ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Design of Unified Power Quality Conditioner for Power Quality Improvement

B. Eswara Rao
JNTUK PG Scholar,
JNTU Kakinada, Andhra Pradesh 533 003, India.

Abstract:

Any power system consists of wide range of electrical, electronic and power electronic equipment in commercial and industrial applications. The quality of the power is affected by many factors like harmonic contamination due to non-linear loads, such as large thyristor power converters, rectifiers etc. Voltage and current flickering due to the arc furnaces, and sag/swell due to the switching loads also influence the sensitive loads to be fed from the system. Unified Power Quality Conditioner (UPQC) is a custom power device that consists of shunt and series converters connected back to back on the dc side and deals with load current and supply-voltage imperfections.

The performance of UPQC mainly depends upon how accurately and quickly reference signals are derived. In the present dissertation an open UPQC model is designed which has a separate dc link for shunt and series compensation.. Shunt compensation and series compensation of open UPQC model are designed using hysteresis controller and Pulse Width Modulation (PWM) technique respectively. A common PI controller is used to produce the firing order to the converters. Using hysteresis controller is a significant feature of this dissertation.

In the literature, PWM controller for shunt compensation is used. From simulation it is found that the Total Harmonic Distortion (THD) of power source is not in the standard IEEE limits. Hence this dissertation tried to reduce this THD by using hysteresis controller to 3.91% from 17.11%. These control strategies are modeled using MATLAB/SIMULINK.

The performance is observed for Low Voltage distribution systems under the influence of utility side disturbances such as harmonics, flicker and spikes. The simulation results with control strategies are presented and analysed.

Index Terms:

Open upqc, DVR, D-Statcom, THD

INTRODUCTION

he Basic block diagram of open UPQC is shown below in fig 5.1. The voltage at PCC may be or may not be distorted depending on the other non-linear loads connected at PCC. When the voltage at PCC gets distorted and harmonics currents injected into system by using non linear loads then the open UPQC is used to mitigate these voltage and current problems. This open UPQC consists of two voltage source inverters with separate energy storage elements. One inverter is connected in parallel with the load.

It acts as shunt APF, helps in compensating load harmonic currents that affecting source side. The second inverter is connected in series with the non linear loads by using a series injection transformer to mitigate the voltage sag that occurred because of balanced faults, unbalanced faults or voltage problems occurred because of nonlinear loads and helps in maintaining the load voltage sinusoidal.

Cite this article as: B. Eswara Rao, "Design of Unified Power Quality Conditioner for Power Quality Improvement", International Journal & Magazine of Engineering, Technology, Management and Research, Volume 6, Issue 1, 2019, Page 12-20.

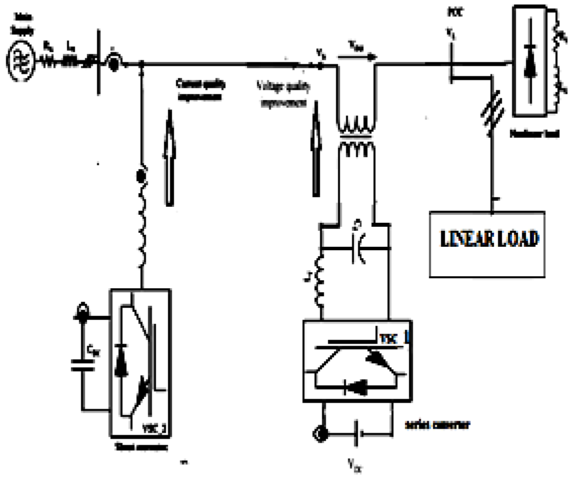


Fig.1.1 Basic Block diagram of open UPQC

The power processing at source, load and for voltage sag and harmonic compensation by means of power electronic devices like active power filters is becoming very popular as they have innumerable advantages. The shunt APF is usually connected in parallel with the loads to compensate for all current problems such as the power factor improvement, current harmonic compensation, reactive power compensation and load unbalance compensation. Whereas the series APF is connected in a series and it acts as a controlled voltage source and can compensate all voltage problems, such as voltage sag/swell, voltage flicker etc.

