ANALYSIS OF UNIFIED POWER QUALITY CONDITIONER
DURING VOLTAGE SAG AND SWELL CONDITIONS

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Abstract
This paper deals with a three-phase unified power quality conditioner (UPQC), with a combination of shunt active power filter and series active power filter is used to eliminate supply current harmonics, compensate reactive power, voltage sag and voltage swell compensation on distribution network. The performance of the active power filter mainly depends on control strategy used to generate reference current for shunt active power filter (APF) and generate reference voltage for series active power filter. The unified power quality conditioner can work in zero active power consumption mode, active power consumption mode and active power delivering mode. The mathematical analysis is based on active power flow and reactive power flow through the shunt and series active power filter, where in series active power filter can absorb or deliver the active power whereas the reactive power requirement is totally handle by shunt active power filter alone during all conditions. The effect of load VAR variation and the impact of % sag or swell on the kVA ratings of both shunt and series APF are also analyzed. This analysis can be very useful for selection of device ratings for both shunt APF and series APF. Simulation results of these two active power filters are carried out.

Index Terms: Power quality, UPQC

1. INTRODUCTION
The power electronic loads in industry causes an increasing deterioration of the power system voltage and current waveforms. As a result, harmonics are generated from power converters or nonlinear loads. This causes the power system to operate at low power factor, low efficiency, increased losses in transmission and distribution lines, failure of electrical equipments, and interference problem with communication system. So, there is a great need to mitigate these harmonic and reactive current components. Active Power filters are a viable solution to these problems. The continuous usage of non-linear loads injects current and voltage harmonic components into the power system and increases reactive power demands and power system voltage fluctuations. Harmonic current components create several problems like, increase in power system losses. Over heating and insulator failures in transformers, rotating machinery, Conductor and cables. Reactive power burden, low system efficiency, poor power factor, system unbalance and causes excessive neutral currents. Malfunctioning of the protective relays and untimely tripping. The amount of distortion in the voltage or current waveform is quantified by means of an index called the total harmonic distortion (THD) [2]. unified power quality conditioner can absorb active power or inject active power. One of the effective approaches is to use a unified power quality conditioner (UPQC) at PCC to protect the sensitive loads. A UPQC is a combination of shunt and series APFs, sharing a common dc link [5-12]. It is a versatile device that can compensate almost all power quality problems such as voltage harmonics, voltage unbalance, voltage flickers, voltage sags & swells, current harmonics, current unbalance, reactive current, etc. This paper is based on the steady state analysis of UPQC during voltage sag and swells on the system. The main objective of this article is to maintain the load bus voltage sinusoidal and at desired constant level in all operating conditions.

2. UPQC CONFIGURATION
The voltage at point of common coupling may be or may not be distorted depending on the other nonlinear loads connected at point of common coupling. Also, these loads may impose the voltage sag or swell condition during their switching ON and/or OFF operation. The unified power quality conditioner is installed in order to protect a sensitive load from all disturbances. It consists of two voltage source inverters connected back to back, sharing a common dc link. One
The second inverter is connected in series with the line using series transformers, acts as a controlled voltage source maintaining the load voltage sinusoidal and at desired constant voltage level. A system configuration for unified power quality conditioner shows in Fig 2.1[1].

**Fig2.1. System Configuration of UPQC**

### 2.1 Configuration Of Three Phase Shunt Active Power Filter

The basic configuration of a three-phase three-wire active power filter is shown in Fig 2.2[3]. The diode bridge rectifier is used as an ideal harmonic generator to study the performance of the Active filter. The current-controlled voltage-source inverter (VSI) is shown connected at the load end. This PWM inverter consists of six switches with anti-parallel diode across each switch. The voltage which must be supported by one switch is uni-polar and limited by the DC voltage $V_{dc}$. The peak value of the current which is bi-directional is imposed by the active filter current. Thus the appropriate semiconductor device may be an IGBT or a MOSFET with an anti-parallel diode and must be protected against over current. The capacitor is designed in order to provide DC voltage with acceptable ripples. In order to assure the filter current at any instant, the DC voltage $V_{dc}$ must be equal to $3/2$ of the peak value of the line AC mains voltage[3].

**Fig.2.2. Configuration of three-phase Shunt Active Power Filter**

### 3. STEADY STATE POWER FLOW ANALYSIS

Steady state operating analysis is done on the basis of fundamental frequency component. The unified power quality conditioner is controlled in such a way that the voltage at load bus is always sinusoidal and at desired magnitude. Therefore the voltage injected by series active power filter must be equal to the difference between the supply voltage and the ideal load voltage. Thus the series active power filter acts as controlled voltage source. The function of shunt active power filter is to maintain the dc link voltage at constant level. In addition to this the shunt active power filter provides the VAR required by the load, such that the input power factor will be unity and only fundamental active power will be supplied by the source[1].

