Analysis of UPQC with Advanced Control Scheme under Different Situations

Rama chandra prabhu A, Padhmanabhaiyappan S

Abstract—Power quality has become an important factor in power systems, for consumer and household appliances with proliferation of various electric and electronic equipment and computer systems. The main causes of a poor power quality are harmonic currents, poor power factor, supply-voltage variations, etc. In recent years unified power quality conditioner (UPQC) is being used as a universal active power conditioning device to compensate both harmonics as well as reactive power. In this work, UPQC has been modeled for both active and reactive power compensation using different control strategies. The behavior of UPQC has been analyzed with sudden switching of R-L loads, and R-C loads as well as occurrences of different shunt faults. The simulation results based on Matlab/Simulink are discussed in detail in this paper.

IndexTerms—Power quality, shunt active filter, series active filter

I. INTRODUCTION

The modern power distribution system is becoming highly vulnerable to the different power quality problems [1-2]. The extensive use of non-linear loads is further contributing to increased current and voltage harmonics issues. Furthermore, the penetration level of small/large-scale renewable energy systems based on wind energy, solar energy, fuel cell, etc., installed at distribution as well as transmission levels is increasing significantly. Unified power quality control was widely studied by many researchers as an eventual method to improve power quality of electrical distribution system [1-3]. The function of unified power quality conditioner is to compensate 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. Therefore, the UPQC is expected to be one of the most powerful solutions to large capacity loads sensitive to supply voltage flicker/imbalance [2]. The UPQC consisting of the combination of a series active power filter (APF) and shunt APF can also compensate the voltage interruption if it has some energy storage or battery in the dc link [3]. The shunt APF is usually connected across the loads to compensate for all current-related problems such as the reactive power compensation, power factor improvement, current harmonic, compensation, and load unbalance compensation (3,4) whereas the series APF is connected in a series with the line through series transformers. It acts as controlled voltage source and can compensate all voltage related problems, such as voltage harmonics, voltage sag, voltage swell, flicker, etc.

In this work, UPQC has been modeled for both active and reactive power compensation using different control strategies. The system has been modeled using MATLAB/SIMULINK 7.5. The analysis has been carried out with non-linear loads using sudden switching of RL loads and RC loads. The analysis has also been carried out with different types of shunt faults.

II. MODELING OF UPQC

The simplified diagram of UPQC with series and shunt active filters has been shown in Fig. 1(a) and its equivalent circuit is shown in Fig. 1(b). In this section, the UPQC modeling has been presented considering the equivalent circuit of UPQC. The compensation strategy, basic control function, series and shunt converter controls have been explained for UPQC model development.

A. Compensation Strategy

As shown in Fig.1, vsis the supply voltage. vc, Icare the series
compensation voltage, shunt compensation current and vL, iL are the load voltage and current respectively. The source voltage may contain negative, zero as well as harmonic components. Per phase voltage of the system can be expressed as:

\[ V_{sa} = V_{1a}(t) + V_{1n} + \sum_{k=2}^{\infty} V_{sk}(t) \quad (1) \]

\[ V_{sa} = V_{1a}(t) + V_{1n} + \sum_{k=2}^{\infty} V_{sk}(t) \quad (2) \]

Where \( V_{1a} \) is the fundamental frequency positive sequence component, \( V_{1n} \) is fundamental frequency negative sequence components respectively. \( V_{1p} \) is the positive sequence voltage amplitude and \( V_{1n} \) is the negative sequence voltage amplitude. The last term of equation represents the harmonic content in the voltage. In order for the load voltage to be perfectly sinusoidal and balanced, the series filter should produce a voltage of:

\[ V_{ca} = (V-V_{1p}) \sin(\omega t+\Theta_{1p}) + V_{1n}(t) - \sum_{k=2}^{\infty} V_{sk}(t) \quad (3) \]

The functions of the shunt active filter is to provide compensation of the load harmonic current, load reactive power demand and also to maintain dc link current constant. To provide load reactive power demand and compensation of the load harmonic and negative sequence components, the shunt APF acts as a controlled current source and its output should include harmonic, reactive and negative sequence components in order to compensate these quantities in the load current [13]. The per phase load current of shunt active filter is expressed as:

\[ I_{a1} = I_{1p}(\omega t+\Theta_{1p}) + I_{1n1} + \sum_{k=2}^{\infty} I_{alk} \quad (4) \]

