other static equipment that provide control of one or more AC T&D system parameters. It is meant to enhance quality, controllability, flexibility and increase power transfer capability of T&D systems [5]. FACTS is defined by the IEEE as "a power electronic based system and other static equipment that provide control of one or more AC transmission system and increase the capacity of power transfer." FACTS can also be defined as: Alternating current transmission system incorporating power electronic based and other static controllers to enhance flexibility of control enhance quality of supply and increase power transfer capability [6].

A. Overview about FACTS

Flexible AC Transmission Systems (FACTS) controllers have been used in power systems since the 70s with the objective of improving system performance and quality of supply. FACTS is a term that has been suggested for the use of solid state electronic devices to control bulk power flow in T&D network. According to present scenario, it appears that the main worth of FACTS lies in improving power transmission and distribution quality, capacity & capability by increasing the flexibility of power flow control by controlling VAR flow and possibly few additional advantages in T&D systems[4]. Due to the environmental conditions, right-of-way, and cost problems in both power T&D lines have been forced to operate at almost their full capacities worldwide. FACTS controllers enhance the static performance by increased loading, congestion management, reduced system loss, economic operation etc., and dynamic performance by increased stability limits, damping of power system oscillation, etc. The need for more efficient electricity systems, management has put efforts to introduce innovative technologies in power generation, transmission and distribution. The combined cycle power station is a good example of a new development in power generation and FACTS as they are generally known are new devices that improve overall performance of power systems. Worldwide transmission systems are undergoing continuous changes and restructuring, they are becoming more heavily loaded and are being operated in ways not originally forecasted. T&D systems must be flexible to react to more diverse generation and loading patterns. In developing countries, the optimized use of T&D systems investments is also important to support industry, create employment and utilize efficiently inadequate economic resources. A FACT is a technology that responds to these needs.

B. FACTS Technology and Potentials

The FACTS technology has a collection of controllers that can be used individually or coordinated with other controls installed in the network, thus permitting to profit better of the network's characteristics of control. The potential of FACTS technology is based on the possibility of control the route of the power flow and the ability of connecting networks, those are not satisfactorily interconnected. FACTS also provide the possibility of trading energy between distant agents.

The following features resume the main advantages of the FACTS technologies:

- They allow a greater control over the power flow, routing it through a predetermined route.
- It is possible to operate at safe load levels (without overload) near to the thermal limits of the transmission lines. Bigger capacity of power transmission between controlled areas, thus reducing considerable reserve margin.
- They increase the system security by enhancement of stability limits.
- They damp the system oscillations that harm the equipment and limit the available capacity of device.
- They provide the flexibility to the transmission and distribution network to install new generating plants.
- Great flexibility in the three operative status of the system: pre-fault, fault, post-fault and capacity to control transitory status and to impact phase in post fault status.

III. PROPOSED CONCEPT OF D-STATCOM AND DVR

A. Basic Structure D-statcom

The shunt active filter approach is based on the principle of injection of harmonic currents into the ac system, of the same amplitude but opposite in phase to that of the load harmonic currents.

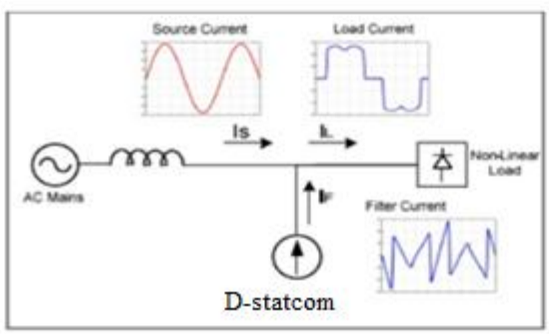

Fig.1 Basic Principle of D-statcom System.

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Fig. 1 shows the D-statcom compensation principle, which is controlled in a closed loop manner to actively shape the source current into sinusoid. Fig 2 demonstrates the simplified configuration of D-statcom [7], which could be dichotomized into reference current calculation section and its counterpart—compensating current generator (consisting of current control, drive and main circuit). The core function of the reference current calculation circuit is to detect the harmonics as well as the reactive power contributed by the non-linear load.

