Chapter 4

Unified Power Quality Conditioner (UPQC)

The aim of a unified power quality conditioner (UPQC) that consists of series active and shunt active filters is to compensate for supply voltage flicker/imbalance, reactive power, negative sequence current and harmonics. In other words, the UPQC has the capability of improving power quality at the point of installation on power distribution systems or industrial power systems. The UPQC, therefore, is expected to be one of the most powerful solutions to large capacity loads sensitive to supply voltage flicker/imbalance. The UPQC can be divided into two parts i.e. general UPQC, for power distribution systems and industrial power systems; and specific UPQC for a supply voltage flicker/imbalance sensitive load, which is installed by electric power consumers on their own premises. In UPQC the series active power filter eliminates supply voltage flicker/imbalance from the load terminal voltage and forces an existing shunt passive filter to absorb all the current harmonics produced by a nonlinear load. Elimination of supply voltage flicker, however, is accompanied by low frequency fluctuation of active power flowing into or out of series active filter. The shunt active filter performs dc link voltage regulation, thus leading to a significant reduction of capacity of dc link capacitor.

As the name suggests, the series-shunt active filter is a combination of series active filter and shunt active filter. The topology is shown in Fig 1.5. The shunt-active filter is located at the load side and can be used to compensate for the load harmonics. On the other hand, the series portion is at the source side and can act as a harmonic blocking filter. This topology is called as Unified Power Quality Conditioner. The series portion compensates for supply voltage harmonics and voltage unbalances, acts as a harmonic blocking filter and damps power system oscillations. The shunt portion compensates load current harmonics, reactive power and load current unbalances. In addition, it regulates the dc link capacitor voltage. The power supplied or absorbed by the shunt portion is the power required by the series compensator and the power required to cover losses [39].

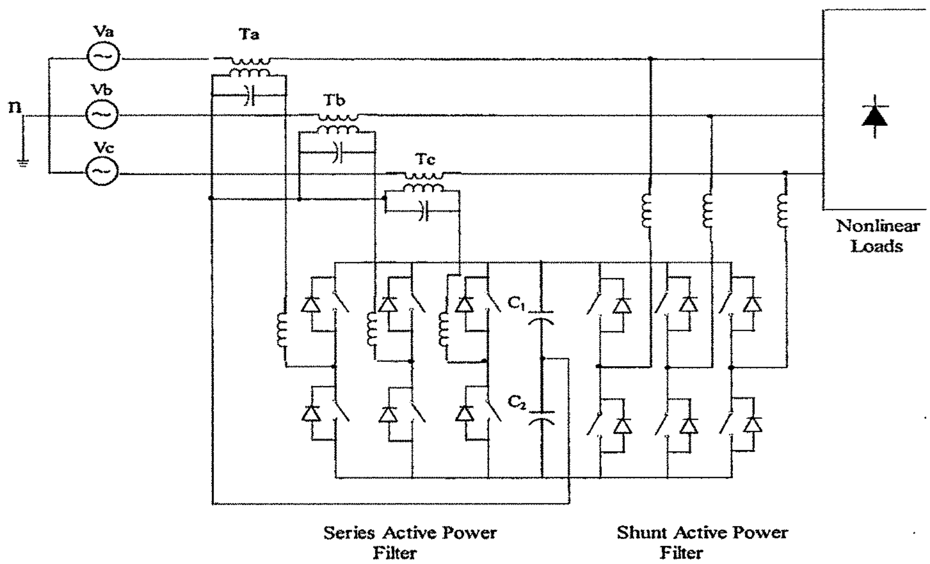


Fig 4.1 Unified Power Quality Conditioner Topology

4.1 Basic Configuration of UPQC

Fig 4.2 shows the basic configuration of a general UPQC consisting of the combination of a series active and shunt active filter.

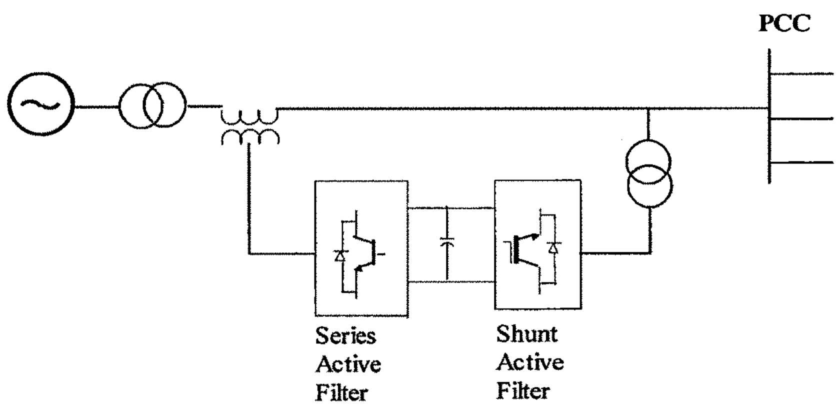


Fig 4.2 General UPQC

The main purpose of the series active filter is harmonic isolation between a sub transmission system and a distribution system. In addition the series active filter has the capability of voltage flicker/imbalance compensation as well as voltage regulation and harmonic compensation at the utility-consumer point of common coupling (PCC). The main purpose of the shunt active filter is to absorb current harmonics, compensate for reactive power and negative sequence current, and regulate the dc link voltage between both active filters [40-41].

