Comparative Analysis of Mitigating THD with Conventional & Proposed UPQC with non-linear Load Conditions

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**Abstract—*Power Quality (PQ) mainly handles with issues like maintaining a fixed voltage at the Point of Common Coupling (PCC) for various distribution voltage levels heedless of voltage fluctuations, maintaining nearly unity power factor power drawn from the supply. Flexible AC Transmission Systems (FACTS) and Custom Power products like STATCOM, DVR and UPQC handles with the issues related to power quality using similar control strategies and concepts. Unlike DVR and STATCOM, unified power quality conditioner (UPQC) employs the integration of both 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. The unified power quality conditioner (UPQC) is being used as a universal active power conditioning device to mitigate both current and voltage harmonics at a distribution side of power system network. This paper emphasizes the importance of UPQC application for better power quality, by comparing the mitigated voltage and current THD values with a conventionally modelled UPQC and a proposed PI-Resonant controller in mitigating THD'S of voltage and current at the load side in the system*, **

Keywords: Total harmonic distribution (THD)[1], Unified power quality conditioner(UPQC), Distribution static compensator(DSTATCOM), Distribution voltage regulator(DVR), Active power filter (APF)

1.Introduction

The IEEE Standard Dictionary of Electrical and Electronics defines power quality as "the concept of powering and grounding sensitive equipment in a manner that is suitable to the operation of that equipment"[1]. Both electric utilities and end users of electric power are becoming increasingly concerned about the quality of electric power, reasons for the increased concern are Newer-generation load equipment, increasing harmonic levels on power systems, power quality issues and many things are now interconnected in a network. Integrated processes mean that the failure of any component has much more important consequences.

A. PROBLEMS ASSOCIATED WITH POWER QUALITY

a) Piece of equipment misoperates at the same time of day.
b) Automated systems stop for no apparent reason.
c) The advent of new power electronic equipment, such as variable speed drives and switched mode power supplies, has brought new disturbances into the supply system
d)

B. DISTURBANCES

The commonly used terms for mentioning issues Voltage sag, voltage swell, transients, notching, Harmonics, inter harmonics ,interruptions distortions etc

C. NEED FOR POWER QUALITY IMPROVEMENT

(a) Fast voltage variations leading to flicker.
(b) With the restructuring of power systems and with shifting trend towards distributed and dispersed generation, the issue of power quality is going to take newer dimensions in developing countries like India.
(c) Excessive increase in reactive power can lead to unnecessary loading of system.
(d) The deregulation of the electricity industry has led to an increased need for quality indicators. Customers are demanding, and getting, more information on the voltage equality they can expect.[1]

1. CUSTOM POWER DEVICES

Now a days many techniques have been evolved in mitigating PQ issues. Among them usage of passive filters with capacitors and inductors tuned at a particular frequency are quite simple.. Although they are simple in operation, they have limitations such as:

a) These filters are not adaptable for a change in the system conditions.
b) we need to use a passive filter for each and every signal in a multiple harmonic frequency
c) Detuning is a problem if operation conditions change.
d) High chances for occurrence of a resonance condition between transformer reactance and passive filters .

Under these circumstances, in order to improve PQ in the distribution systems Active power filters(APF's) are proposed. Usage of these active filters in distribution networks ranging from 1 KV to 38 KV for monitoring and reducing the power quality issues are known as Custom power devices (CPD's).CPDs include

a) Distribution static compensator (DSTATCOM)
b) Dynamic voltage restorer (DVR)
c) Unified power quality conditioner (UPQC)
d) Solid state transfer switch (SSTS)
e) Solid state fault current limiter (SSFCL)

Among the above mentioned devices UPQC can mitigate harmonics on both voltage and current waveform hence more preferable hence providing a better quality of power.