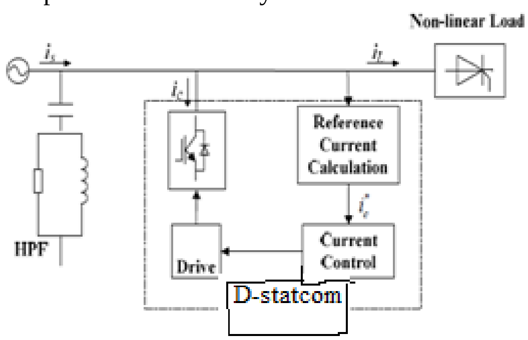

Fig.2. simplified D-statcom configuration.

B. The Calculation of Reference Current

The circuit of reference current calculation is essentially based on three-phase instantaneous reactive power theory [5], which suggests a novel approach to detect the three-phase harmonic current. As shown in Fig 3, i_a, i_b and i_c are initially detected and then served as the input for the next stage of algorithm, which involves specific calculation of instantaneous active current i_p as well as reactive current i_q.

$$\begin{bmatrix} i_p \\ i_q \end{bmatrix} = C \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (1)$$

Where

$$C = \sqrt{\frac{2}{3}} \begin{bmatrix} \sin\omega t & \sin\left(\omega t - \frac{2\pi}{3}\right) & \sin\left(\omega t + \frac{2\pi}{3}\right) \\ -\cos\omega t & -\cos\left(\omega t - \frac{2\pi}{3}\right) & -\cos\left(\omega t + \frac{2\pi}{3}\right) \end{bmatrix} \quad (2)$$

In addition, a three-phase PLL section is prerequisite in order to grasp the angle of phase A. When i_p and i_q flow through the low-pass filter (LPF), the harmonics contained could be eliminated, and thus give rise to the DC component of the load current known as $\overline{i_p}$ and $\overline{i_q}$. With inverse transformation of the transpose matrix of CT, hence the three phase fundamental current of i_{af}, i_{bf} and i_{cf} *could* be readily obtained. Therefore, the reference current i_a^*, i_b^* and i_c^* is obviously the subtraction of those fundamental three-phase currents with the correspondingly original load currents [8].

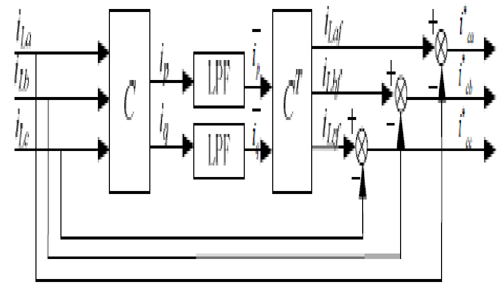

Fig.3. Algorithm of the reference current calculation circuit.

C. Current Tracking Control Circuit

Current tracking is the first step for the production of targeted compensating current, under the basic function of obtaining the PWM signals that are responsible for the switch modes of each device in the main circuit. In addition, the PWM signal is generated by the comparison between the reference current and the real compensating current.

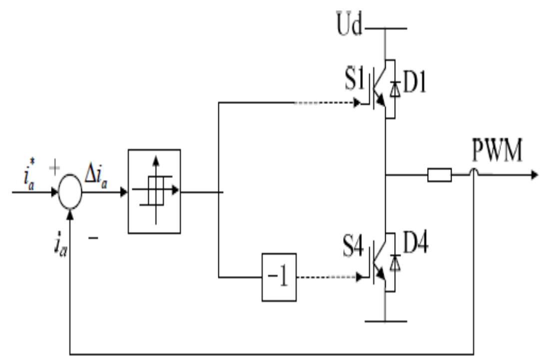

Fig.4.Circuit of current tracking control.

The current-tracking-controlled PWM inverters possess various forms, the most common of which is the hysteresis current tracking control shown in Fig 4. i_a^* Represents the reference value and meanwhile the tracking target of the load current. A hysteresis error h is intentionally established in case of the high frequency of switches in inverters. While $i_a^* - i_a \geq h$, the hysteresis controller produces high level which drives the upper bridge arm S_1 in working mode condition, and thus increasing load current i_a even when i_a is outstripping i_a^*. The increase of load current will not be affected unless i_a is exactly greater by h comparing with the reference current, then follows the reverse working mode of hysteresis controller by switching off S_1 and simultaneously acting on S_4, which may not be necessarily switched on, for the current flows through diode D_4 is not reversed in direction but rather begin decreasing [9].