4.2 Specific UPQC

Fig 4.2 shows the configuration of a specific UPQC. The aim of specific UPQC is not only to compensate for the current harmonics, but also to eliminate the voltage flicker/imbalance contained in the receiving terminal voltage V_R from the load terminal voltage V_L.

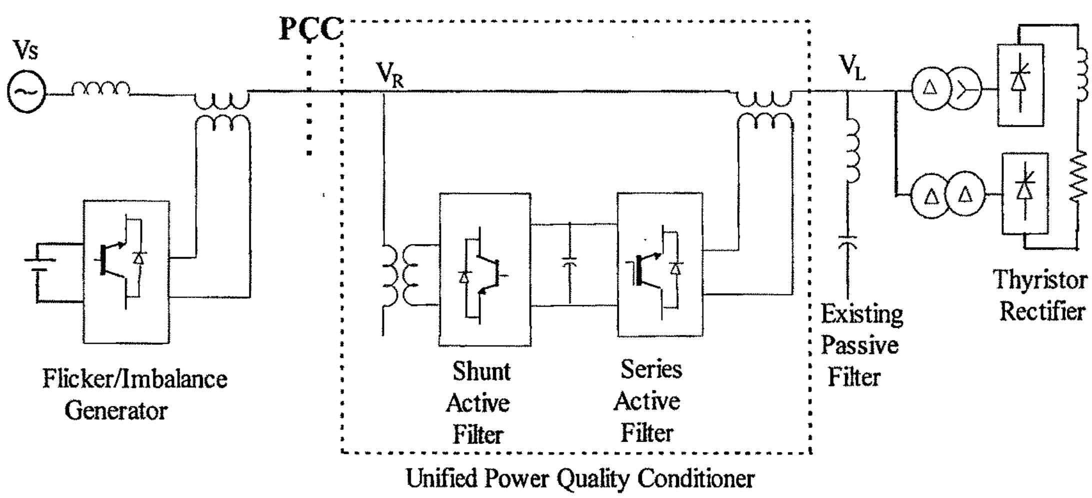


Fig 4.3 Specific UPQC

The receiving terminal in fig 4.3 is often corresponding to the utility-consumer point of common coupling in high power applications. The operation of series active filter greatly forces all the current harmonics produced by the load into an existing shunt passive filter. It also has the capability of damping series/parallel resonance between the supply impedance and the shunt passive filter. The shunt active filter is connected in parallel to the supply by the step up transformer. The only objective of the shunt active filter is to regulate the dc link voltage between both active filters. Thus, the dc link is kept at a constant voltage even when a large amount of active power is flowing into or out of the series active filter during the flicker compensation. Although the shunt active filter has the capability of reactive power compensation, the shunt active filter in fig 4.2 provides no reactive power compensation in order to achieve the minimum required rating of the shunt active filter. There is noticeable difference in the installation point of shunt active filters of figures 4.1 and 4.2. The reason is as follows: In fig 4.1, the shunt active filter compensates for all the current harmonics produced by nonlinear loads downstream of the PCC. Therefore, it should be connected downstream of the series active filter acting as a high resistor for harmonic frequencies. In fig 4.2, the shunt active filter draws or injects the active power fluctuating at a low frequency from or into the supply, while the existing shunt passive filter absorbs the current harmonics. To avoid the interference between the shunt active and passive filters, the shunt active filter should be connected upstream of the series active filter.