The voltage injected by series active power filter can vary from $0^\circ$ to $360^\circ$. However, in changing the voltage phase angle of series active power filter, the amplitude of voltage injected can increase, thus increasing the required KVA rating of series active power filter. In the following analysis, the load voltage is assumed to be in phase with terminal voltage even during voltage sag and swell condition. This is done by injecting the series voltage in phase or out of phase with respective to the source voltage during voltage sag and swell condition respectively. This suggests the real power flow through the series active power filter. The voltage injected by series active power filter could be positive or negative, depending on the source voltage magnitude, absorbing or supplying the real power. In this particular condition, the series active power filter could not handle reactive power and the load reactive power is supplied by shunt active power filter alone. The single phase equivalent circuit for a unified power quality conditioner is shown in the Fig 3.1[1]

**Fig3.1: equivalent circuit of UPQC**

### 3.1 Mathematical Equations

The source voltage, terminal voltage at point of common coupling and load voltage are denoted by $V_S$, $V_T$ and $V_L$ respectively. The source and load currents are denoted by $I_S$ and $I_L$ respectively. The voltage injected by series active...
power filter is denoted by $V_s$, where as the current injected by shunt active power filter is denoted by $I_{sh}$. Taking the load voltage, $V_L$, as a reference phasor and suppose the lagging power factor of the load is $\cos \Phi_L$,

\[
V_L = V_L \text{ at an angle } 0^\circ \qquad (3.1)
\]

\[
I_L = I_L \text{ at an angle } - \Phi_L \qquad (3.2)
\]

\[
V_T = V_L (1+K) \text{ at angle of } 0^\circ \qquad (3.3)
\]

Where factor $K$ represents the fluctuation of source voltage, defined as

\[
K = (V_T - V_L)/V_L \qquad (3.4)
\]

The voltage injected by series active power filter must be equal to,

\[
V_{Ss}= V_L - V_T = -K V_L \qquad (3.5)
\]

The unified power quality conditioner is assumed to be lossless and therefore, the active power demanded by the load is equal to the active power input at point of common coupling. The unified power quality conditioner provides a nearly unity power factor source current, therefore, for a given load condition the input active power at Point of common coupling can be expressed by the following equations,

\[
P_T = |P_L| \qquad (3.6)
\]

\[
V_T = V_L \ast I_L \ast \cos \Phi_L \qquad (3.7)
\]

\[
V_{Ls} = \frac{(1+K) \ast I_S = V_L \ast I_L \ast \cos \Phi_L}{(1+K) \ast \cos \Phi_L} \qquad (3.8)
\]

\[
I_S = \frac{I_L}{(1+K) \ast \cos \Phi_L} \qquad (3.9)
\]

The above equation suggests that the source current $I_S$ depends on the factor $k$, since $\Phi_L$ and $I_L$ are load characteristics and are constant for a particular type of load. The complex power absorbed by the series active power filter can be expressed as,

\[
S_{Sr} = V_s \ast I_s \ast \cos \phi_s \qquad (3.10)
\]

\[
|P_{Sr}| = V_s \ast I_s \ast \sin \phi_s \qquad (3.11)
\]

\[
Q_{Sr} = 0 \quad \text{since unified power quality conditioner is maintaining unity power factor} \quad (3.12)
\]

\[
I_{Ss} = I_S \ast I_L \qquad (3.13)
\]

\[
Q_{Ss} = 0 \qquad (3.14)
\]

The complex power absorbed by the shunt active power filter can be expressed as,

\[
S_{Sh} = V_{Ls} \ast I_{Sh} \qquad (3.15)
\]

The current provided by the shunt active power filter, is the difference between the input source current and the load current, which includes the load harmonics current and the reactive current. Therefore, we can write;

\[
I_{sh} = I_S - I_L \qquad (3.16)
\]

\[
I_{Ss} = I_S \text{ at an angle } 0^\circ - I_L \text{ at an angle } - \Phi_L \qquad (3.17)
\]

\[
I_{Ss} = I_S - (I_L \ast \cos \Phi_L - j \ast I_L \ast \sin \Phi_L) \qquad (3.18)
\]

\[
I_{Ss} = (I_S - I_L \ast \cos \Phi_L) + j \ast I_L \ast \sin \Phi_L \qquad (3.19)
\]

\[
P_{Sh} = V_{Ls} \ast I_{Sh} \ast \cos \phi_{Sh} \qquad (3.20)
\]

\[
= V_L \ast I_{Sh} \ast \cos \phi_{Sh} \qquad (3.21)
\]

\[
Q_{Sh} = V_{Ls} \ast I_{Sh} \ast \sin \phi_{Sh} \qquad (3.22)
\]

\[
= V_L \ast I_{Sh} \ast \sin \phi_{Sh} \qquad (3.23)
\]

### 3.2 Operating Conditions

#### 3.2.1 Case I

The reactive power flow during the normal working condition when unified power quality conditioner is not connected in the circuit is shown in the Figure 3.2(a)[1]. When the unified power quality conditioner is connected in the network and the shunt active power filter is put into the operation, the reactive power required by the load is now provided by the shunt active power filter alone; The reactive power flow during the entire operation of unified power quality conditioner is shown in the Figure 3.2(b)[1].