An open UPQC and UPQC are other mitigating devices that are same in construction to a UPFC. A UPFC is in use at power transmission system whereas a open UPQC and UPQC are in use at power distribution system, to perform the shunt and series compensation simultaneously. But UPFC only needs to provide balance shunt and /or series compensation, since a power transmission system generally operates with balanced, distortion free environment. Considering a LV distribution system 11 kV feeding linear loads and non linear loads, because of the usage of the non linear loads the harmonic currents gets injected into power distribution system. So to mitigate these harmonic currents shunt APF is used.

The purpose of the shunt APF is to inject current harmonics which are equal in magnitude but oppose in direction to that of current harmonics that are in non-linear loads. So, these harmonics will cancel each other and result in sinusoidal line currents and improvement in power factor. The current harmonics that are generated at load side are calculated using fourier analysis. Then these three phase currents are transformed to d-q-0 rotating frame for modal analysis. Then harmonic currents Idl is passed through low pass filter and obtained fundamental current is subtracted with harmonic current Idl. The harmonic current that is to be compensated is obtained oppose in direction for Idl. For Iql it is passed through integrator and converted to oppose harmonic currents to compensate the harmonic currents that are generated because of non linear loads.

These currents are compared with the calculated filter currents and the error signal enters to PI controller. PI controller is a feedback controller that drives the plant that to be controlled with the weighted sum of the error obtained when compared and the integral of that value. The harmonic currents are converted to voltage in order to trigger the IGBT’s used in the VSI. Here hysteresis current control technique is used to generate the pulses for the VSI. The obtained current from the shunt APF is oppose in direction to the harmonics that are produced because of usage of non linear loads.

For the voltage quality problems we use the series APF. Voltage sag is literally a voltage quality problem that becomes severe to industrial customers and because of it there is severe miss operation of several electronic sensitive equipment. That problem can be mitigated using DVR, voltage injection method. Dynamic voltage restorer is a custom power device. Control of DVR is done using PI controller and the pulses generated using pulse width modulation (PWM). Control unit is the important part of DVR where its main operation is to detect the presence of voltage sags in the systems.

Based on that, the required compensating voltage is calculated and the reference voltage is generated for pulse width modulation generator to trigger on the VSI. The components of control system are d-q-0 transformation, PLL and the PI controller. The basic operation of the dynamic voltage restorer is to inject the compensate voltage required, VDVR to compensate sag occurrence. There are two modes of operation for DVR, standby mode and injection mode. In standby mode the DVR is either in short circuited operation or it injects some voltage to cover the drop due to transformer reactance losses. The DVR is in injection mode when a sag occurs in the system.

The DVR is modeled in such a manner that with source voltage of 11 kV fed from substation is then step down to 415V before delivering it to consumers. Three legs VSI inverter is used to convert the generated DC to AC and then injected into line using injection transformer. When the unbalanced sag or balanced sag occurs in the system based on the calculated compensate voltage, then the triggering pulses are generated for VSI inverter and stops triggering pulses when the sag gets compensated. The calculation of voltage is done using park's transformation. The d-q-0 transforms the three phase stationary coordinates to dq rotating coordinate system.

From this we get the information of depth(d) and phase shift(q) of voltage sag, i.e, from Va, Vb and Vc become two constant voltages Vd and Vq for easy control. The measured voltage from the three phase V-I measurement at load converted to dq terms. The sag is then detected by calculating the error between the dq-voltage and the reference values. The d-reference is set to rated voltage at the same time as q-reference is set to zero. Then the dq components are compared with the reference dq values and the error obtained is then entered to PI controller. The outputs from the PI controller are transformed back into Vabc and then forwarded to pulses generation.

Four levels of voltage generated to load for every fault (0.019 to 0.085 sec duration) which are 30%, 50%, 80% and 90% voltage sags. The below scope shows the resultant in balanced sag happened at load as dip as 50% voltage drop.