4.3 Mathematical Modeling of UPQC

In this study, the power supply is assumed to be a three-phase, three-wire system. The two active filters are composed of two 3-leg voltage source inverters (VSI). Functionally, the series filter is used to compensate for the voltage distortions while the shunt filter is needed to provide reactive power and counteract the harmonic current injected by the load. Also, the voltage of the DC link capacitor is controlled to a desired value by the shunt active filter. There can be negative and zero sequence components in the supply when a voltage disturbance occurs. The DC link capacitor bank is divided into two groups connected in series. The neutrals of the secondary of both transformers are directly connected to the dc link midpoint. In this way, as the connection of both three-phase transformers is Y/Yo, zero sequence voltage appears in the primary winding of the series connected transformer in order to compensate for the zero sequence voltage of the supply system. No zero sequence current flows in the primary side of both transformers. It ensures the system current to be balanced when the voltage disturbance occurs. Assuming that the load is non-linear, the power system model considered can be divided into following units: the power supply system, series active filter and shunt active filter. These constituent members of the UPQC are modeled separately in this section. First consider the power supply system. By Kirchhoff's law:

$$v_{if} = e_i - L_s \frac{di_{is}}{dt} - R_s i_{is} - v_{sh} \tag{4.1}$$

$$i_{is} = i_{iL} - i_{ih} \tag{4.2}$$

Where, subscript i refers to a, b and c phases in the power system; L_s and R_s are the inductance and resistance of the transmission line; e_i is source voltage; v_{ih} is the output voltage of the series active filter; i_{is} is the line current; i_{iL} is the load current and i_{is} is the output current of the shunt of the shunt active filter respectively.

For the series active filter,

$$v_{ih} = L_l \frac{di_{is}}{dt} + R_l i_{is} + d_{li} v_{cl} + (1 - d_{li}) v_{c2} \tag{4.3}$$

Where, L_l and R_l are the leakage inductance and resistance of the series transformer, v_{c1} and v_{c2} are the voltages of dc link capacitors; d_{li} is the switch duty ratio of the series active filter. Without loss of generality, the turn's ratio of the transformer is assumed to be unity.

For shunt active filter:

$$L_2 \frac{di_{ih}}{dt} = R_2 i_{ih} - v_{iF} + d_{2i} v_{c1} + (1 - d_{2i})\ v_{c1} \tag{4.4}$$

Where L_2 and R_2 are the leakage inductance and resistance of the shunt-connected transformer, d_{2i} is the switch duty ratio of the shunt active filter. The turn's ratio of this transformer is also assumed to be unity.

The two dc bus capacitor voltages can be described by the equations (5) and (6):

$$\frac{dv_{c1}}{dt} = \frac{i_{c1}}{c_1} = \frac{1}{c_1}\left(\sum_{i=a,b,c} d_{1i} i_{is} - \sum_{i=a,b,c} d_{2i} i_{ih}\right) \tag{4.5}$$

$$\frac{dv_{c2}}{dt} = \frac{i_{c2}}{c_2} = \frac{1}{c_2}\left[\sum_{i=a,b,c} (1 - d_{1i}) i_{is} - \sum_{i=a,b,c} (1 - d_{2i}) i_{ih}\right] \tag{4.6}$$

4.4 Proposed UPQC Operating Principle

Distorted voltages in a 3-phase system may contain negative phase sequence, zero phase sequence as well as harmonic components. The voltage of phase "a" can be expressed as, in general:

$$v_a = v_{1pa} + v_{1na} + v_{1oa} + \sum V_{ka}\sin(kwt + \theta_{ka}) \tag{4.7}$$

Where, v_{1pa} is the fundamental frequency's positive sequence component while v_{1na} and v_{1oa} is the negative and zero sequence components. The last term of equation (4.7), $\sum V_{ka}\sin(kwt + \theta_{ka})$ represents the harmonics in the voltage. In order for the voltage at the load terminal to be perfectly sinusoidal and balanced, the output voltages of the series active filter should be:

$$v_{ah} = v_{1na} + v_{1oa} + \sum V_{ka}\sin(kwt + \theta_{ka}) \tag{4.8}$$

In a later section, it will be shown how the series active filter can be designed to operate as a controlled voltage source whose output voltage would be automatically controlled according to equation (4.8). The shunt active filter performs the following functions:

a) To provide compensation of the load harmonic currents to reduce voltage distortions
b) To provide load reactive power demand
c) To maintain the DC-link voltage to a desired level.

To perform the first two functions, the shunt active filter acts as a controlled current source and its output current should include harmonic, reactive and negative phase sequence components in order to compensate these quantities in the load current. In other words, if the load current of phase "a" is expressed as:

$$i_{aL} = I_{1pm}\cos(\omega t-\theta_1) + I_{aLn} + \sum I_{aLk}$$

$$= I_{1pm}\cos\omega t\cos\theta_1 + I_{1pm}\sin\omega t\sin\theta_1 + I_{aLn} + \sum I_{aLk} \tag{4.9}$$

It is clear that the current output of the shunt active filter should be:

$$i_{ah} = I_{1pm}\sin\omega t\sin\theta_1 + I_{aLn} + \sum I_{aLk} \tag{4.10}$$

Hence, the current from the source terminal will be:

$$i_{as} = i_{aL} - i_{ah} = I_{1pm}\cos\omega t\cos\theta_1 \tag{4.11}$$

This is a perfect, harmonic-free sinusoid and has the same phase angle as the phase "a" voltage at the load terminal. The power factor is unity. It means that the reactive power of load is not provided by the source.