2. Modeling Of Conventional Upqc

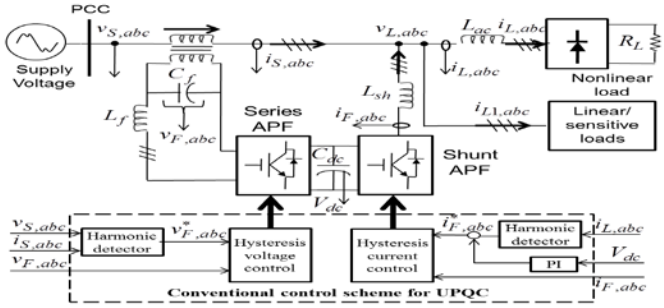

Figure 1 : Basic block diagram of conventional UPQC

UPQC as shown in fig.1 uses two converters that are connected to a common DC link with an energy storage capacitor. The main components that are employed in UPQC are series & shunt power converters, DC capacitors which act as DC supply, low-pass & high-pass passive filters, series & shunt transformers. Series converter employed is a voltage-source converter which is connected in series with the AC line and acts as a voltage source to minimize voltage distortions. It mitigates supply voltage flickers and imbalance from the load terminal voltage. It intimates the shunt branch to absorb current harmonics generated by the distorted load.

We engage shunt active filter to compensate current harmonics and reactive load power. It can compensate negative-sequence current also. The shunt active filter is designed by Voltage source inverter connected to the common DC storage capacitor from the DC side and on to the AC side it is linked in parallel with the load using the shunt inductor (L_{sh}).[8],[9]

Here shunt active filter is used to compensate reactive power of load

By controlling amount of active current took by the shunt active filter from the system, constant voltage is maintained across the DC Link through a PI-controller.

As shown in Fig.1 hysteresis controller is used in control scheme as it is simple and robust in nature. Harmonic content in load current ($I_{L,abc}$) and supply voltage($V_{S,abc}$) are sensed by harmonic detectors. Filter voltage ($V_{F,abc}$) and current ($I_{F,abc}$) are controlled to keep supply voltage and load current sinusoidal .

3. Proposed Model Of Upqc

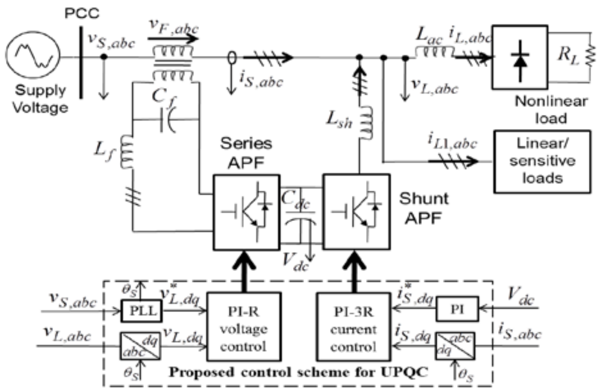

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Figure 2:proposed UPQC control scheme

The main theme of proposed scheme is to eliminate the harmonic detectors by measuring the load voltage and supply current instead of filter voltage and current,there by reducing the sensors count, as only two voltage sensors & one current sensor is neededPresence of switching ripples can affect the operation of hysteresis controller.This problem can be avoided by employing a PI-controller with the help of a resonant controller.In the series APF control scheme, a PI controller with a resonant controller tuned at six multiple of the fundamental frequency of the network ($6\omega_s$) as shown in fig.3 are performed to compensate harmonic voltages, meanwhile in the shunt APF control scheme, a PI controller and three resonant controllers tuned at $6n\omega_s$ (n=1, 2, 3) are achieved to lessen harmonic currents. Thereby, the load voltage and the supply current are governed to be sinusoidal in nature. Thanks to the superiority of the resonant controllers, the control performance of the UPQC is significantly improved compared to the conventional control strategy. The expediency of the proposed UPQC control scheme can be established through simulation results.

A. *Proposed control scheme for the series APF*

The ground zero of the series APF is to outweigh harmonic voltages in the contorted source to maintain the load voltage sinusoidal. Assuming that the source voltage present at the PCC (v_s) is distorted and includes the fundamental (v_{s1}) and harmonic components (v_{sh}) as defined in (1)

$$V_s(\omega t) = v_{s1} + \sum_{h\neq 1} v_{sh} \qquad (1)$$

To make load voltage sinusoidal, the harmonic components existed in (1) must be completely compensated. In the three phase system, harmonic voltages have odd orders:($6n\pm1$) (n =1, 2,3...) of the fundamental frequency of the network (ω_s).Among mentioned harmonics, fifth and seventh harmonics are the most intense components that need to be mollify. A resonant controller with the upper hand in regulating ac signals is an effective solution to carry out this control target[10]. Two resonant controllers tuned at $5\omega_s$ and $7\omega_s$ are able to amply track fifth and seventh harmonics. Moreover, since both fifth and seventh harmonics become sixth harmonic in the fundamental reference frame, one resonant controller with resonant frequency of $6\omega_s$ is also capable of simultaneously fix both fifth and seventh harmonic voltages.

