



ROLE OF PI AND FUZZY CONTROLLERS IN UNIFIED POWER QUALITY CONDITIONER

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ABSTRACT

Any electrical power system consists of wide range of electrical, electronic and power electronic equipment in commercial and industrial applications. Since most of the electronic equipment is nonlinear in nature these will induce harmonics in the system, which affect the sensitive loads to be fed from the system. One among the many compensating devices is Unified Power Quality Conditioner (UPQC) which specifically aims at the integration of series-active and shunt-active power filters to mitigate any type of voltage and current fluctuations and power factor correction in a power distribution network, such that improved power quality can be made available at the point of common coupling. The present work discusses the compensation principle and different control strategies (PI, FUZZY) of the UPQC in detail. The control strategies are modeled using MATLAB/SIMULINK. The performance of UPQC is examined by considering, a thyristor rectifier feeding an RL load (non linear load) that acts as a source of harmonics, to the system of concern. The performance is also observed under influence of utility side disturbances such as sag, swell, flicker and spikes. The simulation results are listed in comparison of different control strategies and for the verification of results.

Keywords: power quality, conditioner, harmonics, voltage sags, swells.

I. INTRODUCTION

The applications of power semiconductor devices are being widely used in various areas, such as large thyristor power converters, rectifiers, and arc furnaces. Complications related to the use of the non-linear loads in these systems are major issues for both power providers and users alike. Consequently, utility power system reliability and power quality has moved to the forefront. As customers increasingly use process and computer equipment, which are highly sensitive to power system interruptions, utilities are being, forced to serve these loads with transmission and distribution systems that are at our exceeding capacity.

The quality of the power is effected by many factors like harmonic contamination, due to the increment of non-linear loads, such as large thyristor power converters, rectifiers, voltage and current flickering due to arc in arc furnaces, sag and swell due to the switching (on and off) of the loads etc. These problems are partially solved with the help of LC passive filters. However, this kind of filter cannot solve random variations in the load current waveform and voltage waveform. Active filters can resolve this problem, however the cost of active filters is high, and they are difficult to implement in large scale. Additionally, they also present lower efficiency than shunt passive filters [1]. One of the many solutions is the use of a combined system of shunt and series active filters like Unified Power Quality Conditioner which aims at achieving low cost and highly effective control.

Voltage sag is one of the prime factors due to which particularly production industries suffer huge loss.

This is evident from many power quality survey reports [2]. Most of these voltage sensitive critical loads are non-linear in nature due to application of fast acting semiconductor switches and their specific control strategy whose presence in a system pose some major concerns as they affect the distribution utility in some highly undesirable ways.

The aim of the paper is to design different control strategies for Unified Power Quality Conditioner (UPQC), which is one of the major custom power solutions capable of mitigating the effect of supply voltage sag, swell, flicker and spikes at the load end or at the Point of Common Coupling (PCC). It also prevents load current harmonics from entering the utility and corrects the input power factor of the load. The control strategies used here are based on PI Controller, Fuzzy Controller and Artificial Neural Network Controller. The relative performance of the three controls is also studied.

II. UNIFIED POWER QUALITY CONDITIONER

The basic circuit of UPQC, (Figure-1) [3] consists of two back to back connected IGBT based voltage source bi-directional converters with a common dc bus. One inverter is connected in series, while the other one is placed in shunt with the nonlinear load. The inverter connected in shunt with the load acts as a current source for injecting compensating current, i_c . While, the supply side inverter connected in series with the load acts as a voltage source feeding compensating voltage, v_c through an insertion transformer. A thyristor bridge rectifier feeding R-L load is considered as nonlinear load.

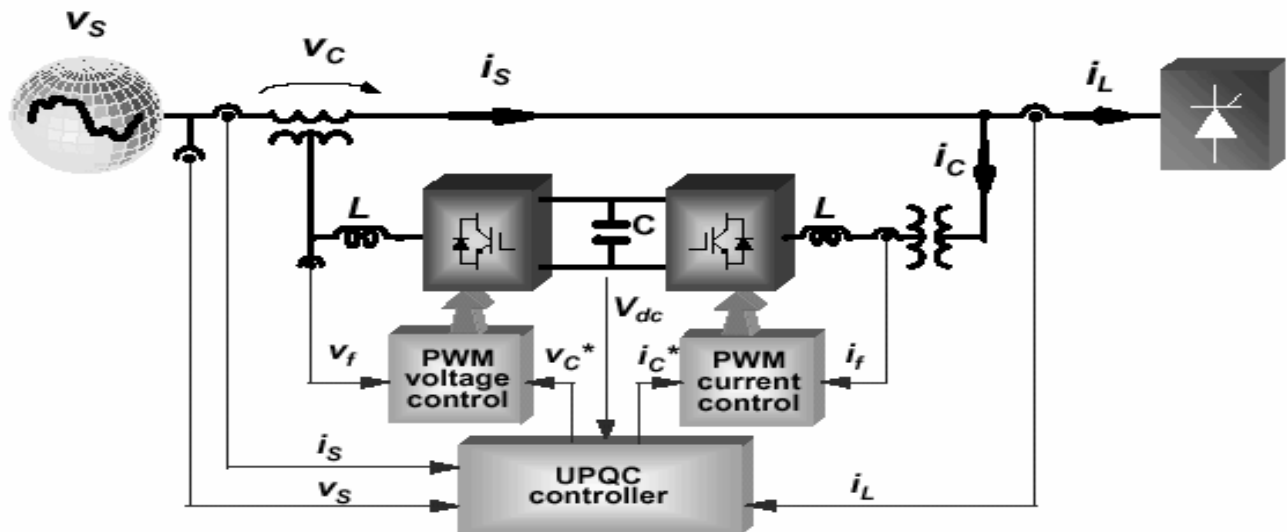


Fig. 1. General configuration of the Unified Power Quality Conditioner — UPQC.