II. GATE PULSE GENERATION FOR SERIES AND SHUNT CONVERTER

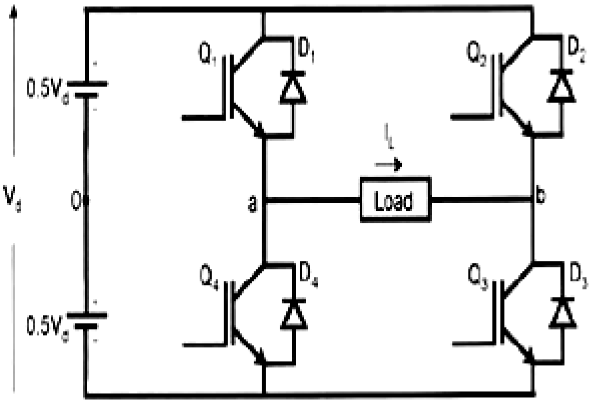
There are various techniques for Gate pulse generation once the necessary reference signals are extracted, each having its own advantage. They are hysteresis method, sinusoidal pulse width modulation, space vector pulse width modulation etc;

Two methods are explained Sinusoidal pulse width modulation

1. Sinusoidal pulse width modulation method.
2. Hysteresis voltage control method

2.1 Sinusoidal pulse width modulation for series unit

In this method, the reference sinusoidal error signal is compared with a carrier signal of magnitude unity and gate pulses that are generated are given to respective switches. The switches Q_1 and Q_3 are on when the amplitude of modulating wave is higher than the carrier wave and switches Q_2 and Q_4 are on when the amplitude of modulating signal is less than that of carrier signal.



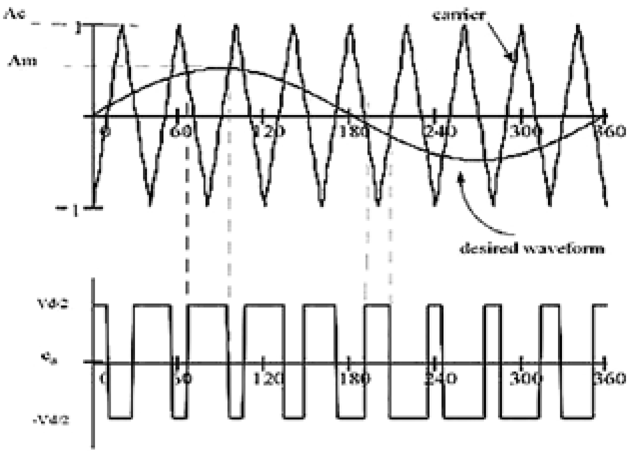


Fig.2.1: Sine-PWM waveforms for single-phase H-Bridge inverter

The modulating signal which is compared with carrier signal for gate pulse generation for leg containing Q_1 and Q_4 is shifted 180^0 and is compared with carrier signal for gate pulse generation for the leg containing Q_2 and Q_3.The output voltage of the inverter is given by the equation.

$$V_0 = E_{dc} M_a \sin wt$$

Where M_a is the modulation index whose value is given by $M_a = V_m/V_c$. But sinusoidal PWM technique uses only 78.5% of dc link voltage.

a. Frequency modulation ratio (Mf): It can be defined as ratio of PWM frequency (Carrier wave frequency) to fundamental frequency (Modulating wave frequency).If frequency modulation is not an integer then there may be sub harmonics at output voltage. If frequency modulation is not odd then DC components may exist and even harmonics may be present at output. To suppress odd multiple of 3 and even harmonics, Frequency modulation should be kept multiple of 3.

b. Modulation Index (M_a): It can be defined as ratio of amplitude of modulating waveform to amplitude of carrier waveform. If M_a<1 it means that PWM inverter operates at under modulation and if Ma >1 it means that PWM inverter operates at over modulation. Generally PWM inverter operates under modulation. If it is operated at over modulation then linear relation between modulating wave and output voltage will not continue.

2.2 Hysteresis current controller for shunt unit

The shunt converter control includes reference signal generation and gate pulse generation. The control block diagram for phase A is shown in figure 5.4. Similarly, it can be done for other phases also.