When the hysteresis control is applied, the real output of the current from inverters could maintain a fluctuation

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value only within h and –h, bouncing up and down in zigzag forms, as one of the examples illustrated in Fig.5.

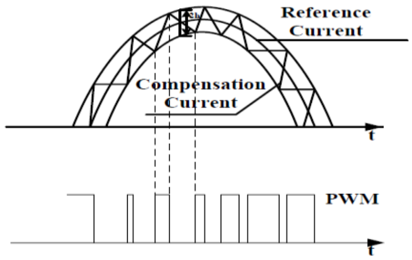

Fig.5. One example of the hysteresis control of the reference and compensating current.

D. Main Circuit Parameter Design

The working mode of the main circuit is determined by the condition of its six switches. Generally speaking, there is always a single device switched on in all three groups (S_1/S_4, S_3/S_6 or S_2/S_5), constructing six different combinations all together. The main circuit is shown in Fig.6.

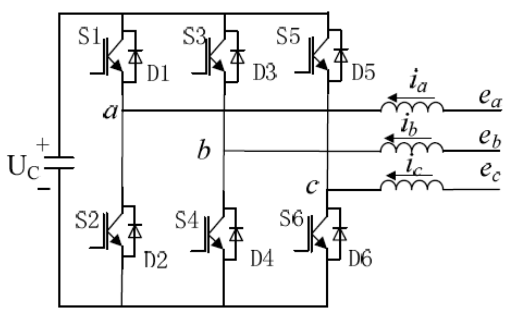

Fig.6. Main circuit

Suppose the sum of three-phase voltage source $e_a+e_b+e_c=0$ along with the current $i_a+i_b+i_c=0$, then the differential equation of phase A could be described as

$$L\frac{di_a}{dt} = e_a + K_a U_c \quad (3)$$

In which K_a denotes the switching coefficient, while e_a represents as the instantaneous value of the ac side voltage and i_a as the compensating current. In addition, when the upper bridge arm of phase A is switched on, the absolute value of K_a is -2/3; similarly, K_a is 1/3 when the lower bridge arm is working. Provided that the sample working time is long enough, the average effect of AC voltage e_a in (2) would be zero [10]-[12]. As the possibility of $K_a=1/3$ is 66.7% while that of $K_a=2/3$ is 33.3%, the mean of K_a is hence 4/9. Within one period of time, (2) could be reshaped as:

$$L\lambda\frac{i^*_{c\max}}{t_c} = \frac{4}{9}U_c \quad (4)$$

Signal of compensating current; the most appropriate value of coefficient λ varies from 0.3 to 0.4 in terms of the overall effect of compensation, which could be obtained by simulation. Taking function (3) and safety concerns into consideration, the prerequisite of $U_c \geq 3E_m$ should be granted, in which E_m the peak value of phase voltage is. Assuming that the DC side capacitor is always in transition from charging to discharging states within a single switching cycle, the maximum acceptable deviation of DC side capacitor voltage is [6]:

$$\Delta U_{c\max} = \frac{\left|i^*_{c\max}\right|}{Ct_c} \quad (4)$$

IV. DYNAMIC VOLTAGE RESTORER

Dynamic Voltage Restorer is one of custom power device specially used to maintain the load voltage constant in the distribution system. DVR has two operating modes. In normal operation mode it is in standby mode in which voltage injection by DVR is zero. Most of the time DVR will be in standby mode and hence reduces the losses. The primary function of DVR is to compensate voltage sags and swells but it can also perform the tasks such as: harmonic compensation, reduction of transient in voltage and fault current limitation. The main parts of DVR are injection transformer, harmonic filter, a voltage source converter, and energy storage device and control & protection system. As soon as control circuit detects the any voltage disturbance, reference voltage is generated for required magnitude, duration and phase and is injected through injection transformer. This mode of DVR is known as injecting mode [1]. This injection should satisfy the equation (5)

$$V_L = V_S + V_{inj} \quad (5)$$

Where V_S is the source voltage, V_{inj} is the injected voltage by DVR and VL is the load voltage.