#### 3.2.2 Case II

If $k < 0$, i.e. $V_t < V_L$, then from equation (3.4) and (3.13), PSR, will be positive, means series active power filter supplies the active power to the load. This condition is possible during the utility voltage sag condition. From equation (3.9), $I_S$ will be more than the normal rated current. Thus we can say that the required active power is taken from the utility itself by taking more current so as to maintain the power balance in the network and to keep the dc link voltage at desired level[1].

![Fig.3.3 Overall Active Power Flow During Sag Condition](image-url)
Psr=power injected by series APF in such a way that sum Ps"+Psr" will be the required load power during normal working condition
Psh'=power absorbed by shunt APF during voltage sag condition
Ps'= Psh'
The overall active power flow is shown in Fig 3.3[1].

3.2.3 Case III
If k > 0, i.e. V_t > V_L, then by equation (3.4) and (3.13), PSR, will be negative, this means series active power filter is absorbing the extra real power from the source. This is possible during the voltage swell condition. In other words we can say that the unified power quality conditioner feeds back the extra power to the supply system. The overall active power flow is shown in Fig.3.4 [1].

3.2.4 Case IV
If k = 0, i.e. V_t = V_L, then there will not be any real power exchange though unified power quality conditioner. This is the normal operating condition. The overall active power flow is shown in Fig. 3.5[1].

4. SIMULATION RESULTS

4.1 System Data
To validate the proposed algorithm, the UPQC device with shunt APF and series APF was simulated using Power System Block set in MATLAB/SIMULINK. The system parameters are shown in Table 4.1.

<table>
<thead>
<tr>
<th>Table 4.1 system parameters</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage, V_s</td>
<td>415 V</td>
</tr>
<tr>
<td>Supply frequency</td>
<td>50 Hz</td>
</tr>
<tr>
<td>DC Bus voltage, Vdc</td>
<td>750 V</td>
</tr>
<tr>
<td>Injection Inductor, L</td>
<td>10 mH</td>
</tr>
<tr>
<td>DC side capacitor, C</td>
<td>5000 uF</td>
</tr>
<tr>
<td>Sensitive load active power</td>
<td>2460 watts</td>
</tr>
<tr>
<td>Sensitive load reactive power</td>
<td>1000 Vars</td>
</tr>
<tr>
<td>Series filter transformer</td>
<td>10 kVA</td>
</tr>
</tbody>
</table>

4.2 Simulink Model For Shuntapf

The simulink model of the system used for simulating the ShuntAPF is shown in the Fig 4.1 Wave forms of load currents, reference currents, compensating currents, D.C link capacitor voltage and source currents and source voltages are shown from Fig 4.2(a) to Fig 4.2(f).
Thus results shows Shunt APF controller effectively compensates harmonics, reactive power compensation and maintains D.C link voltage constant.

4.3 Simulink Model For Series Apf

Fig 4.4(a) Terminal voltage(b) Reference Voltages from 0.04sec to 0.2sec(c) Voltage Injected by Series APF 0.04sec to 0.2sec During sag(d) Voltage sag compensation

Test system shown in Fig 4.3. Wave forms of load voltage, reference voltages, series injecting voltages, load voltages during sag condition, swell condition and both conditions are
shown from Fig 4.4 to Fig 4.6. Thus results shows Series APF controller effectively compensates voltage sag and maintains load voltage constant.

4.3.2 During voltage Swell

![Voltage Injected by Series APF 0.04sec to 0.2sec During swell(b) Load voltage](image1)

Thus results shows Series APF controller effectively compensates voltage swell and maintains load voltage constant.

4.3.3 During voltage swell and sag

![Load from 0.04sec to 0.24sec During Sag and Swell terminal voltage(b) Loadvoltage](image2)

Thus results shows Series APF controller effectively compensates both voltage sag and swells and maintains load voltage constant.

4.4 Simulink Model Forupqc

![SIMULINK MODEL FOR UPQC](image3)

5. CONCLUSION

From the simulation responses, it is evident that the Shunt APF, reference current generator, hysteresis current controller and also for Series APF, reference voltage generator, hysteresis voltage controller are performing satisfactorily. The source current waveform is in phase with the utility voltage and free from harmonic components. The load voltage waveform is maintain constant during voltage sag and swell conditions. The three phase terminal voltages, three phase load voltages, three phase source currents and the dc link voltage are sensed and used to generate the switching patterns for shunt and series APFs. The shunt active power filter helps series active power filter during voltage sag and swell condition by maintaining the dc link voltage at set constant level, such that series active power filter could effectively supply or absorb the active power. In addition to this shunt active power filter also provides the required load VARs and thus making the input power factor close to unity. This analysis is very useful in selection of kVA ratings of both series and shunt active power filter depending on the sag and swell needed to be compensated. Hard ware implementation can be carried out for all types of constant and variable loads. Regarding shunt APF instead of using PI controller with neural network we can achieve better performance than earlier.
REFERENCES


BIOGRAPHIES

B.Jyothi received the B.tech degree from S.K.University, Anathapur in 2002, M.tech Degree from JNTU Hyderabad in 2008. She is currently pursuing Phd at Acharya nagarjuna university, Guntur, working as an Asst Professor in KL university, Guntur, AP. Her interest focus on Power Electronics, power electronics drives and Electrical machines.

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