Component design considerations

Active filtering system

The philosophy of active filtering system addresses the load current distortion from a time domain rather than a frequency domain approach. The most effective way to import the distortive power factor in a non-sinusoidal situation is to use a nonlinear active device that directly compensates for the load current distortion. The performance of these active filters is based on three basic design criteria. They are:

- Design of power inverter (semiconductor switches, inductances, capacitors, dc voltage);
- PWM control method (hysteresis, triangular carrier, periodical sampling); and
- Method used to obtain the current reference or the control strategy used to generate the reference template.

Design of power inverters

Inverters: Both series voltage control and shunt current control involve use of voltage source converters. Both these inverters each consisting of six IGBTs with a parallel diode connected in reverse with each IGBT are operated in current control mode employing PWM control technique [4].

Capacitor: Capacitor is used as an interface between the two back to back connected inverters and the voltage across it acts as the dc voltage source driving the inverters.

III. CONTROL STRATEGY FOR UPQC

Shunt control strategies:

Shunt control strategy involves not only generating reference current to compensate the harmonic currents but also charging the capacitor to the required value to drive the inverters [5].

PI control

With a view to have a self regulated dc bus, the voltage across the capacitor is sensed at regular intervals and controlled by employing a suitable closed loop control. The dc link voltage, v_{dc} is sensed at a regular interval and is compared with its reference counterpart v_{dc}^* . The error signal is processed in a PI controller. The output of the PI controller is denoted as $i_{sp(n)}$. A limit is put on the output of controller this ensures that the source supplies active power of the load and dc bus of the UPQC. Later part of active power supplied by source is used to provide a self supported dc link of the UPQC. Thus, the dc bus voltage of the UPQC is maintained to have a proper current control.

Fuzzy PI control

The Fuzzy control is basically a nonlinear and adaptive in nature, giving the robust performance in the cases where in the effects of parameter variation of controller is present. It is claimed that the Fuzzy logic controller yields [6, 7] the results which are superior to those obtained with the conventional controllers such as PI, PID etc. In the Fuzzy PI controller, the simplicity of a PI controller is combined with the intelligent and adaptive ness of the fuzzy logic based control system.



E1 \ E2	NVL	NL	NM	NS	Z	PS	PM	PL	PVL
NVL	Z	NS	NM	NL	NVL	NV L	NVL	NVL	NV L
NL	PS	Z	NS	NM	NL	NL	NVL	NVL	NV L
NM	PM	PS	Z	NS	NM	NL	NL	NVL	NV L
NS	PL	PM	PS	Z	NS	NM	NL	NL	NV L
Z	PVL	PL	PM	PS	Z	NS	NM	NM	NL
PS	PVL	PL	PL	PM	PS	Z	NS	NM	NM
PM	PVL	PVL	PL	PM	PM	PS	Z	NS	NM
PL	PVL	PVL	PVL	PL	PL	PM	PS	Z	NS
PVL	PVL	PVL	PVL	PVL	PVL	PL	PM	PS	Z

Figure-2. Set of fuzzy rule representation for FPI.

Inputs to the fuzzy PI controller are categorized as various linguistic variables with their corresponding membership values as shown in the Table. Depending upon the range (very large, large, medium, small and Zero) and the sign (positive or negative) of the error signals E1 and E2, the FPI searches the corresponding output from the linguistic codes given in the Table [5].

Generating compensating currents

Direct method: The output, i_{sp} is considered as magnitude of three phase reference currents. Three phase unit current vectors (u_{sa} , u_{sb} and u_{sc}) are derived in phase with the three phase supply voltages (v_{sa} , v_{sb} and v_{sc}). These unit current vectors (u_{sa} , u_{sb} and u_{sc}) form the phases of three phase reference currents. Multiplication of magnitude I_{sp} with phases (u_{sa} , u_{sb} and u_{sc}) results in the three-phase reference supply currents (i_{sa}^* , i_{sb}^* and i_{sc}^*). Subtraction of load currents (i_{la} , i_{lb} and i_{lc}) from the reference supply currents (i_{sa}^* , i_{sb}^* and i_{sc}^*) results in three phase reference currents (i_{sha}^* , i_{shb}^* and i_{shc}^*) for the shunt inverter.

These reference currents i_{ref} (i_{sha}^* , i_{shb}^* and i_{shc}^*) are compared with actual shunt compensating currents i_{act} (i_{sha} , i_{shb} and i_{shc}) and the error signals are then converted into (or processed to give) switching pulses using PWM technique which are further used to drive shunt inverter. In response to the PWM gating signals the shunt inverter supplies harmonic currents required by load. In addition to this it also supplies the reactive power demand of the load. In effect, the shunt bi-directional converter that is connected through an inductor in parallel with the load terminals accomplishes three functions simultaneously. It injects reactive current to compensate current harmonics of the load. It provides reactive power for the load and thereby improve power factor of the system. It also draws the fundamental current to compensate the power loss of

the system and maintains the voltage of DC capacitor constant.