Fig.7 shows the basic configuration and operation of DVR which consist of an injection transformer, Voltage Source Converter (VSC), harmonic filter, storage device and control system

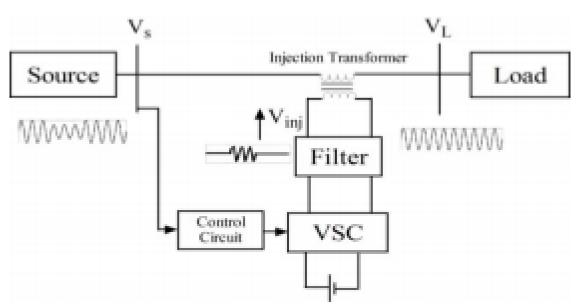

Fig.7 Structure of DVR.

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A. Injection Transformer

Injection transformer is used to connect the DVR to the distribution network via High Voltage winding and injects the compensating voltage generated by VSC after the detection of any disturbance in supply voltage by control circuit. Another main task of injection transformer is that it will limit the coupling of noise and isolate VSC and control circuit from the system.

B. Voltage Source Converter (VSC)

VSC is a power electronic device consists of storage device and switching devices used to generate the compensating sinusoidal voltage of required magnitude, duration, in phase as that of system and instantaneously. In DVR voltage source converter provides the missing voltage during voltage sag.

C. Harmonic filter

Output of VSC contains large content of harmonics. Harmonic filter is used to keep this harmonic content in permissible limit.

D. Storage device

It is basically used to supply the necessary energy to VSC to generate the compensating voltage.

E. Control circuit

Control circuit continuously monitors the supply voltage. The function of control system is to detect the disturbance in the supply voltage, compare it with the set reference value and then generate the switching pulses to the VSC to generate the DVR output voltages which will compensate the voltage sag/swell.

V. DESIGN OF DVR

The aim of the control scheme is to maintain constant voltage magnitude at the sensitive load under voltage disturbance condition. The proposed control scheme based on comparison of actual supply voltage and desired load voltage. The error is determined dynamically based on difference between desired and measured value. In the control scheme the actual voltage is measured and also the desired voltage. These voltages are converted in dq0 with the Parks transformation.

$$f_{qd0} = K_s f_{abc} \tag{6}$$

Where

$$\left(f_{qd0}\right)^T = \left(f_q \;\; f_d \;\; f_0\right) \tag{7}$$

$$\left(f_{abc}\right)^T = \left(f_a \;\; f_b \;\; f_c\right) \tag{8}$$

$$K_s = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \tag{9}$$

$$\omega = \frac{d\theta}{dt} \tag{10}$$

It can be shown that for the inverse transformation we have

$$\left(K_s\right)^{-1} = \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta - \frac{2\pi}{3}\right) & 1 \\ \cos\left(\theta + \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) & 1 \end{bmatrix} \tag{11}$$

The angular velocity ω and displacement θ are related by

$$\theta = \int \omega \, dt \tag{12}$$

The control system employs abc to dqo transformation to dq0 voltages. During normal condition and symmetrical condition, the voltage will be constant and *d*-voltage is unity in p.u. and *q*-voltage is zero in p.u. but during the abnormal conditions it varies. After comparison *d*-voltage and *q* voltage with the desired voltage error *d* and error *q* is generated. These error components are converted into *abc* component using *dq0* to *abc* transformation. Phase Locked Loop (PLL) is used to generate unit sinusoidal wave in phase with main voltage. This *abc* components are given to generate three phase Pulses using Pulse Width Modulation (PWM) technique. Proposed control technique block is shown in Fig 9.

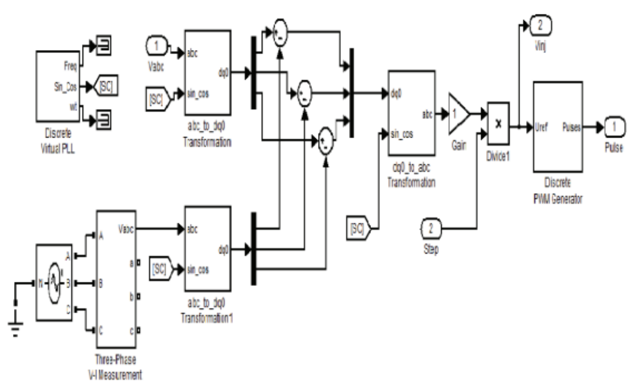

Fig. 8 Control block diagram for DVR.

