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Improvement of Power Quality using an Integrated Control Technique of Unified Power Quality Conditioner (UPQC)

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Abstract-In this paper an ideal control strategy of harmonics and the load-reactive power demand compensation by connecting a three-phase unified power quality conditioner (UPQC) is presented. To reduce the power quality problems the flexible dual control technique of UPQC is more reliable for power distribution system. The polluted loads at the end user side are always creates the power quality problems at the point of common coupling (PCC). The UPQC system can use for series and parallel power conditioning and they act as sinusoidal current and voltage source inverters respectively. The main purpose of series and shunt active power filter (APF) is to inject voltage and current at significant phase angle which converts non-ideal mains into ideal mains without changing the supply frequency. This is also called as dual compensation methodology. The proposed UPQC system can connect to both three-phase three-wire and three-phase four-wire distribution systems and the fourth wire act as neutral conductor. In this paper simulation results based on MATLAB/Simulink are performed, analyzed and studied.

Index Terms-Active Power Filter (APF), Non-Linear Load, Point of Common Coupling (PCC), Power Quality (PQ), Power System Harmonics, Reactive Power Compensation, Three-Phase Distribution System, Total Harmonic Distortion (THD), Unbalanced Load, UPQC.

1. INTRODUCTION

The definition of electric power quality (PQ) can be written as, maintaining the generated voltage, current and frequency waveforms to standard sinusoidal. The PQ problems are harmonic distortion, under voltages and over voltages, voltage unbalance, voltage flicker, fluctuations, voltage notching, voltage interruption, transient disturbances and frequency variations. These PQ problems are responsible for false triggering signals for relays, circuit breakers, malfunction of sensitive electronic equipments, false reading of digital measuring meters, heating of electric machines, noise in the machines, increase or decrease in the speed of motors and hunting. The causes of harmonic currents are non-linear loads, unbalanced loads, and reactive power due to the heavy inductive loads as electric induction furnace. Voltage sag occurs due to switching of heavy loads and voltage swells occurs due to single line to ground faults in the distribution system. Some active power injection techniques like unified power quality conditioners (UPQC), shunt filters, series filters, and hybrid active power filters (APFs), synchronous condenser, static synchronous compensators (STATCOMs) and dynamic voltage restorers (DVRs) confines the PQ problems [10].

The simple and good idea is to use APFs for the termination of PQ issues. The fundamental principle of series and shunt APFs are as, the shunt APFs confines the current related problems, which are current harmonics, reactive current, current unbalance and voltage related issues such as voltage harmonics, voltage sag, swell and voltage unbalance are compensates by the series APF. UPQC has the above two converter/filter and provides the active power conditioning the three-phase distribution system by using dual compensation methodology. The UPQC solves both the current and voltage related problems from the three-phase distribution system simultaneously [8].

The main advantages of the UPQC are as: i) eliminates harmonic current as well as voltage simultaneously ; ii) reactive power compensation to the load; iii) balances the load; iv) balance the voltage and current equally at 120 degrees to each other; v) interruption free power; vi) eliminate the flicker from the supply. In this UPQC system, input/output current and voltage is controlled by the synchronous reference frame (SRF) dependent controllers. Here continuous control references into the SRF based controllers is allowed due to voltage and current references are alternating sinusoidal which decreases errors by the use of proportional-integral (PI) controllers. In this UPQC system, phase angle θ evaluates by phase locked loop (PLL) and θ is also use to generate the sinusoidal input current references. To determining the coordinates of the unit vector ($\sin\theta$ and $\cos\theta$) θ can be use for it. In the UPQC system, a three-phase PLL method is used, a self-tunning filter (STF) eliminates the harmonic currents and unbalances and transient in the load. The location of STF is in between bus voltage and the 3pPLL. In the first stage 3pPLL calculates angular frequency and in second stage this angular frequency sets by the STF cut-off frequency. The flexible UPQC can connect in three-phase three-wire (3P3W) or three-phase four-wire (3P4W) distribution system to compensate the losses of the line and enhance the PQ at utility as well as at the end user side and makes the supply system reliable. At plant site generally UPQC uses 3P3W, for single phase loads, the load requires the fourth wire called neutral conductor. In this paper control of the UPQC based 3P4W distribution system is calculated by the MATLAB/simulation and the p-q theory is used to obtain the references of the voltage and current as compensation. Static and dynamic performance of the distribution system with the UPQC is obtained by MATLAB/simulink software [10].