Accordingly, the control scheme is simplified since only one controller is required to regulate two harmonic voltages. The open-loop transfer function of the resonant controller is defined as

$$G_R = \frac{k_{r6}\omega_c s}{s^2+2\omega_c s+(6\omega_s)^2} \quad (2)$$

where K_{r6} and ω_c are the resonant gain and the cut-off frequency of the resonant controller, respectively.

In addition, in order to adjuste a small voltage drop on the system impedance and the series transformer as well as to improve dynamic response of the series APF[10], a PI controller is employed. Consequently, the voltage control scheme for the series APF consists of a PI controller and a resonant controller, and the transfer function is given as follows

$$G_{PI\text{-}R} = k_p + \frac{k_i}{s} + \frac{k_{r6}\omega_c s}{s^2+2\omega_c s+(6\omega_s)^2} \quad (3)$$

PLL is encountered with voltage harmonic components,in order to avoid this adverse effect a LPF(low pass filter) is added ahead PLL .

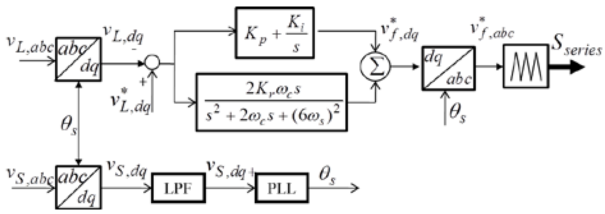

Figure 3 : control scheme of series APF

The resonant controller given in (2) has two control parameters, i.e., K_{r6} and ω_c where $Kr6$ gain regulates the steady-state performance and ω_c determines the control bandwidth of the resonant controller around the selected resonant frequency [10]. In fact, steady-state performance is considered more prominant than dynamic response in the harmonic voltage compensation. Hence, in order to get good steady-state performance, ω_c should be small and $Kr6$ should be increased as high as possible to make the resonant controller have a narrow bandwidth. According to the design method reported in [12],ω_c = 5*rad* / *s* and K_{r6} = 500 are selected. Generally, a large K_{r6} does not affect to the system stability since this gain has the same devolopment as integral gain in the PI controller[10]

B. Proposed control scheme for shunt APF

Subsequently, the control scheme is simplified since only one controller is necessary to control two harmonics. The open-loop transfer function of the resonant controller is defined as Three-phase diode rectifier delivering a dc load introduces harmonic currents into the networks, which have odd orders:($6n\pm1$) (n = 1, 2, 3...) of ω_S . To make the supply current sinusoidal, the shunt APF must infuse the currents having the same magnitude and opposite phase with harmonics in the nonlinear load current. Adding to this, the shunt APF also has a responsibility to maintain the DC-link voltage of series and shunt APF (V_{dc}) in stable condition. As a result, the shunt APF control strategy includes the outer voltage control loop and the inner current control loop as shown in Fig. 5

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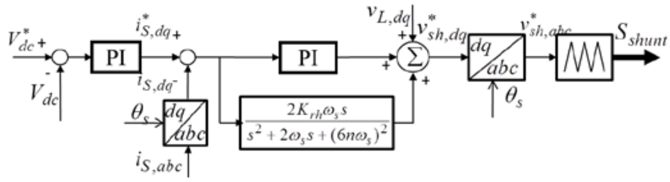

Figure 4 : control scheme of shunt APF

In the V_{dc} voltage control loop, a simple PI controller is sufficient to control the DC-link voltage to be constant at desired value because this voltage has delayed dynamic response. But, in the current control loop, shunt APF must generate harmonic currents which are high frequency signals, the PI controller cannot be a possible solution due to its limitation on control bandwidth. In order to adequately regulate harmonic currents, the resonant controller is employed. It is the same as the harmonics in voltage case that the ($6n\pm1$) harmonic currents become $6n$ harmonics in the fundamental reference frame. Hence, one resonant controller with a resonant frequency of $6n\omega_s$ is suitable enough in regulating a pair of ($6n\pm1$) harmonic currents. Open loop transfer function of shunt controller is as mentioned as below

$$G_{3R} = \sum_{h=6,12,18} \frac{k_{rh}\omega_c s}{s^2+2\omega_c s+(h\omega_s)^2} \quad (4)$$

where h=6,12,18 are the order of harmonic currents in the fundamental reference frame. In addition, since the shunt APF must regulate *DC voltage*, a PI current controller is also needed to regulate fundamental current to charge *DC voltage* . As a result, the current controller of the shunt APF consists of a PI controller and three resonant controllers as fabricated in Fig. 5.