4.5 Design of Proposed UPQC Control model

It is clear from the above discussion that UPQC should first separate out the fundamental frequency positive sequence from the other components. Then it is necessary to control the outputs of the two active filters in the way shown in equations (4.8) and (4.10) in order to improve overall power quality at the load terminal [42, 43].

To solve the first problem, a synchronous d-q-0 reference frame is used. If the 3-phase voltages are unbalanced and contain harmonics, the transformation to the d-q-0 axes results in

$$\begin{bmatrix} v_d \\ v_q \\ v_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\omega t) & \cos(\omega t - 120^0) & \cos(\omega t + 120^0) \\ -\sin(\omega t) & -\sin(\omega t - 120^0) & -\sin(\omega t + 120^0) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$$

$$= \sqrt{\frac{3}{2}} \left\{ \begin{bmatrix} V_{pm}\cos\phi_p \\ V_{pm}\sin\phi_p \\ 0 \end{bmatrix} + \begin{bmatrix} V_{nm}\cos(2\omega t + \phi_n) \\ -V_{nm}\sin(2\omega t + \phi_n) \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ V_{0m}\cos(\omega t + \phi_0) \end{bmatrix} + \begin{bmatrix} \sum V_k\cos(k-1)(\omega t + \phi_k) \\ \sum V_k\sin(k-1)(\omega t + \phi_k) \\ 0 \end{bmatrix} \right\}$$

$$= \Delta \begin{bmatrix} v_{dp} \\ v_{qp} \\ 0 \end{bmatrix} + \begin{bmatrix} v_{dn} \\ v_{qn} \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ v_{00} \end{bmatrix} + \begin{bmatrix} v_{dk} \\ v_{qk} \\ 0 \end{bmatrix} \tag{4.12}$$

Equation (12) shows that the fundamental positive sequence components of voltages are represented by dc values in the d-q-0 frame. Here, ϕ_p is the phase difference between the positive sequence component and the reference voltage (phase "a"). For the proper functioning of a power supply system, it is desirable that the voltages at .the load terminal should be perfect sinusoids with constant amplitude. Even under a voltage disturbance, the load still requires a constant voltage. This means that when transformed to the d-q-0 axis, the load voltage become:

$$\begin{bmatrix} v_{dF}^* \\ v_{qF}^* \\ v_{0F}^* \end{bmatrix} = \sqrt{\frac{3}{2}} \begin{bmatrix} V_m \\ 0 \\ 0 \end{bmatrix} \tag{4.13}$$

Where, V_m is the rated or desired voltage at the load terminal. Only one value, V_m, in the d-axis would be sufficient to represent the balanced, perfect sinusoidal, 3-phase voltages in the abc frame. As a reference quantity, it is a known quantity and more suitable for use in UPQC control than that proposed in [3]. Therefore v_{dp} should be maintained at, $\sqrt{3/2}V_m$ while all the other components should be eliminated by the series active filter. Similar expression can be obtained for the currents:

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\omega t) & \cos(\omega t - 120^0) & \cos(\omega t + 120^0) \\ -\sin(\omega t) & -\sin(\omega t - 120^0) & -\sin(\omega t + 120^0) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

$$= \sqrt{\frac{3}{2}} \left\{ \begin{bmatrix} I_{1pm}\cos\theta_1 \\ I_{1pm}\sin\theta_1 \\ 0 \end{bmatrix} + \begin{bmatrix} I_{1nm}\cos(2\omega t + \theta_n) \\ -I_{1nm}\sin(2\omega t + \theta_n) \\ 0 \end{bmatrix} + \begin{bmatrix} \sum I_k \cos(k-1)(\omega t + \theta_k) \\ \sum I_k \sin(k-1)(\omega t + \theta_k) \\ 0 \end{bmatrix} \right\} \tag{4.14}$$