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VI. CONTROL ALGORITHM

The basic functions of a controller in a DVR are the detection of voltage sag/swell events in the system; computation of the correcting voltage, generation of trigger pulses to the sinusoidal PWM based DC-AC inverter, correction of any anomalies in the series voltage injection and termination of the trigger pulses when the event has passed. The controller may also be used to shift the DC-AC inverter into rectifier mode to charge the capacitors in the DC energy link in the absence of voltage sags/swells. The dqo transformation or Park's transformation [8-10] is used to control of DVR. The dqo method gives the sag depth and phase shift information with start and end times. The quantities are expressed as the instantaneous space vectors. Firstly convert the voltage from abc reference frame to d-q-o reference. For simplicity zero phase sequence components is ignored. Fig 9 illustrates a flow chart of the feed forward dqo transformation for voltage sags/swells detection. The detection is carried out in each of the three phases.

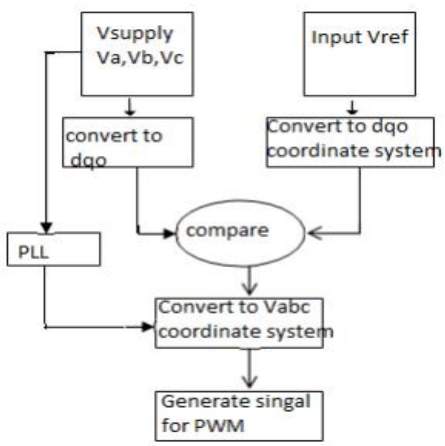

Fig.9. Flow chart of feed forward control technique for DVR based on dqo transformation

The control scheme for the proposed system is based on the comparison of a voltage reference and the measured terminal voltage (Va, Vb, Vc).The voltage sags is detected when the supply drops below 90% of the reference value whereas voltage swells is detected when supply voltage increases up to 25% of the reference value. The error signal is used as a modulation signal that allows generating a commutation pattern for the power switches (IGBT's) constituting the voltage source converter. The commutation pattern is generated by means of the sinusoidal pulse width modulation technique (SPWM); voltages are controlled through the modulation. The block diagram of the phase locked loop (PLL) is illustrated in Fig 9. The PLL circuit generates a unit sinusoidal wave in phase with mains voltage.

Equation (13) defines the transformation from three phase system a, b, c to dqo stationary frame. In this transformation, phase A is aligned to the d axis that is in quadrature with the q-axis. The theta (θ) is defined by the angle between phase A to the d-axis.

$$\begin{pmatrix} V_d \\ V_q \\ V_o \end{pmatrix} = \begin{pmatrix} \cos(\theta) & \cos\left(\theta - \frac{2\pi}{3}\right) & 1 \\ -\sin(\theta) & -\sin\left(\theta - \frac{2\pi}{3}\right) & 1 \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{pmatrix} \begin{pmatrix} V_a \\ V_b \\ V_c \end{pmatrix} \quad (13)$$

VII. MATLAB MODELING AND SIMULATION RESULTS

Here simulation is carried out in different cases 1). Implementation of d-statcom using Inverter. 2). Mitigation of Voltage Sag/Swell using VSI Based DVR

Case 1: Implementation of D-statcom using Inverter

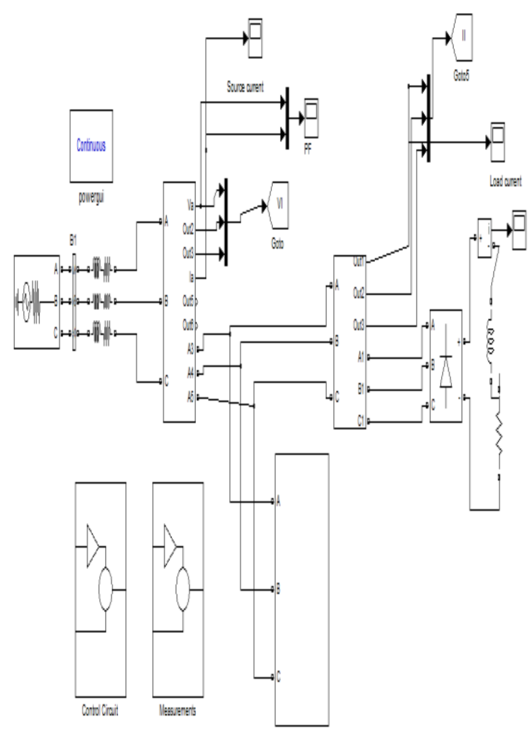

Fig.10 Matlab/Simulink Model of Proposed D-statcom.