B. Shunt converter control

The shunt APF compensates current harmonics in addition to maintaining the dc link current at a constant level. To achieve this, dc link current of the UPQC is compared with a constant reference current of magnitude equal to peak of harmonic current [14]. The error between measured dc link current and reference current is processed in a PI controller. The output of PI controller is added to real power loss current and reference current of magnitude equal to peak of this, dc link current of the UPQC is compared with a constant equal to peak amplitude of fundamental input voltage. The compensation signals for series filter are thus obtained by comparing these reference load voltages with actual source voltage using equation (14).

\[
\begin{bmatrix}
  v_a^* \\
  v_b^* \\
  v_c^*
\end{bmatrix} =
\begin{bmatrix}
  1/2 & -1/2 & -1/2 \\
  0 & \sqrt{3}/2 & -\sqrt{3}/2
\end{bmatrix}
\begin{bmatrix}
  v_a \\
  v_b \\
  v_c
\end{bmatrix}
\]

\[
\begin{bmatrix}
  I_a^* \\
  I_b^* \\
  I_c^*
\end{bmatrix} =
\begin{bmatrix}
  1/2 & -1/2 & -1/2 \\
  0 & \sqrt{3}/2 & -\sqrt{3}/2
\end{bmatrix}
\begin{bmatrix}
  i_a \\
  i_b \\
  i_c
\end{bmatrix}
\]

From equation 9 the values of \( p \) and \( q \) can be expressed in terms of dc components plus the ac components as follows:

\[ p = \bar{p} + p_c, \quad q = \bar{q} + q_c \]

Where \( \bar{p} \) is the dc component of the instantaneous power \( p \), and is related to the fundamental active current. To compute harmonic free unity power factor, three- phase currents, compensating powers \( p_c \) and \( q_c \) are selected as:

\[ p_c = p_{dc} + p_{loss} \quad (11) \]

\[ q_c = 0 \quad (12) \]

Where, \( p_{loss} \) is the instantaneous active power corresponding to the switching loss and resistive loss of UPQC. The orthogonal components of the fundamental current are obtained as follows:

\[
\begin{bmatrix}
  I_a^* \\
  I_b^*
\end{bmatrix} =
\begin{bmatrix}
  \bar{v}_a & \bar{v}_b \\
  -\bar{v}_b & \bar{v}_a
\end{bmatrix}
\begin{bmatrix}
  p_c \\
  q_c
\end{bmatrix}
\]

C. Series converter control

The load voltage to be perfectly sinusoidal and balanced, the series filter should produce a voltage equal to equation (3). The reference load voltages are obtained by multiplying the unit vector templates with a constant equal to peak amplitude of fundamental input voltage. The compensation signals for series filter are thus obtained by comparing these reference load voltages with actual source voltage using equation (14).

\[
\begin{bmatrix}
  v_a^* \\
  v_b^* \\
  v_c^*
\end{bmatrix} =
\begin{bmatrix}
  \bar{v}_a - v_a \\
  \bar{v}_b - v_b \\
  \bar{v}_c - v_c
\end{bmatrix}
\]

The series-APF should behave as a controlled voltage source and its output should follow the pattern of voltage given in equation (2). This compensating voltage signal can be obtained by comparing the actual load terminal voltage with the desired value. These compensation signals are compared with actual signals at the terminals of series filter and the error is taken to hysteresis controller to generate the required gating signal for series filter as shown in Fig. 3.

Fig.2 Control block diagram of shunt filter controller
Fig. 3 Control block diagram of series-APF

III. SIMULATION RESULTS

An ideal three-phase sinusoidal supply voltage of 11kV, 50Hz is applied to the non-linear load (diode rectifier feeding an RL load) injecting current harmonics into the system.

Fig. 4 (a)

Fig. 4 Simulated results of UPQC (a) Load Voltage (b) Load current with the switching of RL Load

Fig. 5 (a)

Fig. 5 Simulated results of UPQC (a) Load Voltage (b) Load current with the sudden switching of RC load

The power transfer capability of long transmission lines is usually limited by their thermal capability. Utilizing the existing transmission line at its maximum thermal capability is possible with UPQC. The series inverter injects voltage of variable magnitude and phase into the transmission line at the point of its connection, thereby controlling real and reactive power flow through the line. For the shunt fault conditions the UPQC is switched on at the time interval between 0.3s to 0.4s respectively.

Fig. 6 (a)
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IV. CONCLUSION

This paper describes an improved control strategy for UPQC system operation. The performance of UPQC has been studied under different cases of R-L, R-C loads switching and different kind of shunt faults. AC voltage regulation and power factor of the transmission line is also improved. The UPQC provides an improvement in the real and reactive power flow through the transmission line. UPQC provides reliable performance in switching of loads as well as different types of shunt faults. UPQC provides compensation as well as improves power factor.

REFERENCES