Unlike load voltage, load current can change according to the connected loads. Therefore, it is not possible to assign it a reference value. Instead, a new "moving time window" method is applied here to capture the active quantity of the fundamental positive sequence component which is expressed as a dc value in the d-axis. Furthermore, from equation (4.14), it is evident that the average of the other components, apart from $I_{1pm}\cos\theta_1$, in the d-axis is zero in one fundamental cycle period because all of them are harmonics of the fundamental. Therefore a time window with a width of 0.02 seconds (for 50 Hz system) maybe selected to calculate the dc value. The calculation for the first fundamental cycle is $\frac{1}{T}\int_0^T i_d \, dt = I_{1pm}\cos\theta_1$. After this, the window is moved forward. If the moving frequency is also 50 Hz, the delay caused by the calculation is 0.02s. However if the moving frequency is n times of 50 Hz, the delay will be 0.02/n seconds. As the window moving frequency increases, calculation delay becomes shorter but the frequency at which the data moving into and out of the window is higher. It may need longer computation time. Fortunately, in practical power systems, load current changes slowly. As a compromise, 500 Hz is selected as the window moving frequency in this paper. The two voltage-source inverters (VSIs) are used as the series and shunt active filters. The series active filter should behave as a controlled voltage source and its output voltage should follow the pattern of voltage given in equation (4.8). This compensating voltage signal can be obtained by comparing the actual load terminal voltage with the desired value v_F*.Since the desired v_F* is already defined, it is easy to calculate v_h (= v_F* - v_s) as v_s is a known quantity. After obtaining the voltage signal v_h , the switching duty ratio of the series active filter is obtained by giving this signal to the hysteresis controller. The shunt active filter acts as a controlled current source. It means that the inverter operates in the current-regulated modulation mode. There are various ways to control the inverter in such a mode, such as the hysteresis control, and predictive control. But in this thesis work the hysteresis control has been used as given in chapter 6, later in this report.

4.5.1 Design of DC-link Bus Capacitor Voltage

The dc-link capacitor is divided into two units connected in series, c_l and c_2. The voltages v_{cl} and v_{c2} are such that v_{cl} = -v_{c2} under balanced operating conditions. Usually, the DC link voltage is maintained at a desired value under all operating conditions. It can be shown that apart from the power loss due to line and winding resistances, a certain amount of power needs to be supplied to or absorbed by the capacitor to restore a voltage during a voltage disturbance. For example, if voltage sag occurs in phase "a", v_{ah} is higher than the normal value; the dc-link capacitors will supply the power through the series active filter. In the proposed scheme, a PI controller is used to control the capacitor voltage.

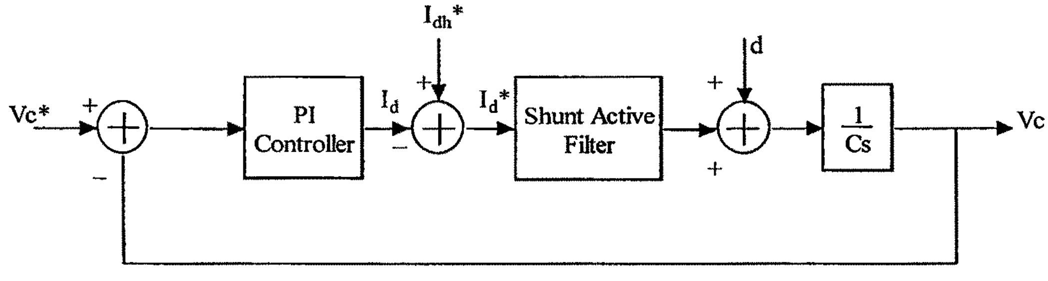


Fig. 4.4 Control scheme of Vc

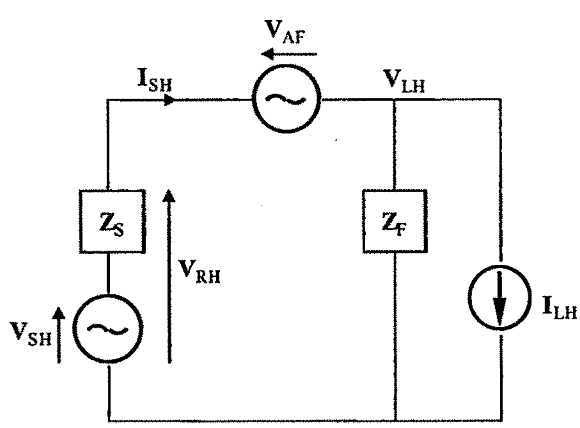
Fig 4.4 shows the basic control scheme. The input to the PI controller is the error between the actual capacitor voltage and its desired value. The output of the PI controller is added to the reference current component in the d axis, i_d; to form the new reference current i_d*. It means that the power needed to charge the two capacitors comes from the active power of the power supply system. The shunt active filter acts like a regulator. Its currents are used to adjust the capacitor voltages to within a certain range. Here only one PI controller is used to control the two capacitor voltages. Although these voltages will not be symmetrical when the system is unbalanced, this is caused by the zero sequence current in the UPQC [46].