Series control

The series inverter, which is also operated in current control mode, isolates the load from the supply by introducing a voltage source in between. This voltage source compensates supply voltage deviations such as sag, swell, flicker and spikes. In closed loop control scheme of the series inverter, the three phase load voltage (v_{la} , v_{lb} and v_{lc}) are subtracted from the three phase supply voltage (v_{sa} , v_{sb} and v_{sc}), and are also compared with reference supply voltage which results in three phase reference voltages (v_{la}^* , v_{lb}^* and v_{lc}^*). These reference voltages are to be injected in series with the load. By taking recourse to a suitable transformation, the three phase reference currents (i_{sea}^* , i_{seb}^* and i_{sec}^*) of the series inverter are obtained from the three phase reference voltages (v_{la}^* , v_{lb}^* and v_{lc}^*). These reference currents (i_{sea}^* , i_{seb}^* and i_{sec}^*) are fed to a PWM current controller along with their sensed counterparts (i_{sea} , i_{seb} and i_{sec}). The gating signals obtained from PWM current controller ensure that the series inverter meets the demand of voltage sag and swell, flicker etc. Thereby providing sinusoidal voltage to load. Thus series inverter plays an important role to increase the reliability of quality of supply voltage at the load, by injecting suitable voltage with the supply, whenever the supply voltage undergoes sag. The series inverter acts as a load to the common dc link between the two inverters. When sag occurs series inverter exhausts the energy of the dc link. Thus, UPQC, unlike Dynamic Voltage Restorer, does not need any external storage device or additional converter (diode bridge rectifier) to supply the dc link voltage.



IV. MODEL EQUATIONS OF THE UPQC

Computation of control quantities of shunt inverter

The amplitude of the supply voltage is computed from the three phase sensed values as:

$$V_{sm} = [2/3(V_{sa}^2 + V_{sb}^2 + V_{sc}^2)]^{1/2}$$

The three phase unit current vectors are computed as:

$$u_{sa} = V_{sa}/V_{sm}; \quad u_{sb} = V_{sb}/V_{sm}; \quad u_{sc} = V_{sc}/V_{sm}; \quad (2)$$

Multiplication of three phase unit current vectors (u_{sa} , u_{sb} and u_{sc}) with the amplitude of the supply current (i_{sp}) results in the three-phase reference supply currents as:

$$i_{sa}^* = i_{sp} \cdot u_{sa}; \quad i_{sb}^* = i_{sp} \cdot u_{sb}; \quad i_{sc}^* = i_{sp} \cdot u_{sc}; \quad (3)$$

To obtain reference currents, three phase load currents are subtracted from three phase reference supply currents:

$$\begin{aligned} i_{sha}^* &= i_{sa}^* - i_{la}; & i_{shb}^* &= i_{sb}^* - i_{lb}; \\ i_{shc}^* &= i_{sc}^* - i_{lc}; \end{aligned} \quad (4)$$

These are the i_{ref} for Direct current control technique of shunt inverter. The i_{ref} are compared with i_{act} in PWM current controller to obtain the switching signals for the devices used in the shunt inverter.

Computation of control quantities of series inverter

The supply voltage and load voltage are sensed and there from, the desired injected voltage is computed as follows:

$$V_{inj} = V_s - V_l \quad (5)$$

The magnitude of the injected voltage is expressed as:

$$V_{inj} = |V_{inj}| \quad (6)$$

Whereas, the phase of injected voltage is given as:

$$\delta_{inj} = \tan(\text{Re}[V_{pq}]/\text{Im}[V_{pq}]) \quad (7)$$

for the purpose of compensation of harmonics in load voltage, the following inequalities are followed:

$$\begin{aligned} V_{inj} &< V_{injmax} \quad \text{magnitude control;} \\ 0 &< \delta_{inj} < 360^\circ \quad \text{phase control;} \end{aligned}$$

Three phase reference values of the injected voltages are expressed as:

$$\begin{aligned} V_{la}^* &= \sqrt{2}V_{inj}\sin(\omega t + \delta_{inj}) \\ V_{lb}^* &= \sqrt{2}V_{inj}\sin(\omega t + 2\pi/3 + \delta_{inj}) \\ V_{lc}^* &= \sqrt{2}V_{inj}\sin(\omega t - 2\pi/3 + \delta_{inj}) \end{aligned} \quad (8)$$

The three phase reference currents (i_{ref}) of the series inverter are computed as follows:

$$\begin{aligned} i_{sea}^* &= V_{la}^*/Z_{se}; \\ i_{seb}^* &= V_{lb}^*/Z_{se}; \\ i_{sec}^* &= V_{lc}^*/Z_{se}; \end{aligned} \quad (9)$$

The impedance Z_{se} includes the impedance of insertion transformer.

The currents (i_{sea}^* , i_{seb}^* and i_{sec}^*) are ideal current to be maintained through the secondary winding of insertion transformer in order to inject voltages (V_{la} , V_{lb} and V_{lc}), thereby accomplishing the desired task of compensation of the voltage sag. The currents i_{ref} (i_{sea}^* , i_{seb}^* and i_{sec}^*) are compared with i_{act} (i_{sea} , i_{seb} and i_{sec}) in PWM current controller, as a result six switching signals are obtained for the IGBTs of the series inverter.

V. CASE STUDY

For the purpose of analyzing the performance of UPQC designed using the control strategies discussed above, an experimental setup is considered:

A three phase supply of 230v, 60Hz is considered to be feeding a thyristor rectifier fed RL Load (non-linear load) with a rating of 2KVA. Source impedance is considered almost negligible with R_s and L_s values being 0.1ohms and 0.1mH respectively. Both series and shunt inverters are modeled using universal bridges with IGBT/diodes.

The values of shunt elements, interfacing shunt inverter and the system are:

$$R_{sh} = 1 \text{ ohm}, L_{sh} = 30 \text{ mH}, C_{sh} = 700\mu\text{f}.$$

The values of series elements, interfacing series inverter with the system are:

$$R_{se} = 0.1 \text{ ohm}, L_{se} = 12 \text{ mH}.$$

The values of the shunt passive filter are:

$$R_{psh} = 3 \text{ ohm}, L_{psh} = 15 \text{ mH}.$$

The values of proportional and integral constants of the PI controller are taken to be 0.5 and 500 respectively. The value of the capacitor providing dc link voltage is 700μf.

Flicker and spikes are injected using three phase voltage sources.