2. BASIC SYSTEM CONFIGURATION

Fig.1 shows a basic block diagram of the UPQC system, series and shunt APF which is shown by single line diagram. Both the filter injects the active voltage and current in the system at a significant level. The series-active filter terminates the harmonics between a sub-transmission system and a distribution system and also diminishes the voltage flicker/imbalance as well as increases the voltage regulation and harmonic compensation at PCC. The shunt APF absorbs the current harmonics, compensates reactive power demand and removes the negative-sequence current, and regulates the dc-link voltage between both active filters at a significant level.

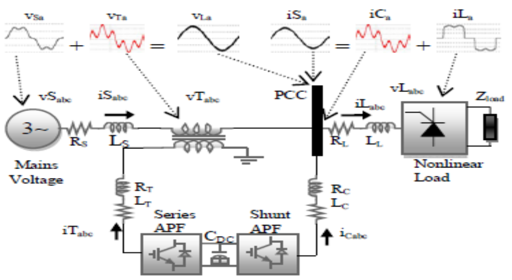

Fig. 1. Basic UPQC system configuration

The UPQC is the ideal combination of series APF and shunt APF [12].

3. CONTROL STRATEGY

The dual compensation strategy is presented is shown in Fig. 1. Both the PWM converters are sharing the same dc-link. The UPQC is connected between a 3P3W distribution system and a 3P4W plant site composed of several types of three-phase and single-phase loads, non-linear and unbalanced loads. It is assumed that the single-phase loads use the neutral conductor to operate the single phase loads. In the case of 3P4W distribution system is necessary, which is composed of three line conductors and a neutral conductor to feed the end user loads. Thus, it is to be noted that, in the UPQC system of 3P4W distribution system the neutral current flows through the fourth wire connected to shunt APF which is also called as neutral conductor.

3.1. *Series APF*

The series APF uses the concept of unit vector template (UVT). The UVT is generated from the unbalance supply quantities [11]. The extraction process is shown in Fig. 2. The load terminal voltage (v_{La}, v_{Lb}, v_{Lc}) should be balance and sinusoidal with required amplitude and with in proper phase angle. Series APF injects voltage opposite to the non-ideal mains voltage and these voltage comes opposite to each other and cancels them self. The load reference voltage obtained by this dual control strategy is compared with the load voltage signals and the error is feedback to a hysteresis controller which generates the required gating signal for the series inverter PWM controller.

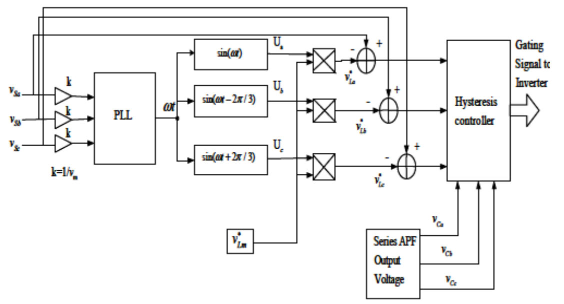

Fig. 2. Control block diagram of series APF

The hysteresis band controller generates and controls the pattern of switching in the inverters. Hysteresis controller works on the feedback error signals [4].

3.2. *Shunt APF*

The reference signals for the shunt APF are generated by the reactive power theory. Fig. 3 describes the control technique of the shunt APF. By equation “Eq. (1)” and “Eq. (2)” the three-phase voltage and current is converted to α-β-0 [4].

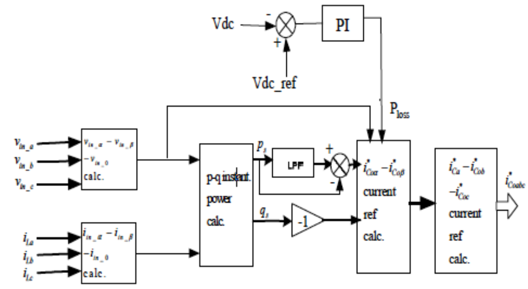

Fig. 3. Control block diagram of shunt APF

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{\frac{3}{2}} & -\sqrt{\frac{3}{2}} \end{bmatrix} \begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix} \qquad \text{Eq. (1)}$$

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{\frac{3}{2}} & -\sqrt{\frac{3}{2}} \end{bmatrix} \begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} \qquad \text{Eq. (2)}$$

"Eq. (3)" contains real power (p), imaginary power (q) and the zero-sequence components of the load.