4.5.2 Compensation scheme for Voltage and Current

Fig 4.5 shows a single phase equivalent circuit for fig 4.2. For the sake of simplicity, the shunt active filter is removed from fig 4.4 because it has no effect on harmonic and flicker compensation. Three kinds of control methods are discussed as follows:

1) current detecting method

$$V^*_{AF}=K*I_{SH} \qquad (12)$$



Equivalent circuit for harmonics

Fig 4.5

2) Voltage detecting method

$$V^*_{AF}=V_{RH} \tag{13}$$

3) Combined method

$$V^*_{RH}=K*I_{SH}+V_{RH} \tag{14}$$

Where K is a proportional gain with a real number.

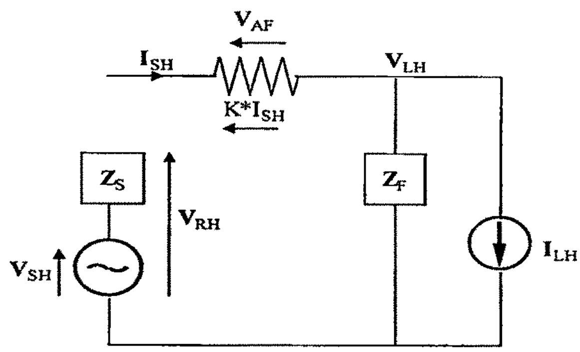
4.5.3 Current Detecting Method

The function of shunt active filter is to compensate harmonics current, small capacity of reactive power current and unbalance current. When the output current of shunt active filter is kept equal to the current I_{LH} to be compensated, the harmonics current, reactive power current and negative sequence current will not flow into power source. This compensation method is called current detecting method. Fig 4.6 shows an equivalent circuit, where the current detecting method is applied. Equation (12) means that the series active filter acts as a resistor of K ohms for harmonics. The load terminal voltage harmonics V_{LH} and the supply current harmonics I_{SH} are given as follows:

$$V_{LH}=\frac{Z_F}{Z_S+Z_F+K}V_{SH}-\frac{Z_S+K}{Z_S+Z_F+K}Z_F I_{LH} \tag{15}$$

$$I_{SH}=\frac{1}{Z_S+Z_F+K}V_{SH}+\frac{Z_F}{Z_S+Z_F+K}I_{LH} \tag{16}$$

If the feedback gain K is set as $K>>Z_S+Z_F$, neither the voltage harmonics nor the voltage flicker appears at the load terminal, irrespective of voltage harmonics and flicker existing at the receiving terminal. Then a small amount of harmonic voltage Z_F*I_{LH} is included in V_{LH}. However, no voltage flicker is contained in V_{LH} because a thyristor rectifier essentially produces no current flicker if no voltage flicker exists. As a result both the load terminal



Equivalent circuit for current detecting method

Fig. 4.6

voltage and the supply current become purely sinusoidal. It is however difficult to set K much larger than Z_S+Z_F for voltage flicker because Z_F exhibits high capacitive impedance at the fundamental frequency. Thus, the current detecting method is not suitable for voltage flicker compensation.

4.5.4 Voltage Detecting Method

The compensation method for series active filter is called as voltage detecting method. Fig 4.7 shows an equivalent circuit based on the voltage detecting method given by equation (13).

Because the output voltage of the series active filter V_{AF} cancels the receiving terminal voltage harmonics V_{RH}, neither the supply voltage harmonics nor supply voltage flicker appears at the load terminal, that is,

$$V_{LH}=0 \tag{17}$$

However, the existing shunt passive filter loses the capability of trapping current harmonics produced by the load escape to the supply,

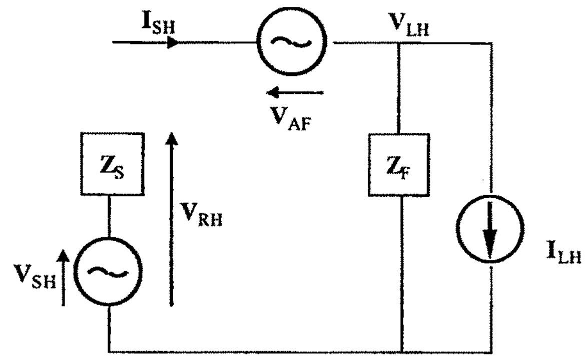


Fig. 4.7 Equivalent circuit for voltage detecting method

that is,

$$-I_{SH}=I_{LH} \tag{18}$$

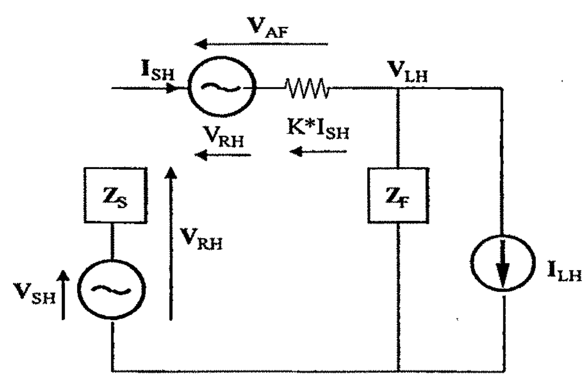
Thus the voltage detecting method is not suitable for harmonic compensation of the load.