VI. SIMULATION RESULTS AND DISCUSSION

UPQC with PI controller

Case(i): Compensating load current harmonics using direct current control technique

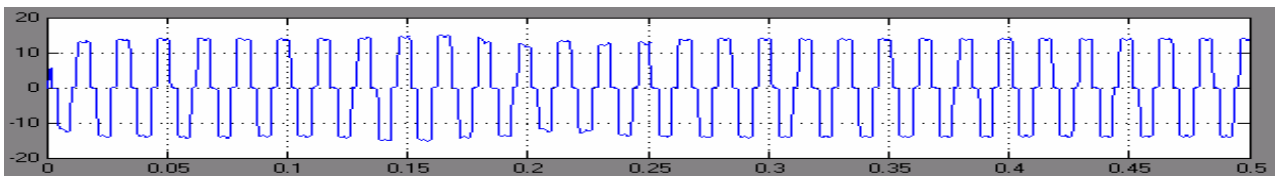
An ideal three-phase sinusoidal supply voltage of 230v, 60Hz is applied to the non-linear load (thyristor rectifier feeding an RL load) injecting current harmonics into the system. Plot-1(b) shows supply current in phase C before compensation.

UPQC with direct current control scheme for shunt inverter is able to reduce the harmonics from entering into the system. The THD (Total Harmonic Content) in load current (Plot-1(a)) is found to be 27%. The source current THD, which was, also 27% before compensation was effectively reduced to 10.53 % after compensation as can be seen from Plot-1(c).

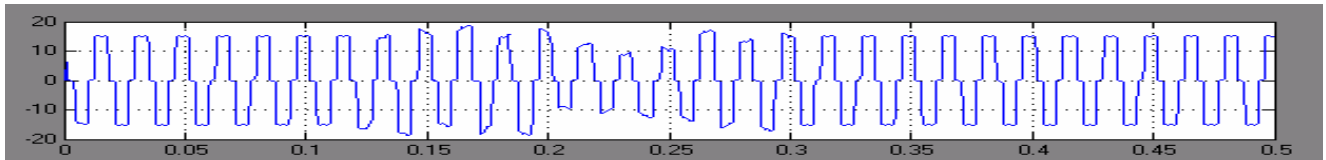
The compensating shunt currents (Plot-1(d)) generated contain harmonic content of the load current but with opposite polarity such that when they are injected at the point of common coupling the harmonic content of supply current is effectively reduced. Plot-1(e), is the dc link voltage (voltage across the dc capacitor) that feeds both the shunt and series inverters. The capacitor is effectively charged to the reference voltage, V_{dc} drawing the charging current from the supply. Once it is charged to required value, it is held constant using PI controller. There is no drop in the capacitor voltage when it feeds shunt inverter, because shunt inverter draws only reactive power to compensate the load current harmonics. The load current before compensation on the D.C side of the



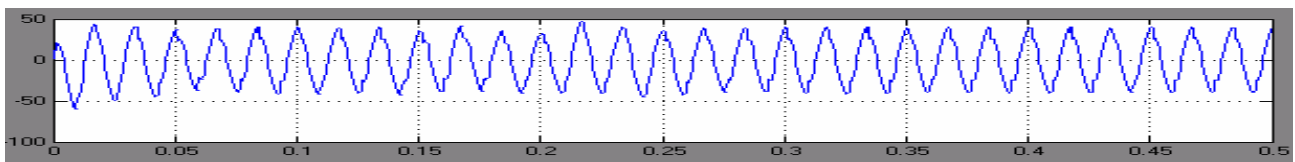
inverter is shown in plot-1(f). The load current after compensation using UPQC is also shown in plot-1(g).



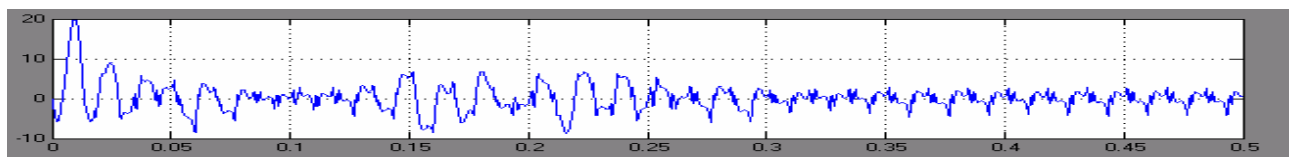
Plot-1(a). Load current at the inverter terminals without UPQC.



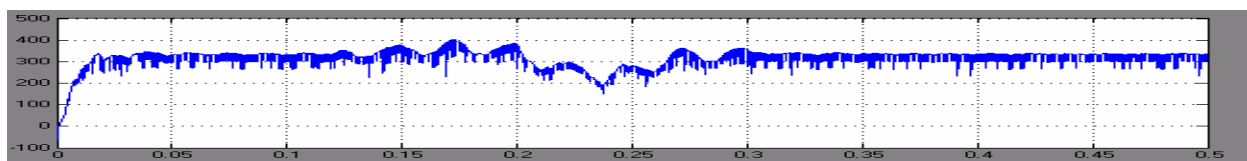
Plot-1(b). Line current without UPQC.



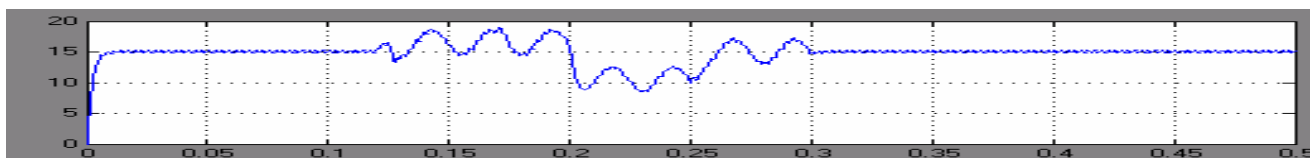
Plot-1(c). Line current with UPQC (using PI).