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \qquad \text{Eq. (3)}$$

The real and imaginary power is,

$$p_0 = v_0 * i_0 \; ; \; p = \bar{p} + \tilde{p} \qquad \text{Eq. (4)}$$

p_0 is calculated by using average and oscillating components.

$$\begin{bmatrix} i *_{s\alpha} \\ i *_{s\beta} \end{bmatrix} = \frac{1}{v^2_\alpha + v^2_\beta} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \bar{p} + p_0 + \bar{p}_{loss} \\ 0 \end{bmatrix} \qquad \text{Eq. (5)}$$

$i *_{s\alpha,}$ $i *_{s\beta}$ and $i *_{s0}$ are the reference current of shunt filter in $\alpha - \beta - 0$ coordinates. These currents are transformed to three-phase system as below.

$$\begin{bmatrix} i *_{sa} \\ i *_{sb} \\ i *_{sc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \sqrt{\frac{3}{2}} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\sqrt{\frac{3}{2}} \end{bmatrix} \begin{bmatrix} i *_{s0} \\ i *_{s\alpha} \\ i *_{s\beta} \end{bmatrix} \qquad \text{Eq. (6)}$$

The load side neutral current is compensated by finding the reference current. After finding the reference current, signals are then compared with the three-phase source currents, and the errors feedback to the hysteresis band PWM controller to generate the required gating signals for the shunt APF switches [5].

4. MATLAB MODELING

In Fig.4 the three-phase non-linear load is connected through the three-phase supply. The shunt APF is connected across the loads through transformer, whereas the series APF is connected in a series with the line through series transformers. The three-phase and single phase load is connected at the end user sides. The series and shunt APF controls the reactive power in the system by maintaining the significant value of phase angle between the voltage and current. In the figure above the three-phase and single-phase diode bridge rectifier is connected in the system to convert AC into DC supply as required by the load.

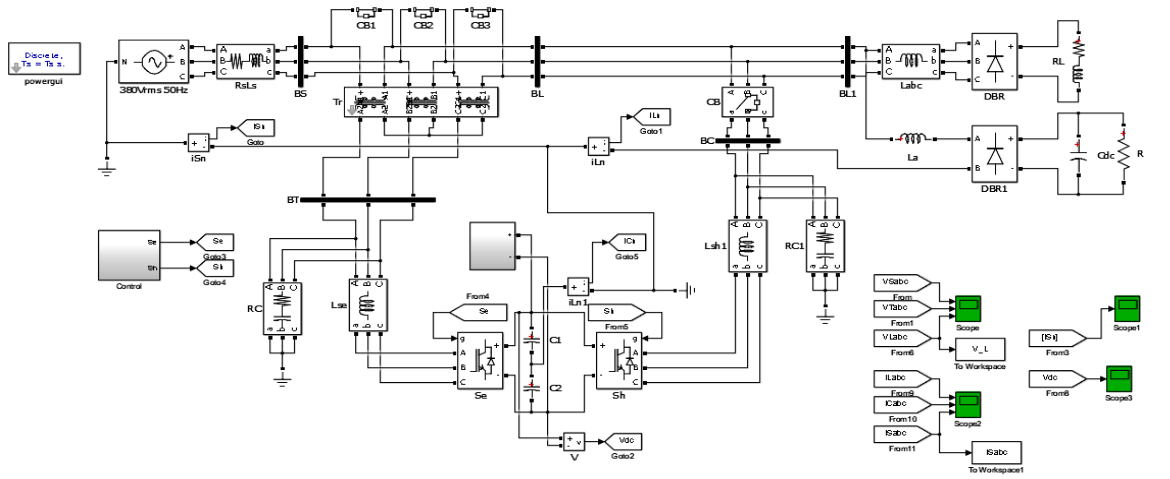

Fig.4. Simulink diagram of the UPQC system

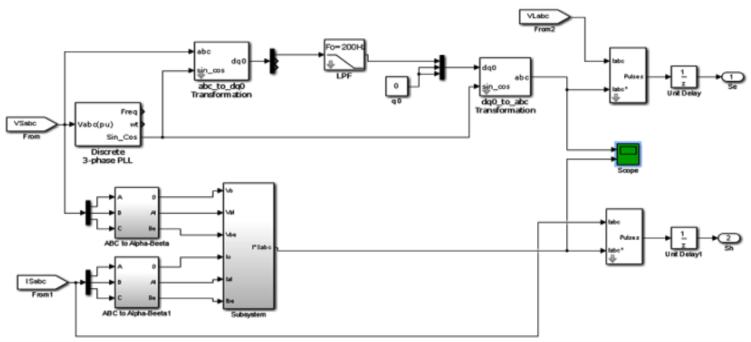

Fig. 5. Simulation of combine series and shunt APF controller

In the Fig. 5 the simulink diagram of the combine series and shunt APF is as shown. This system uses abc to dq0 park transformation conversion. The output signal of the PLL is given to the abc to dq0 converter block. The PLL compares the input frequency with output frequency with the feedback loop. The PLL contains the three major blocks in it which is phase detector, low pass filter (LPF) and voltage controlled oscillator.