4.5.5 Voltage and Current Combined Method

Fig 4.7 shows an equivalent circuit combining the circuits in figures 4.6 and 4.7 It is clear from equation (14) that the series active filter looks like a series connection of a voltage source V_{RH} and resistor K ohms. The receiving terminal voltage harmonics V_{RH} and supply current harmonics I_{SH} are given by the following:

$$V_{LH} = -\frac{KZ_F}{Z_F + K} I_{LH} \tag{19}$$

$$I_{LH} = \frac{Z_F}{Z_F + K} I_{LH} \tag{20}$$



Equivalent circuit for combined method

Fig. 4.8

If K is set larger than Z_F for harmonics, the combined method can eliminate the supply current harmonics I_{SH} as effectively as the current detecting method can. Note that the supply harmonic and/or flicker voltage V_{SH} is excluded from equation (19). The first term on the right hand side of equation (14) plays an important role in harmonic current compensation of the load, while the second term contributes to the voltage flicker cancellation from V_{LH}. Assuming that K is infinite, the output voltage of the series active filter V_{AF} is given by

$$\lim_{K \to \infty} V_{AF} = Z_F I_{LH} + V_{SH} \tag{21}$$

The feedback gain K in the combined method can be set lower than that in the current detecting method because the voltage detecting loop in the combined method compensates for voltage flicker. The key idea of this control strategy is to obtain the component to be compensated by subtracting standard wave from the measured waves. Because the delay of detection and calculation it is difficult for either series active filter or shunt active filter to realize perfect voltage and current compensation. So the predictive control method is adopted to improve the compensation effect. It means that we take the calculated value, the component to be compensated, of the previous period as the compensating value of the next period, that is

for series active filter

$$V_{AF}^{(n+1)}(k)=V^{n}_{SH}(k) \tag{22}$$

and, for shunt active filter

$$I_{CF}^{(n+1)}(k)=I_{LH}^{(n)}(k) \tag{23}$$

The detection of compensation component:

According to the instantaneous active power definition, we have

$$p_n = v_{an}i_{an} + v_{bn}i_{bn} + v_{cn}i_{cn} \qquad \text{where n} = 1, 2, 3\ldots\ldots\ldots \text{N} \tag{24}$$

Where N is the sampling number per period, the average active power in one cycle can be given as:

$$\overline{P} = \frac{1}{N}\sum_{n=1}^{N} p_n \tag{25}$$

I. Detection of current to be compensated

To detect the current to be compensated, the main problem is to separate active current component from the whole current. The load current can be divided into two parts, one is the active component, and the other is the current to be compensated, which comprises of reactive current, harmonic current and negative sequence current. Thus the load current can be expressed as follows:

$$i_L = i_{1p} + i_c \tag{26}$$

Where i_l is the load current, i_{1p} is the active component and i_c is the current component to be compensated. In the analysis of the shunt active power filter, we assume that the system voltage wave is sinusoidal, balanced and symmetrical. The RMS value of phase voltage and active current can be calculated as

$$V\varphi = \sqrt{\frac{1}{N}\sum_{n=1}^{N} v_n^2} \tag{27}$$

$$I\varphi = \frac{\overline{P}}{3V\varphi} \tag{28}$$

The real time value of fundamental active current can be obtained by the following equations

$$\begin{aligned} i_a &= \frac{\overline{P}}{3V\varphi} sin\omega t \\ i_b &= \frac{\overline{P}}{3V\varphi} sin(\omega t - 2\pi/3) \\ i_c &= \frac{\overline{P}}{3V\varphi} sin\,(\omega t + 2\pi/3) \end{aligned} \tag{29}$$

But these equations are difficult to be used to calculate the real time current because of the difficulties of determining the variable t. the active load equivalent resistance;

$$R\varphi = \frac{V\varphi}{I\varphi} \tag{30}$$

Where $V\varphi$ and $I\varphi$ is the RMS value of phase voltage and current. Therefore, we can obtain the active current with the same frequency and phase shift as the system voltage:

$$\begin{aligned} i_{ap} &= \frac{v_a}{R\varphi} \\ i_{bp} &= \frac{v_b}{R\varphi} \end{aligned} \tag{31}$$

$$i_{cp} = \frac{v_c}{R\varphi}$$

Subtracting the currents i_{ap}, i_{bp} *and* i_{cp} from detected load current i_a, i_b and i_c respectively, the current to be compensated can be obtained as:

$$\begin{aligned} i_{ac} &= i_a - i_{ap} \\ i_{bc} &= i_b - i_{bp} \\ i_{cc} &= i_c - i_{cp} \end{aligned} \tag{32}$$