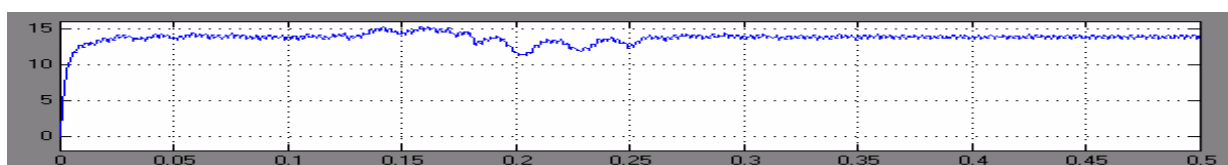
Plot-1(d). Shunt compensating current produced by the shunt inverter.



Plot-1(e). Vdc maintained by the shunt inverter.



Plot-1(f). D.C load current without UPQC.



Plot-1(g). Load current with UPQC (i.e. d.c side of the thyristor).

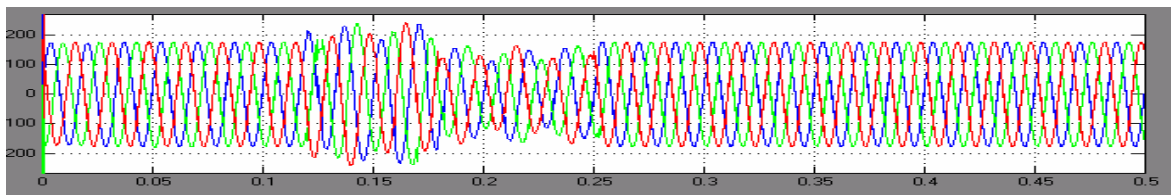


Case(ii) : UPQC-mitigating the effect of both voltage sag, swell of 20%, flicker of 10% and spikes of 15% using series voltage control

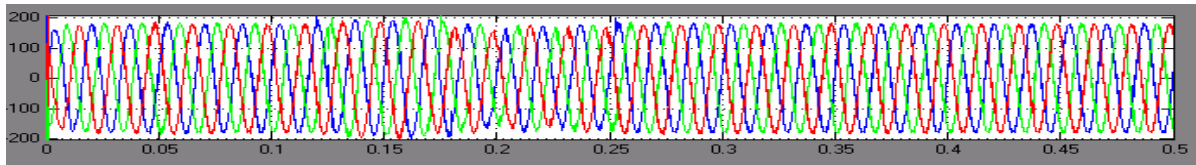
A three-phase supply voltage (230V, 60Hz) is imposed with voltage sag and swell of 20% is applied to the non-linear load (thyristor rectifier feeding an RL load). Apart from that a flicker component with a magnitude of 10% of the fundamental component and a spike component with 15% of fundamental component are also imposed to study the realistic situation where there is chance of the simultaneous existence of one or more of them. Plot-2(a) shows the supply voltage with the above disturbances imposed.

UPQC with its series voltage control detects and calculates the required voltage to be injected in series with the line to compensate both the dip and swell in the supply voltage. In effect, series inverter in combination with the insertion transformer produces the series injected voltage as calculated to mitigate the effects of the fluctuations of supply voltage by drawing the required power from the dc link.

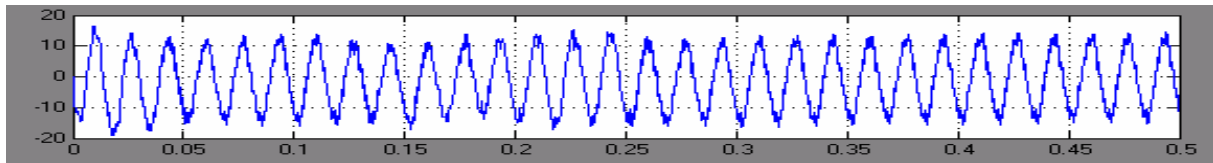
Plot-2(b) shows the compensated supply voltage that is supplied to the load where a swell and sag of 40% is compensated with in a margin of (+/-) 10 %.



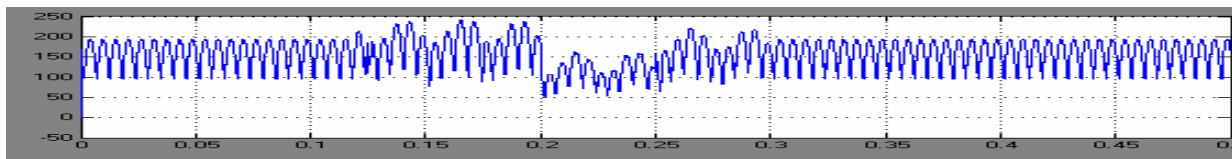
Plot-2(a). Supply voltage without UPQC.



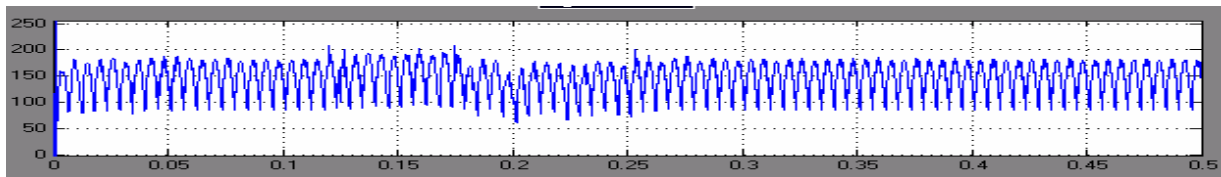
Plot-2(b). Supply voltage with UPQC (PI).