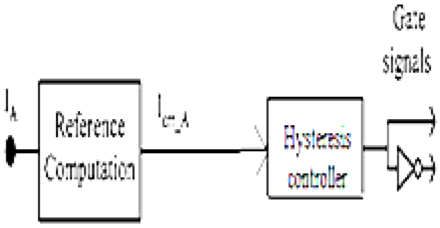


Fig.2.2: Block diagram of Shunt converter control

The operation of hysteresis voltage controller and current controller in [1] is similar. The gate pulses for the 3-phase inverter are produced by comparing the reference value values i_a^* ,i_b^*, i_c^* with the measured values from the inverter and inverter is operated to reduce the deviation between the two values. The gate pulse generation unit figure is shown in figure 5.5.

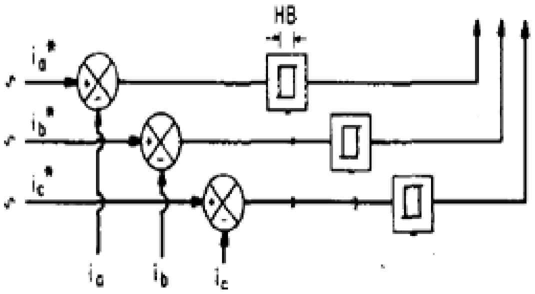


Fig.2.3: Gate pulse generating unit for 3-phase inverter.

The shunt active power filter which is operated without an energy storage device has been proposed by Gyugi. Considering one leg say $S_1$and S_4 whose output is connected to the line through an inductance as shown in the fig.5.6.

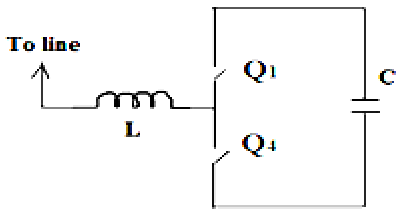


Fig.2.4: Showing a leg of 3-phase shunt converter under operation

Suppose that the capacitor is initially charged to a voltage V_c. It remains at V_c since no net energy is transferred from capacitor while supplying the harmonics. Suppose when Q_1 is on and Q_4 is off, the current through the inductor raises as ramp and when it touches the 0.01 band above the reference Signal then Q_1 is off and Q_4 is on then the current through the inductor drops down until it touches the -0.01 band below the reference signal and this process continues and the reference signal is tracked within the hysteresis band as shown in the figure 2.4. Thus the reference signal being the harmonics required by the diode bridge rectifier supplying a load, are injected into the line and hence supply current becomes smoother.

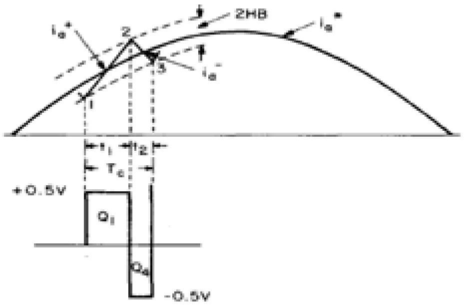


Fig.2.5: Phase A current with a sinusoidal reference.

The equations of the current can be given as:

$I_{inv} = 1/L \int V_c(t).dt$

Where V_c (t) is nothing but rectangular waveform

Hence, $I_{inv} = V_{Ref} \pm (V_c/L).t$

2.3. REFERENCE SIGNAL GENERATION

Reference voltages are generated using phase locked loop (PLL). The three phase distorted input source voltage at PCC contains fundamental component and distorted component. To get unit input voltage vectors Eabc, the input voltage is sensed and multiplied by gain equal to 1/Vm, where Vm is equal to peak amplitude of fundamental input voltage. These unit input voltage vectors are taken to phase locked loop (PLL). With proper phase delay, the unit templates generated.

$$Ea = \sin(wt)$$
$$Eb = \sin(wt-120)$$
$$Ec = \sin(wt+120)$$

Multiplying the peak amplitude of fundamental input voltage with unit vector templates of above equation gives the reference load voltage signals,

$$V^*abc = Vm.\ Eabc$$

The shunt APF is used to compensate the harmonics that are generated because of non linear loads. The calculation of shunt injected current magnitude and phase angle is not required, an alternative approach is done for shunt part. The reference source currents are generated directly from the shunt active filter that is feedback from that. The PI control then process the error. The output signal from PI controller is then processed by a hysteresis current controller with certain band, generating gating signals for shunt APF.