Fig.10 shows the Matlab/Simulink Model of Proposed D-statcom using Matlab/Simulink Platform.

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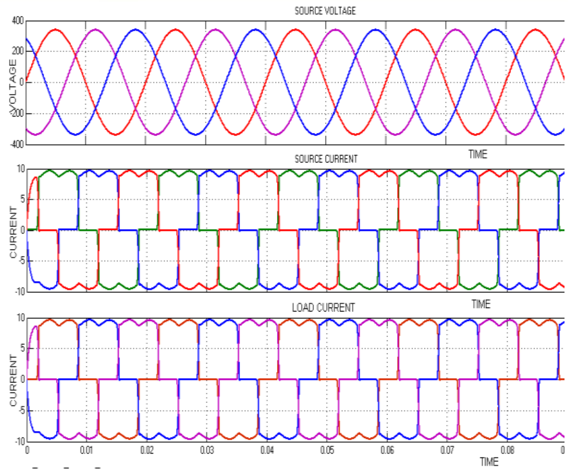

Fig.11.Source voltage, current and load current without D-statcom.

Fig. 11 shows the three phase source voltages, three phase source currents and load currents respectively without D-statcom. It is clear that without D-statcom load current and source currents are same.

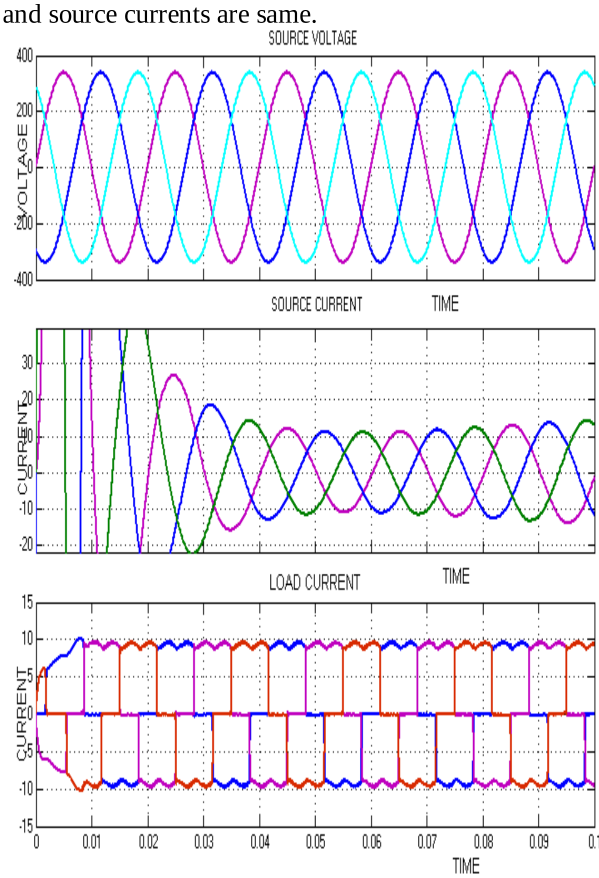

Fig. 12. Source voltage, current and load current with D-statcom.

Fig. 12 shows the three phase source voltages, three phase source currents and load currents respectively with D-statcom. It is clear that with D-statcom even though load current is non sinusoidal source currents are sinusoidal.