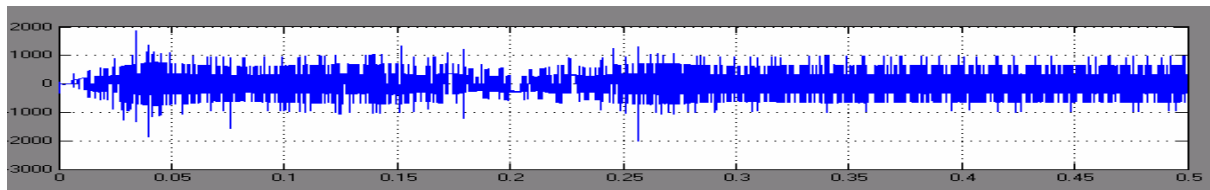
Plot-2(c). Compensating current produced by series inverter.



Plot-2(d). D.C voltage across the load terminals without UPQC.



Plot-2(e). D.C voltage across the load terminals with UPQC.



Plot-2(f). Line to line series compensating voltage (by series inverter).

Plot-2(e) shows the dc link voltage which more or less reflects the disturbance in the supply voltage. Soon after, as can be seen from the plot, the capacitor voltage (dc link voltage) tries to come back to the reference value, v_{dc} after compensation. Plot-2(c) shows the series compensating current required to generate the series compensation voltage, which is 180° out of phase with supply voltage in case of sag compensation and in phase with supply voltage in case of swell.

Plot-2(d) shows the D.C voltage on the load side of the thyristor bridge which acts as a nonlinear load, before compensation (i.e. with out UPQC). Plot-2(e) shows the same after compensation. Plot 2(f) shows the line-to-line compensating voltage generated by series inverter.

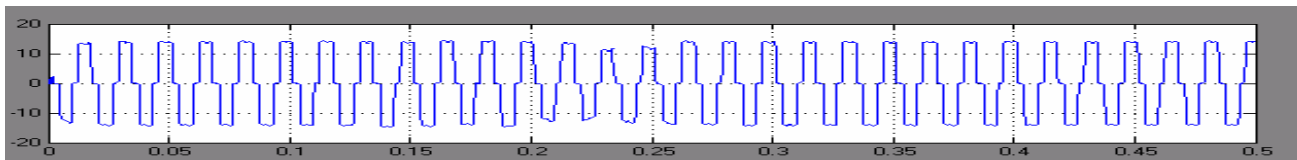
UPQC with FUZZY controller

Case(i): Compensating load current harmonics using direct current control technique

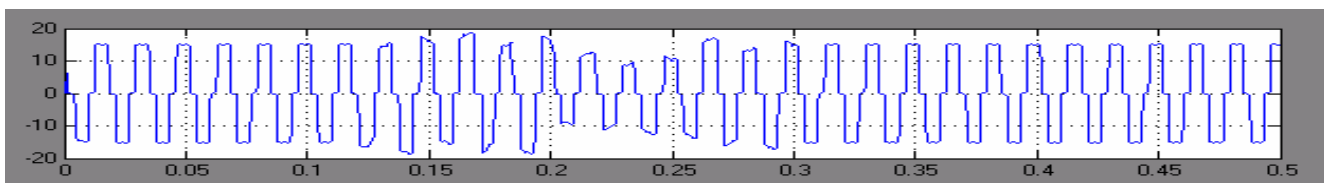
An ideal three-phase sinusoidal supply voltage of 230v, 60Hz is applied(as in case of PI)to the non-linear load (thyristor rectifier feeding an RL load) injecting current harmonics into the system. Plot-3(b) shows supply current in phase C before compensation.

UPQC with direct current control scheme for shunt inverter is able to reduce the harmonics from entering into the system. The THD (Total Harmonic Content) in load current (Plot-3(a)) is found to be 27%. The source current THD, which was, also 27% before compensation was effectively reduced to 10.84 % after compensation as can be seen from Plot-3(c).

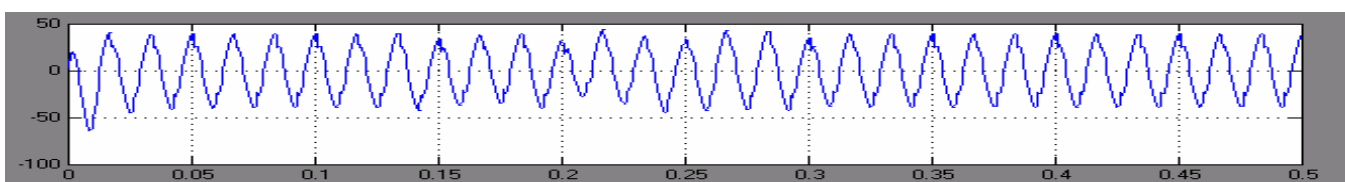
The compensating shunt currents (Plot-3(d)) generated contain harmonic content of the load current but with opposite polarity such that when they are injected at the point of common coupling the harmonic content of supply current is effectively reduced. Plot-3(e), is the dc link voltage (voltage across the dc capacitor) that feeds both the shunt and series inverters. The capacitor is effectively charged to the reference voltage, v_{dc} drawing the charging current from the supply. Once it is charged to required value, it is held constant using Fuzzy-PI controller. There is no drop in the capacitor voltage when it feeds shunt inverter, because shunt inverter draws only reactive power to compensate the load current harmonics. The load current before compensation on the D.C side of the inverter is shown in plot-3(f). The load current after compensation using UPQC is also shown in plot-3(g).