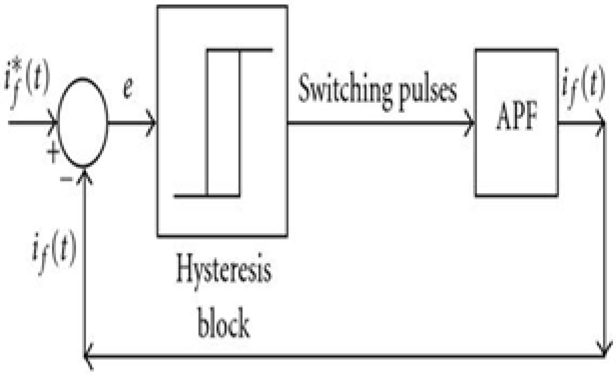


Fig 2.6 Reference signal generation for shunt APF

ISSN No: 2348-4845
International Journal & Magazine of Engineering,
Technology, Management and Research
A Peer Reviewed Open Access International Journal

III. SIMULATION OF OPEN UPQC

To verify the operating performance of the open UPQC, a 3-phase electrical system, reference signal generation and hysteresis control for shunt and pulse width modulation for series unit open UPQC is simulated using MATLAB software. The simulation results are shown below. Both the series and shunt APF’s conducts based on the compensation requirement i.e., balanced/unbalanced fault occurs at 0.019 to 0.085 sec, then the voltage gets distorted from its nominal value. Based on the distortion series active power filter comes into conduction and compensate the voltage sag obtained. Shunt APF comes into conduction to compensate the harmonics generated by non linear loads at source side when generated. Fig. 3.1 shows the simulation block diagram of the open UPQC which consists of a series and a shunt units with separate dc-link. The open UPQC is in conduction for a LV distribution (11kV) feeding linear load and the nonlinear loads with internal impedance. Linear load with parameters of 2kW active power and non linear loads with rectifier fed 8.67ohm resistive load. The fault that occurred on the distribution line is unbalanced with a fault resistance of 4.6 ohms; the sag obtained is 50% from its nominal value and is compensated by injecting voltage at that instant time i.e., 0.019 to 0.085 sec. The energy storage device with 200V is connected to the series active power filter.

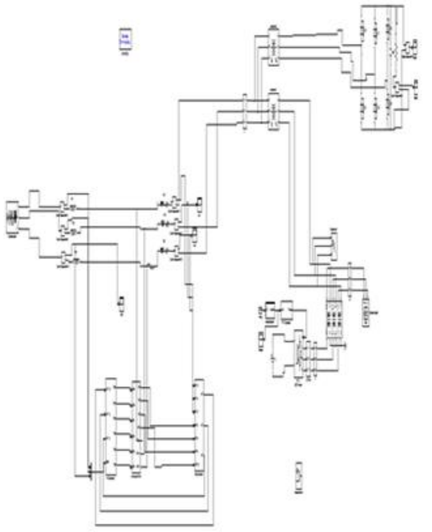


Fig 3.1 Simulink model of open UPQC

Case (i):

Fig 6.2 shows the injection voltage using series unit for particular instant time for the sag generated. The instant time the fault occurred in phase A is 0.019 to 0.085 sec, the sag generated is 50% of the nominal value in phase A with a fault resistance of 4.7 ohms. The series unit injects voltage at that particular time sag obtained through injection transformer and compensates balanced sag. From the above fig it is shown that when the sag obtained then the DVR operates and compensates the sag obtained. As the sag obtained is 50% because of balanced fault then the DVR calculates the decrease of voltage from the nominal value and operates for that particular time sag obtained. By using this open UPQC the reduction in voltage is compensated and the load voltage is maintained.