In the harmonic current compensation, both steady-state performance and dynamic response are important factors since the load is not always stable. However, it is difficult to achieve simultaneously good steady-state performance and apt dynamic response. Hence, a good steady-state performance and adequately fast dynamic response is needed which reveals k_{rh} *should* be high and ω_c should be sufficiently large to make the resonant controller have large bandwidth. In fact, as the order of harmonic current increased, its magnitude is diminished. Hence, resonant gain should be smaller at higher order. As a result,K_{r6} = 300, K_{r12} = 200, K_{r18} =100 , and ω_c=10*rad/s* are selected according to [11].

1) Simulation Results

The above mentioned designs of UPQC in the paper are designed in MATLAB/SIMULINK with the system parameters as mentioned below[12]

Table 1: load specifications

S.NO	NAME	SPECIFICATION
1	3ph-ACvoltage Source	Vrms=1kv;f=50hz;connection=Yg
2	Rectifier load	Bridge arms=3;Snubber resistance Rs =1e5 Ω;R_{ON}= 1e-3Ω; R=20Ω;
3	Three phase breaker	Transition times=[0.30.4];R=0.001Ω;
4	2-winding 3-phase t/f	w/g1=D1 and w/g2=Yg
5	RL load	Y grounded; v_{rms} =100V;f=50HZ

A sensitive load is designed by joining two RL loads of v_{rms} of 100V (ph-ph) and the neutral is grounded. The terminals of the above designed network are connected to a circuit breaker with transition times of [0.3 0.4] and the other end of the breaker is linked to a RL load of 100V (ph-ph).

Both the rectifier load and the sensitive load are connected to system at a time and respective voltage and current THD'S are calculated at the load end with and without UPQC(both conventional & proposed models) . We have used FFT analysis to calculate THD'S and it is run for 1 cycle by keeping the fundamental frequency at 50HZ.

Case (i): WITH OUT UPQC TO THE SYSTEM-LOAD:

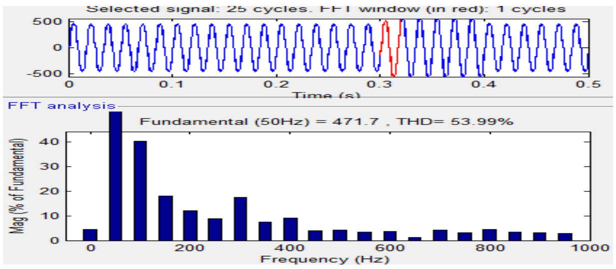

Figure 5 ::voltage THD without UPQC

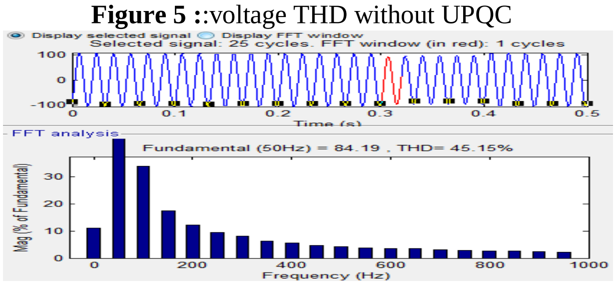

Figure 6 :current THD without UPQC

TABLE 2 : V & I THD analysis without any CPD'S

Voltage(V)	53.99%
Current(I)	45.15%

Case(iv):WITH UPQC TO THE SYSTEM-LOAD

A) CONVENTIONAL MODEL:

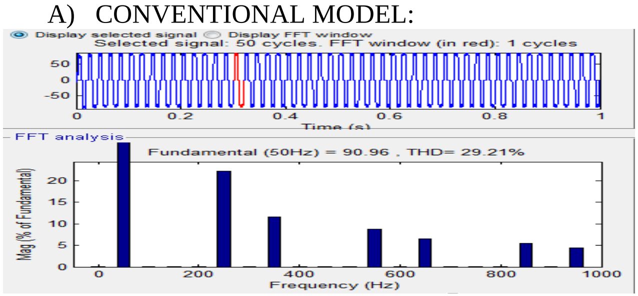

Figure 7 :voltage THD with conventional UPQC

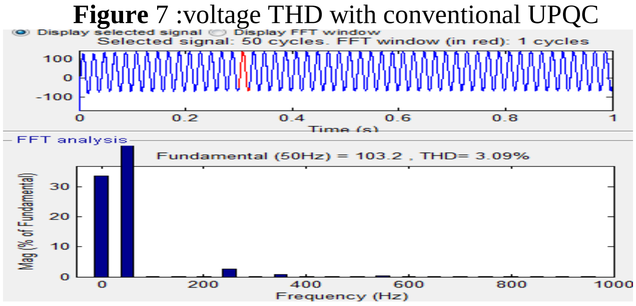

Fig.8: voltage THD with conventional UPQC

TABLE 3 : V & I THD analysis with conventional UPQC

Voltage(V)	29.21%
Current(I)	3.09%

B) PROPOSED MODEL

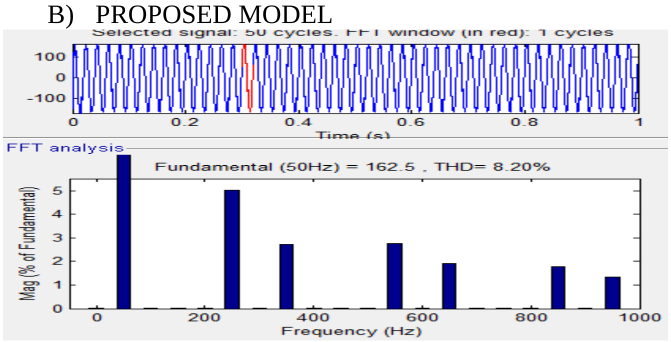

Fig.9: voltage THD with proposed UPQC

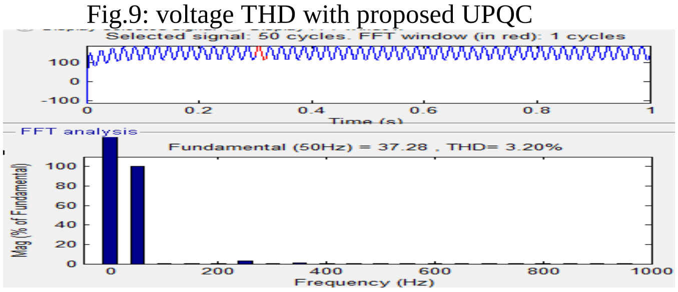

Fig.10: current THD with proposed UPQC

TABLE 4 : V & I THD analysis with proposed UPQC

Voltage(V)	8.20%
Current(I)	3.20%

By comparing Table:1&3 we can infer that conventional UPQC can compensate both voltage and current harmonic THD'S.

By comparing with table:1&4 we can infer that UPQC with proposed design will compensate harmonics of voltage and current better than all custom power devices discussed in the paper.

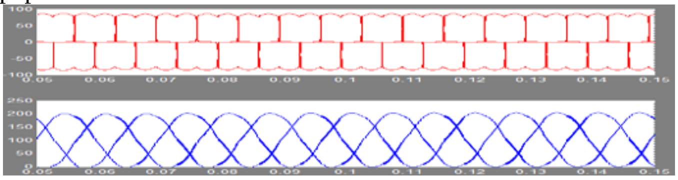

Fig.11:V_L and I_L of conventional UPQC design

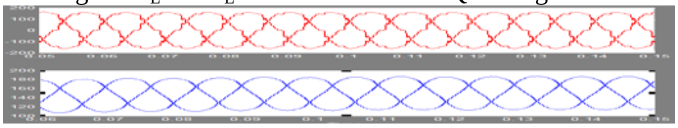

Fig.12:V_L and I_L of proposed UPQC design

TABLE 2 : comparative analysis for both models of UPQC

	Proposed control scheme	Conventional control scheme
THD VALUES	V-8.20%;I-3.20%	V-29.21%;I-3.09;
POWER LOSS	630W	2000W

4. Conclusion

From the above analysis we incurred that proposed model of UPQC suits better for reducing THD at the load current and voltage flicker than the conventional model, the proposed model for UPQC has better harmonic compensation and voltage imbalance elimination properties.

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