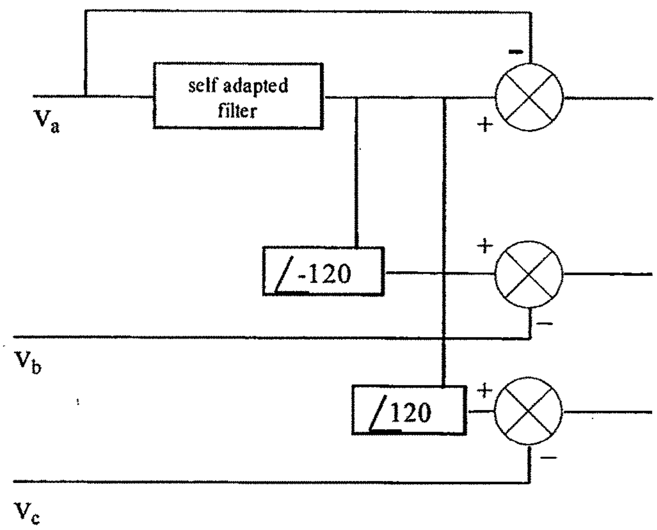
II. Detection of voltage to be compensated

In the analysis of shunt active power filter, we assume that the three phase voltage is balanced and symmetrical. Series active power filter is designed to compensate voltage harmonics and voltage flick. The assumption that voltage is sinusoidal is not valid in this situation. Hence, to get balanced and symmetrical three phase voltage the self adaptive filter method can be used which is shown in fig 4.8 given below. In this method the fundamental phase voltage is measured by the self adapted filter firstly. Then one can obtain the power frequency voltage of phase b and c,

$$\begin{aligned} v_{ba} &= v_{aa}\angle -120 \\ v_{ca} &= v_{aa}\angle 120 \end{aligned} \tag{33}$$

Subtracting the v_{aa}, v_{ba} *and* v_{ca} from voltage measurement system respectively, voltage component to be compensated can be determined as follow

$$\begin{aligned} v_{ac} &= v_a - v_{aa} \\ v_{bc} &= v_b - v_{ba} \\ v_{cc} &= v_c - v_{ca} \end{aligned} \tag{34}$$



4.6 Implementation of the Proposed UPQC Algorithm

The realization of the UPQC can be divided into two parts: circuit realization and control strategy. The topology circuit was shown in fig 4.2. The flow chart of control strategy is shown in fig 4.9 [48, 49].

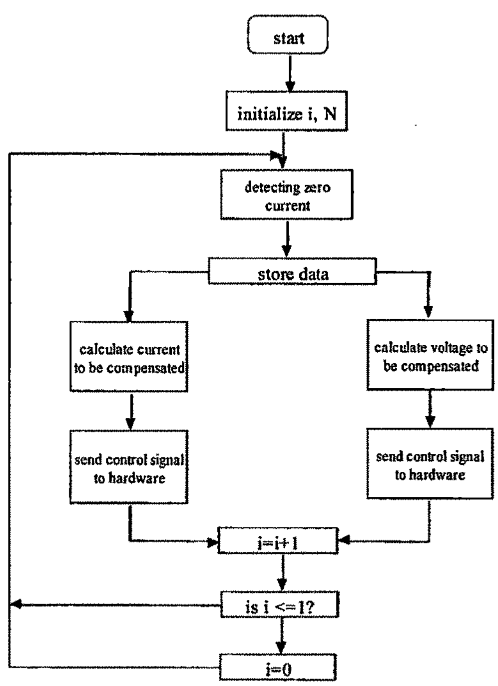


Fig. 4.9 Flow chart for control strategy of UPQC

4.7 Conclusion

In this chapter the unified power conditioner (UPQC) has been discussed in detail. In this the Mathematical Modeling, Operating Principle and Control scheme of the UPQC have been discussed in detail. The simulation blocks and their respective results of shunt and series active power filters and unified power quality conditioner have been shown. A very simple hysteresis current controller based control technique with help of unit vector template is proposed for STATCOM. DVR is simulated with abc to dq0 base new control algorithm to generate the pulse Phase Locked Loop (PLL) is used to generate unit sinusoidal wave in phase with main voltage. The combination of shunt and series Fact devices test on the RL load and DC machine