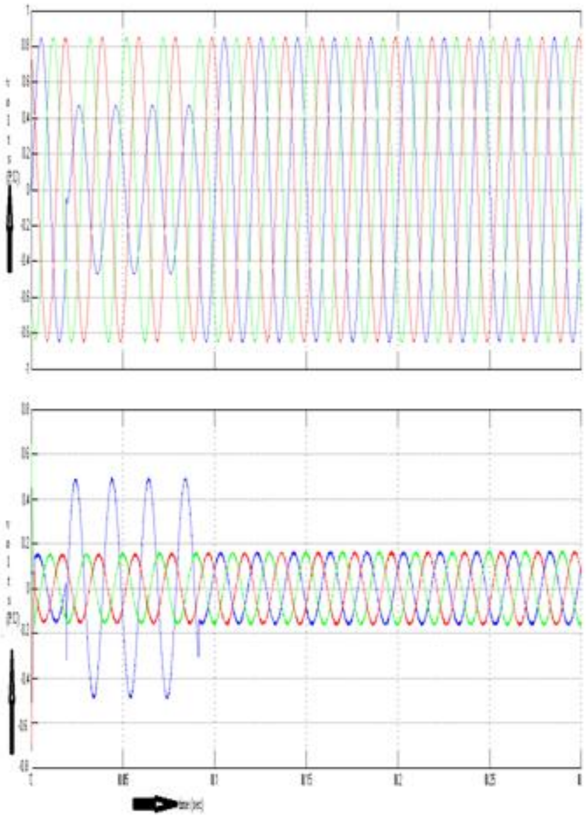


Fig 3.2 Mitigation of balanced sag using open UPQC

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Case (ii):

Fig 3.3 shows unbalanced fault occurred in the distribution system for a instant time 0.019 to 0.085 sec. The unbalanced sag gets compensated by injecting the voltage through injection transformer. The instant time the fault occurred in system with a fault resistance of 4.6 ohms, sag will be obtained for this system. The series unit injects voltage for that particular time sag obtained by calculating the decrease of voltage from the nominal value and operates for that particular time.

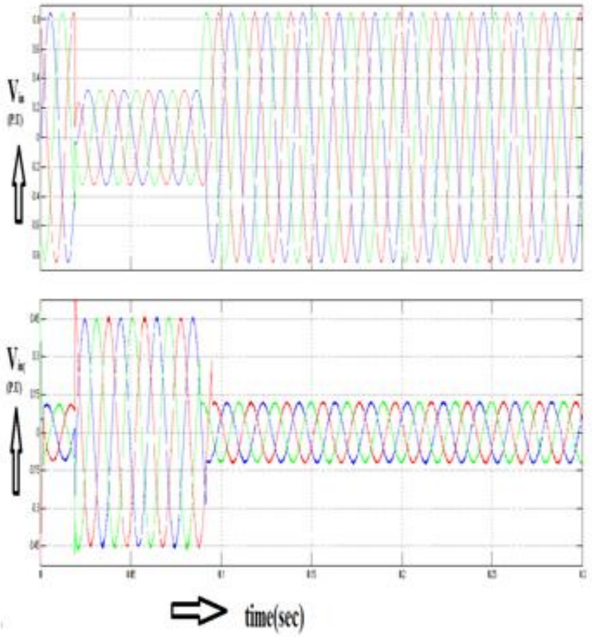


Fig 3.3 Mitigation of unbalanced sag using open UPQC

Case (iii):

Fig 6.4 shows the compensating harmonics that are generated because the usage of non linear loads. The compensating of harmonics is done by injecting the current harmonics which are equal in magnitude but oppose in direction to that of current harmonics that are in non linear loads using shunt active power filter. So, these harmonics cancel each other and result in sinusoidal line currents and improvement in power factor. The THD of the system is reduced to 3.91% using hysteresis current control pulse generator from 17.71%.