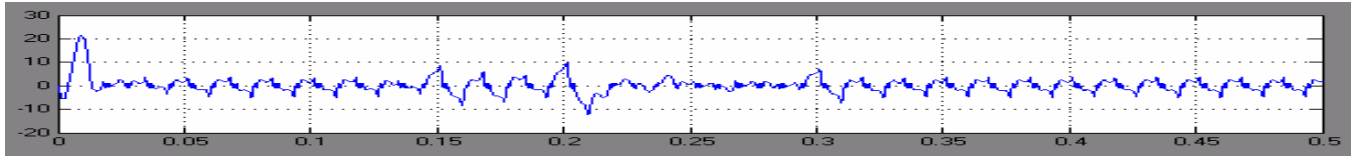
Plot-3(a). Load current at the inverter terminals.



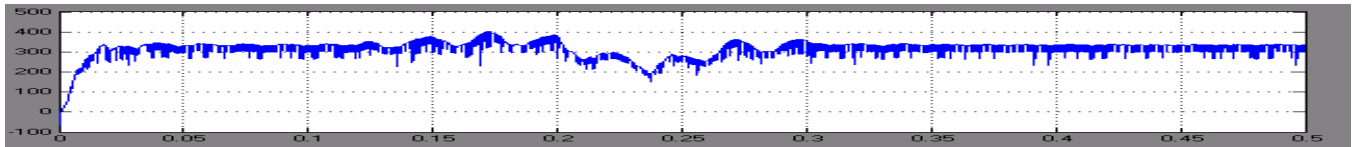
Plot-3(b). Line current without UPQC.



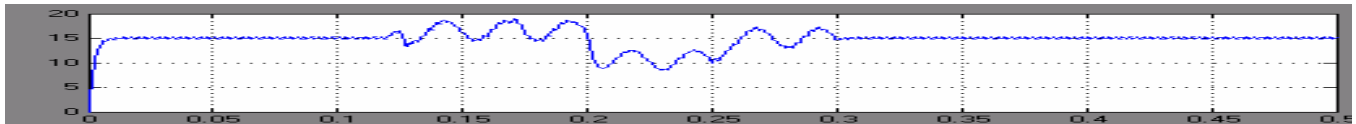
Plot-3(c). Line current with UPQC (Fuzzy-PI).



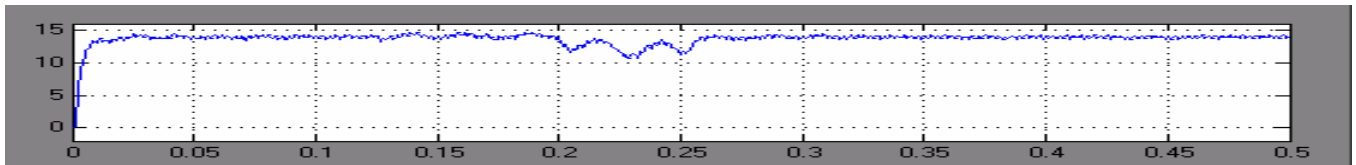
Plot-3(d). Shunt compensating current produced by the shunt inverter.



Plot-3(e). Vdc maintained by the shunt inverter.



Plot-3(f). D.C load current without UPQC.



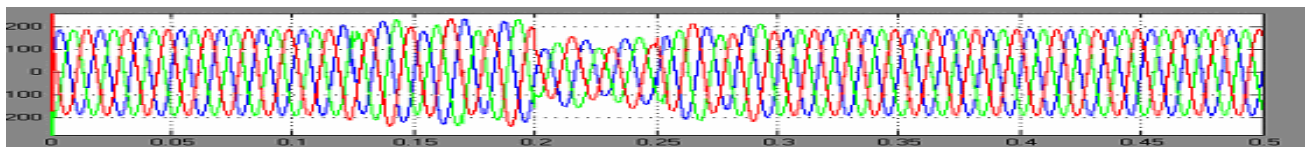
Plot-3(g). load current (i.e. d.c side of the thyristor) with UPQC.

Case(ii): UPQC-mitigating the effect of both voltage sag, swell of 20%, flicker of 10% and spikes of 15% using series voltage control

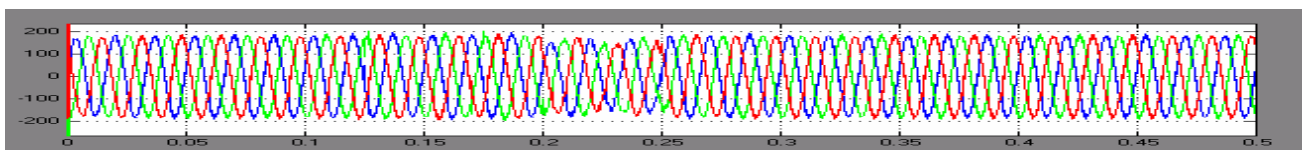
A three-phase supply voltage (230V, 60Hz) is imposed with voltage sag and swell of 20% is applied to the non-linear load (thyristor rectifier feeding an RL load). Along with that a flicker component with a magnitude of 10% of the fundamental component and a spike component with 15% of fundamental component are also imposed to study the realistic situation where there is chance of the simultaneous existence of one or more of them. Plot-4(a) shows the supply voltage with the above disturbances imposed.

UPQC with its series voltage control detects and calculates the required voltage to be injected in series with the line to compensate both the dip and swell in the supply voltage. In effect, series inverter in combination with the insertion transformer produces the series injected voltage as calculated to mitigate the effects of the fluctuations of supply voltage by drawing the required power from the dc link.

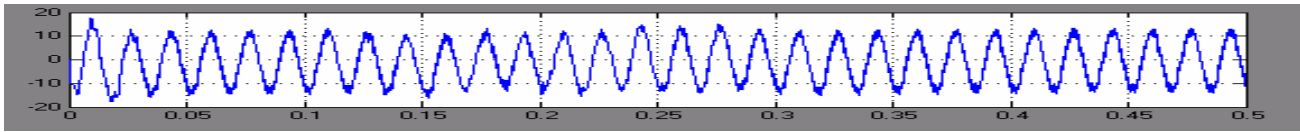
Plot-4(b) shows the compensated supply voltage that is supplied to the load where a swell and sag of 40% is compensated with in a margin of (+/-) 10%.