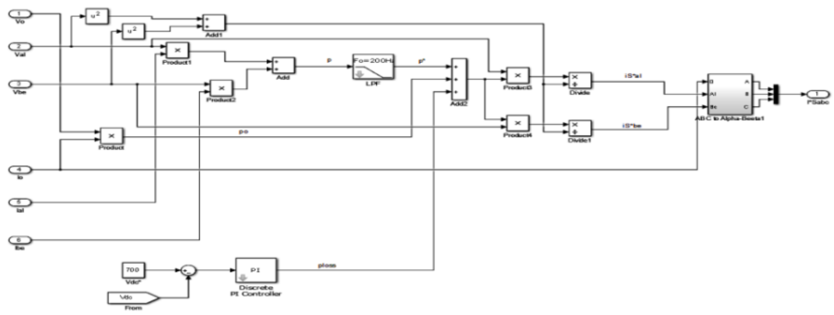

Fig. 6. Simulation of shunt APF reference current signal generation

5. SIMULATION AND RESULTS

Fig. 7 shows the three-phase source voltage, terminal voltage and load voltage (VS_{abc}, VT_{abc} and VL_{abc}), before 0.2 second the UPQC is not connected in the system and after 0.2 second the UPQC is connected in the system and the system performance is analyzed.

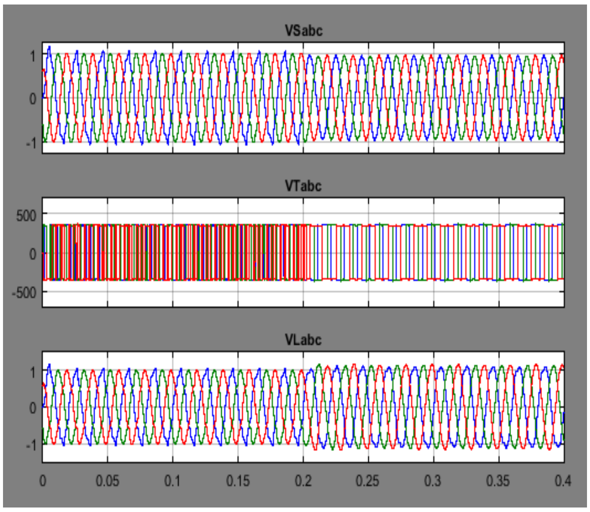

Fig. 7. Waveforms of the three-phase source voltage, terminal voltage and load voltage

After 0.2 seconds the source voltage, terminal voltage and the load voltage have less distortion. Here the performance of the UPQC system is obtained under steady-state and dynamic load operation.

In Fig. 8(a) the %THD of source current IS_{abc} when UPQC is not connected in the system is as shown. The %THD is 27.27% which is high.

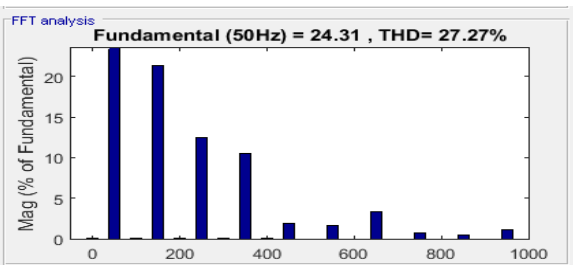

Fig. 8(a). %THD of source current IS_{abc} when the UPQC is not connected in the system

Percentage THD should be as minimum as possible, THD decreases then power quality increases.

In the next figure it is seen that implementation of UPQC in the system results in the significant reduction in the % THD.

In Fig. 8(b) the %THD of source current IS_{abc} when UPQC has been connected in the system is as shown. The %THD is 4.99% which is in permissible limit.

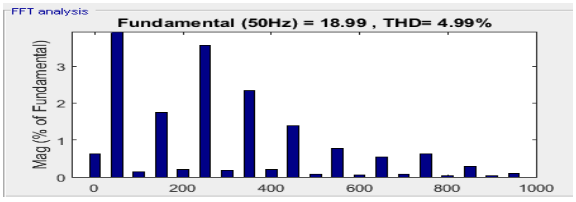

Fig. 8(b). %THD of source current IS_{abc} after the UPQC has been connected in the system

Fig. 9(a) shows the %THD of load voltage V_L when UPQC is not connected in the system. The %THD is 10.36% which is high and creates the PQ problems at PCC.