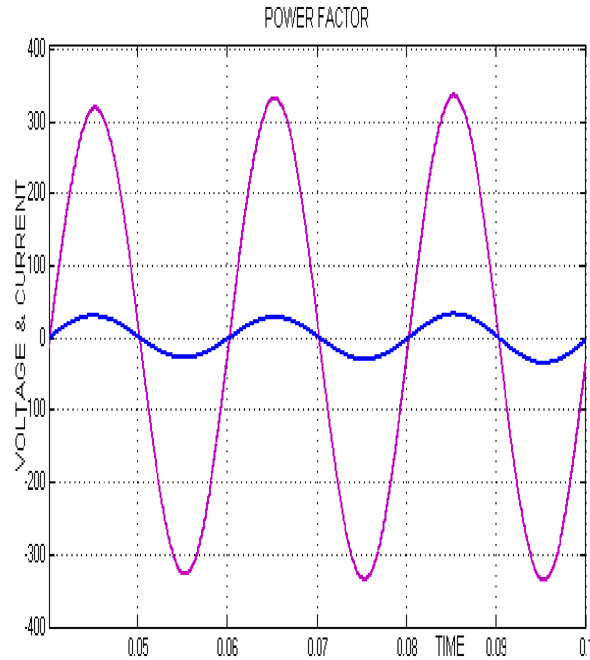

Fig.13. Phase-A source voltage and current.

Fig.13. shows the phase-A source voltage and current, even though the load is non linear RL load the source power factor is unity.

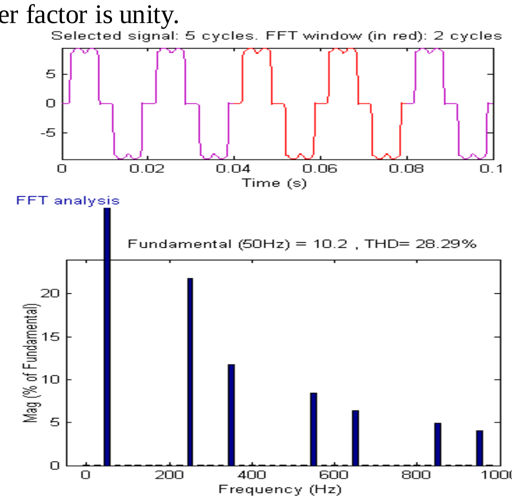

Fig.14.Harmonic spectrum of Phase-A Source current without D-statcom.

Fig.14. Shows the harmonic spectrum of Phase –A Source current without D-statcom. The THD of source current without D-statcom is 28.29%.

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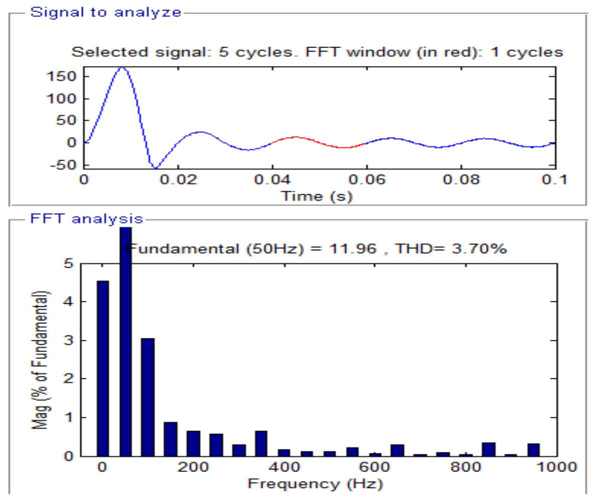

Fig.15. Harmonic spectrum of Phase-A Source current with D-statcom

Fig.15. shows the harmonic spectrum of Phase –A Source current with D-statcom. The THD of source current without D-statcom is 3.70%.

Case 2: Mitigation of Voltage Sag/Swell using VSI Based DVR

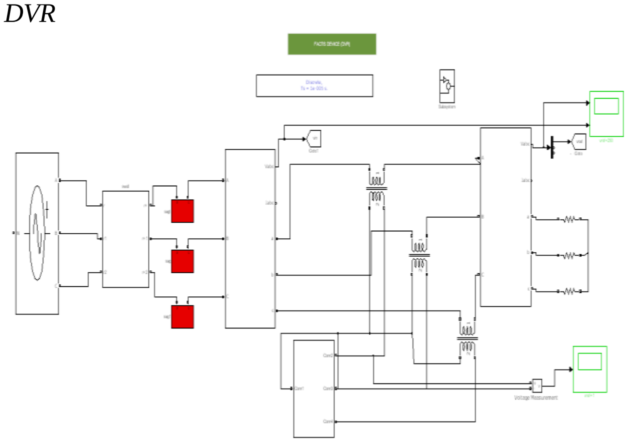

Fig.16 MATLAB/Simulink model of three phase VSI based DVR

Fig.16 shows the Matlab/Simulink model of three phases VSI based DVR using Matlab/Simulink Platform.