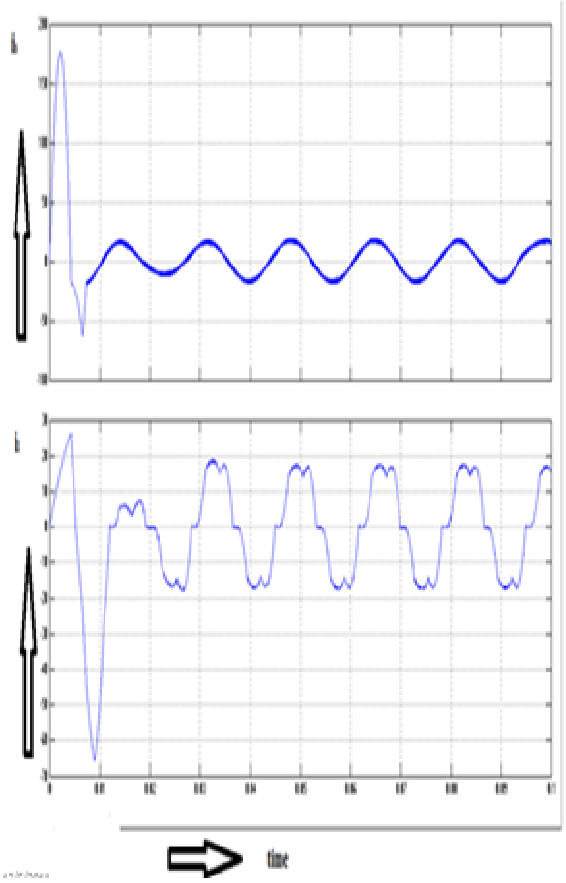
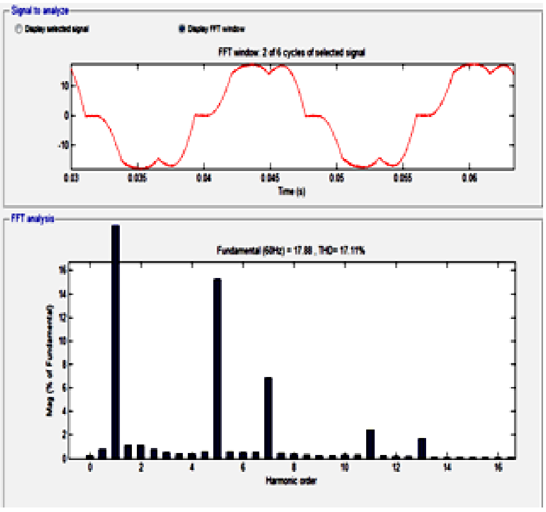
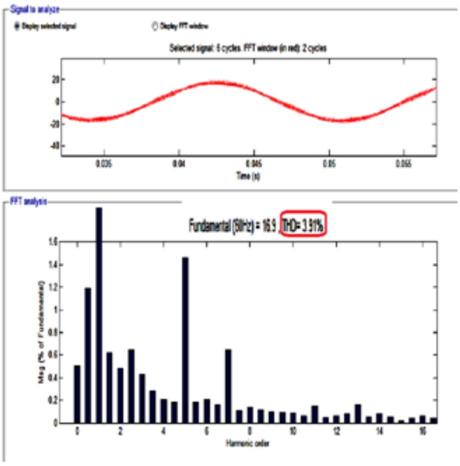


Fig 3.4 Mitigation of harmonics at source side using open UPQC

Before using this open UPQC the harmonics in the system due to non linear load (rectifier) is 17.71%.



So, here used open UPQC to reduce the harmonics in the system at power source side. The shunt unit (D-STATCOM) of open UPQC conducts to compensate these current harmonics present in the system as they cause damage to the equipment. The harmonics gets reduced and the THD is reduced to 3.91% when the controlling is done using hysteresis current control technique.



The below fig 6.5 shows the simulink model of series active power filter which compensates the distortion in voltage from its nominal value to maintain the power quality using series injection transformer. Here it compensates the voltage in a fault system to its nominal value using a pulse width modulation technique.

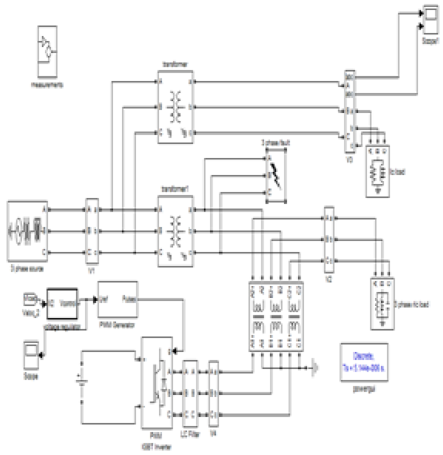


Fig 3.5 Simulink model of series active power filter (DVR)

The below fig 3.6 shows the simulink model of the shunt active power filter which compensates the current quality problems. It compensates the harmonics generated by a rectifier bridge fed load by injecting current harmonics but oppose in direction. These harmonics will cancel and results in sinusoidal line currents and improvement in power factor. Here used the hysteresis control for the pulses generation, this reduces the THD to 3.91% from 17.7%.