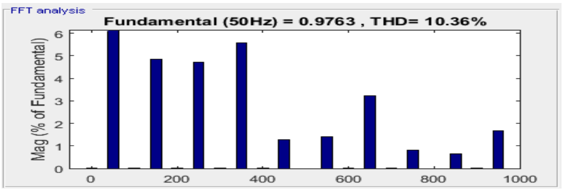

Fig. 9(a). %THD of load voltage V_L before the UPQC operation

Fig. 9(b) shows the %THD of load voltage V_L when UPQC has been connected in the system. The %THD is 7.45%.

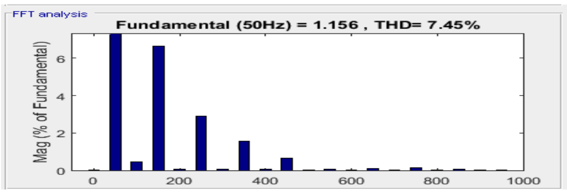

Fig. 9(b). %THD of load voltage after the UPQC operation

In the Fig. 10 the neutral current is zero. When neutral current is zero, all the three voltages and currents are in phase and phase angle is near to zero.

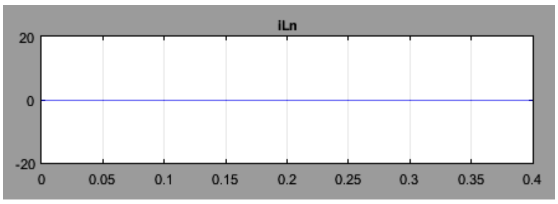

Fig. 10. Waveform of the neutral current

In Fig. 11, the source current IS_{abc} is shown. When the UPQC is not connected in the system the source current is 45 A. AS soon as the UPQC put in the operation the source current reduced to 20 A. When source current reduces the power factor of the system improves.

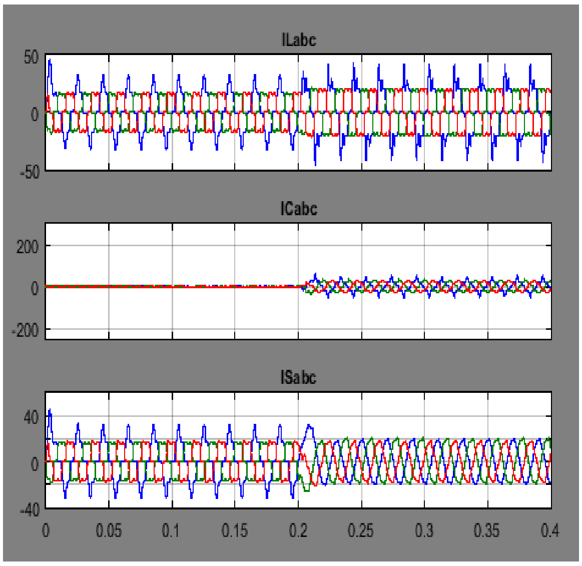

Fig. 11. Waveforms of the load current, filter current and source current of the system

The waveform of the dc-link voltage is as shown in the Fig. 12. The dc-link has the magnitude of 700V DC.

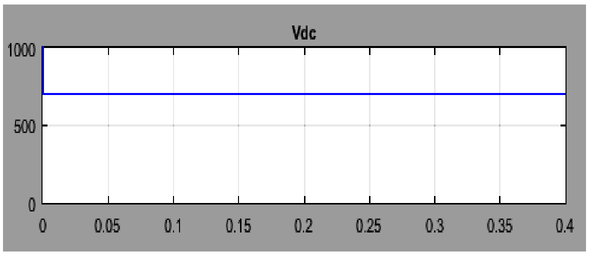

Fig. 12. Waveform of the dc-link voltage

6. CONCLUSION

In this paper it is seen that the dual control technique of UPQC is useful to mitigate PQ problems. It is seen that when the UPQC is connected in the three-phase distribution system, it compensates reactive power and reduces the voltage and current harmonics at the PCC. The p-q theory is utilized to generate the reference signals for the shunt APF and the series APF used the concept of unit vector template (UVT). From the above simulation results, the performance analysis on the basis of %THD and it is observed that harmonics are reduced as per IEEE Standard.

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