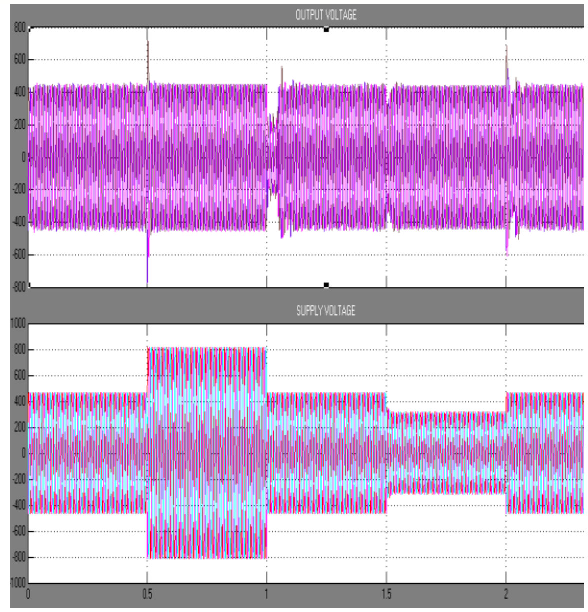

Fig. 17 Source voltage and Load voltage during Voltage Swell and Sag

Fig.17 shows simulation results for voltage swell and sag compensation. From the simulation result it is clear that even through there is swell and sag in the supply voltage, output voltage is almost constant.

Fig. 18 Inverter output voltage during voltage swell and sag mitigation.

Fig.18 shows the voltage source converter/inverter output voltage. It is clear that under normal condition voltage source converter/inverter output voltage is zero, but during swell voltage source converter/inverter is producing equal and opposite voltage to swell and sag.

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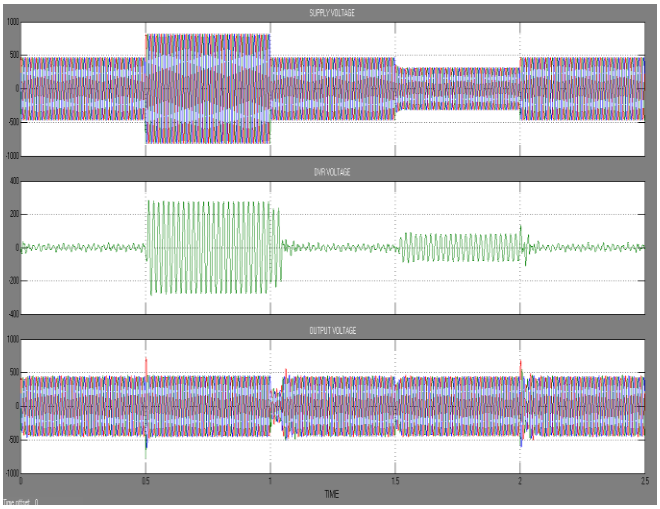

Fig.19 Overall Compensation

Fig.19 shows the overall compensation of voltage swell and sag occurs in the input supply voltage that time inverter buck the voltage in the swell condition and boost the voltage in the sag condition but the output voltage maintain constant.

IV.CONCLUSION

This proposed model is implemented using Matlab/Simulink software and the obtained resultant waveforms were evaluated and the effectiveness of the system stability and performance of power system have been established. D-statcom with the proposed controller reduces harmonics and provides reactive power compensation due to non-linear load currents; as a result source current(s) become sinusoidal and unity power factor is also achieved under both transient and steady state conditions and another Now a day these issues of power quality are very important for customer and utility also. So for this custom power device, Dynamic Voltage Restorer (DVR) is used to mitigate these power quality problems and also it shows that the hysteresis voltage control technique is very good technique for dynamic voltage restorer as it plays an important role in mitigation of voltage sag, voltage swell, harmonics etc. by using this Z-source network to eliminate the short-circuit currents from the VSI topology and boost the DC link voltage with respect to low value of DC voltage.

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