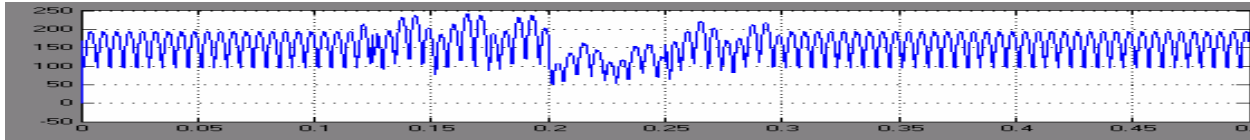
Plot-4(a). Supply voltage without UPQC.



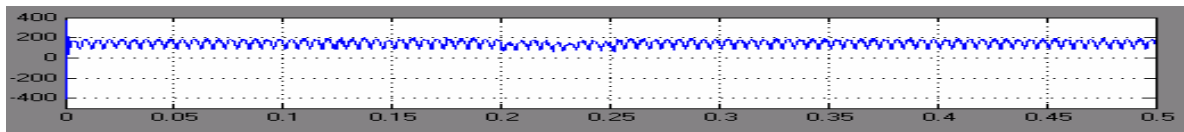
Plot-4(b). Supply voltage with UPQC (Fuzzy-PI).



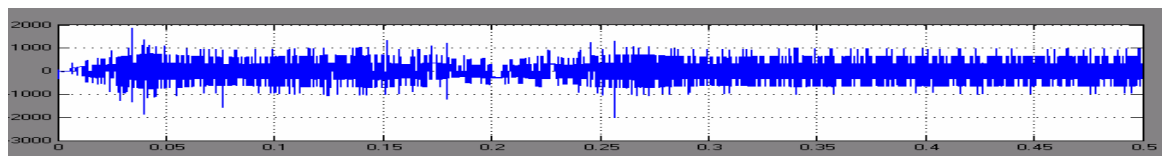
Plot-4(c). Compensating current produced by series inverter.



Plot-4(d). D.C voltage across the load terminals without UPQC.



Plot-4(e). D.C voltage across the load terminals with UPQC.



Plot-4(f). Line to line series compensating voltage (by series inverter).

Plot-4(e) shows the dc link voltage which more or less reflects the disturbance in the supply voltage. Soon after, as can be seen from the plot, the capacitor voltage (dc link voltage) tries to come back to the reference value, v_{dc} after compensation. Plot-4(c) shows the series compensating current required to generate the series compensation voltage, which is 180° out of phase with

supply voltage in case of sag compensation and in phase with supply voltage in case of swell

Plot 4(d) shows the D.C voltage on the load side of the thyristor bridge which acts as a nonlinear load, before compensation (i.e. with out UPQC). Plot-4(e) shows the same after compensation. Plot 4(f) shows the line-to-line compensating voltage generated by series inverter.

Table-1. Comparison of three different controllers used for UPQC.

	Factor	PI Controller	Fuzzy Controller
1	Utility side THD	5.361%	4.45%
2	Line current THD with UPQC	10.53%	10.84%
3	Multi mode oscillations in voltage waveform	Observed	Not observed
4	Charging of DC link	Slower	Faster
5	Time taken for capacitor voltage to reach first over shoot	0.043sec	0.0195 sec
6	Sag, Swell, flicker and spikes in supply voltage are eliminated.	Eliminated	Eliminated

CONCLUSIONS

The closed loop control schemes of Direct Current control, for the proposed UPQC have been described. A suitable mathematical model of the UPQC has been developed with different shunt controllers (PI and FUZZY) and simulated results have been described which establishes the fact that in both the cases the compensation is done but the response of FUZZY controller is faster and the THD is minimum for both the

voltage and current which is evident from the plots and comparison table (Table-1).

The IEEE standards recognize the voltage drop as sag only when the voltage magnitude is some where in between 90% to 10% of the normal magnitude. This consideration is used as basis to explain the slight changes in the magnitude (around 5-10%) when the out put voltage is observed.



In the present work a passive filter is included at the shunt inverter, which helps in mitigating the flicker component in current and to maintain DC link voltage. The draw back of the same is it reduces the voltage magnitude and increases the THD, hence in the work considered the current compensation is not totally free of harmonics with a residual THD of around 10%. It was not totally possible to get down the current THD below 5%, which is the permissible limit according to IEEE standards with out affecting the voltage THD.

The increment in current magnitude is attributed to the consumption of the UPQC and associated passive filters. However no stress has been made with respect to the power factor improvement even though it is one of the salient properties of the UPQC. This is because the issue of power factor (pf) correction forces the calculation of equations which involve higher order differential equations. This not only makes the design of simulation block difficult but also increases the memory of the simulation file which has direct effect on the speed of operation which cannot be solved with a given PC configuration.

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LIST OF SYMBOLS

$V_{sa}, V_{sb} \text{ \& } V_{sc}$	Three phase source voltages
$i_{sa}, i_{sb} \text{ \& } i_{sc}$	Three phase source currents
V_{dc}	DC link voltage
$V_{la}, V_{lb} \text{ \& } V_{lc}$	Three phase load voltages
$i_{la}, i_{lb} \text{ \& } i_{lc}$	Three phase load currents
$i_{sha}, i_{shb} \text{ \& } i_{shc}$	Three phase shunt compensating currents
$i_{sea}, i_{seb} \text{ \& } i_{sec}$	Three phase series compensating currents
$V_{ia}, V_{ib} \text{ \& } V_{ic}$	Three phase series injected voltages