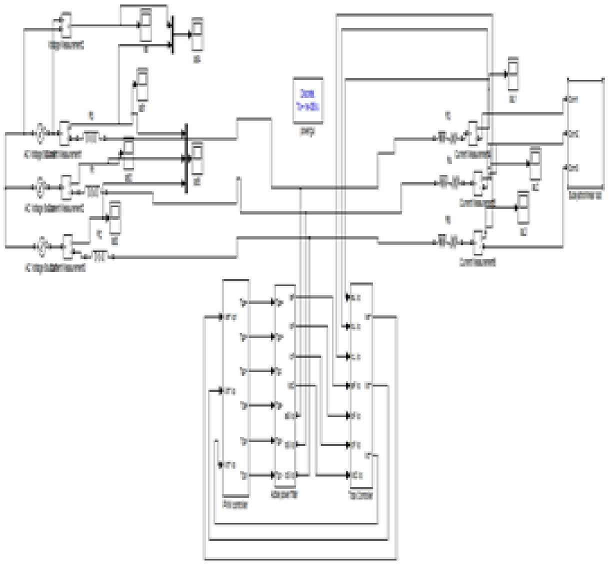


Fig 3.6 Simulink model of shunt active power filter (D-STATCOM)

IV. Conclusion

Custom power devices like DVR, D-STATCOM, UPQC and open UPQC can enhance power quality in the distribution system. Based on the power quality problems at the load or at the distribution system, there is a choice to choose particular custom power device with specific compensation. Open UPQC is the combination of series and shunt APF, which mitigates voltage and current quality problems in the distribution system to maintain power quality. The open UPQC considered in this project is a malfunction power conditioner which can be used to compensate for various voltage disturbances of the power supply, to correct any voltage fluctuation and to prevent the harmonic load current from entering the power system.

The control techniques used are hysteresis and pulse width modulation for shunt and series units respectively to maintain power quality standards in a distribution system. A first PWM controlled harmonic reference based technique is presented with some exclusive features as given below, when compared to previous conventional methods. (a) The reference frame transformation and a digital low pass filter are used to compute the harmonics of the nonlinear load current.(b) The voltage decouplers and pole-zero cancellation method are used in the current controllers of the active power filter to provide fast current harmonic compensation and simplify the control scheme.(c) The delay times of both current response of an active power filter and DC-link voltage feedback are considered. This results in decreasing the settling time of the DC-link voltage and reducing the high frequency current harmonic components of the power system From simulation it is found that the Total Harmonic Distortion (THD) of power source is not in the standard IEEE limits when used pulse width modulation for shunt compensation. Hence this dissertation tried to reduce this THD by using hysteresis controller to 3.91% from 17.11%. Proposed model has been simulated in MATLAB. The simulation results show that the voltage sag and current harmonics caused by non linear load can be compensated effectively by the proposed control strategy.

V. References

[1] Morris Brenna, Roberto Faranda and Enrico Tironi,"A New Proposal for Power Quality and Custom Power Improvement: OPEN UPQC" IEEE transactions on power delivery, vol. 24, no. 4, october 2009

[2] Ahmet Teke, Mehmet Tumay, "Unified Power Quality Conditioner : A Literature Survey", Journal of Electrical Systems,2011,vol.2,no.4,**p**p.122-130

[3] H.-H.Kuo, S.-N.Yeh and J.-C.Hwang, "Novel analytical model for design and implementation of three-phase active power filter controller"

[4] Bimal.K, "An Adaptive Hysteresis-Band Current Control Technique of a Voltage Fed PWM inverter for Machine Drive System", IEEE transaction on Industrial Electronics, vol.37, no. 5, October 1990

[5] F. Blaabjerg, M. Newman, H. Nielsen, and J. G. Nielsen, "Control and testing of a dynamic voltage restorer (DVR) at medium voltage level," IEEE Trans. Power Electron., vol. 19, no. 3, pp. 806–813, May 2004**.**