Control Approach of shunt active power filter for Current compensation

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Abstract - Power system can employ many attractive applications of power electronics technologies for current compensation. A control approach of shunt active filter is proposed for power quality improvement in three phase distribution system. The shunt active filter is utilized to overcome all current related problems, such as current harmonics, reactive current and current unbalance. The steady state and dynamic operation of control circuit in different load current and utility voltages conditions is studied through simulation results. This method has acceptable dynamic response with a very simple conFigureuration of control circuit.

Key Words: Harmonics, Active Power Filter, Current Compensation, Power Quality, Voltage Source Inverter

I.INTRODUCTION

The demands to the power reliability and the power quality become stricter due to the popular application of variable frequency and variable speed drives, robots, automated production lines, accurate digital-control machines, programmable logic controllers, information manage systems in computers and so on. These devices and computer systems are very sensitive to the power supply ripple and various disturbances[1].

All these devices are nonlinear loads and become sources of harmonics. The power quality problems in distribution power systems are not new, but customer awareness of these problems has recently increased[2]. For example, for many years interruptions shorter than several minutes were not considered as a cause of concern to most consumers. When the consumer demands of quality power are rising, the term power quality receives a special significance. Low quality power affects electricity customers in many ways. The lack of quality power can cause loss of production, damage of equipment or appliances or can even be detrimental to human health. Therefore, it is very important to maintain a high standard of power quality [3].

There are sets of conventional solutions to the power quality problems, which have existed for a long time. However these conventional solutions use passive elements and do not always respond correctly as the nature of the power system conditions change[4].The increased power capabilities, ease of control, and reduced costs of modern semiconductor devices have made power electronic converters affordable in a large number of applications. New flexible solutions to many power quality problems have become possible with the aid of these power electronic converters.

Power electronic based power processing offers higher efficiency, compact Size and better controllability. But on the flip side, due to switching actions, these systems behave as non-linear loads. Therefore, whenever, these systems are connected to the utility, they draw non-sinusoidal or lagging current from the source.

As a result these systems pose themselves as loads having poor displacement as well as distortion factors[5]. Hence they draw considerable reactive volt amperes from the utility and inject harmonics in the power networks. .

Custom Power devices also called as power quality compensator employ power electronic or static controllers in medium or low voltage distribution systems for the purpose of supplying a level of power quality that is needed by electric power customers that are sensitive to root mean square (RMS) voltage variations and voltage transients[6]. Custom Power (CP) devices include static switches, power converters, injection transformers, master control modules and/or energy storage modules that have the ability to perform current interruption and voltage regulation functions in a distribution system to improve power quality[7].

Active Power Filter is a shunt connected compensating device. The main purpose of this device is to protect supply currents from current harmonics in the load side. This is accomplished by rapid shunt current injection to compensate for the harmonics in the load current. Dynamic Voltage Restorer is a series connected compensating device that protects sensitive loads from sag/swell disturbances in the supply side[8].This is performed by rapid series voltage injection to compensate for the drop/rise in the supply voltage.A Unified Power Quality Conditioner is an up-to-date Power Quality conditioning device of the custom power device family. It is speculated that this will be a universal solution to all power quality issues because of its voltage and current compensating capability[9]. The UPQC is realized by the integration of series and shunt active power filters (APF) sharing a common dc bus capacitor. This compensator can solve power quality problems such as voltage sag, reactive power, voltage and current harmonics and control the power flow and voltage stability[10].

Active filter have been designed, improved, and commercialized in past three decades. They are applicable to compensate current based distortions such as current harmonics, reactive power and neutral current. They are also used for voltage based distortion such as voltage harmonics, voltage flickers, voltage sags and voltage swells and voltage imbalances[11].

II. SHUNT ACTIVE FILTER

Based on topologies, they are two kinds of active filters such as current source and voltage source active filters. Current source active filters (CSAF) employ and inductor as the DC energy storage device as shown in Figure 1. In voltage source active filter (VSAF), a capacitor acts as the storage element as shows in Figure 2. Between these two topologies VSAF are inexpensive, lighter, and easier to control compare to CSAF. There are types of connection that can be used for active filter such as shunt active filter, series active filter, parallel active filter, and hybrid active filter.

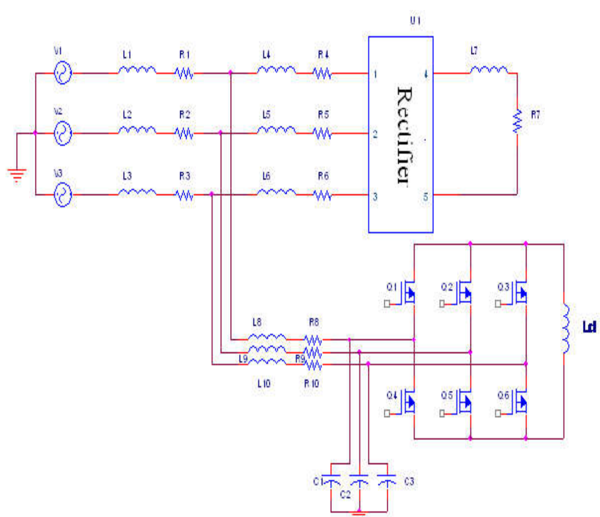

Figure-1:*A typical three phase current source active filter*

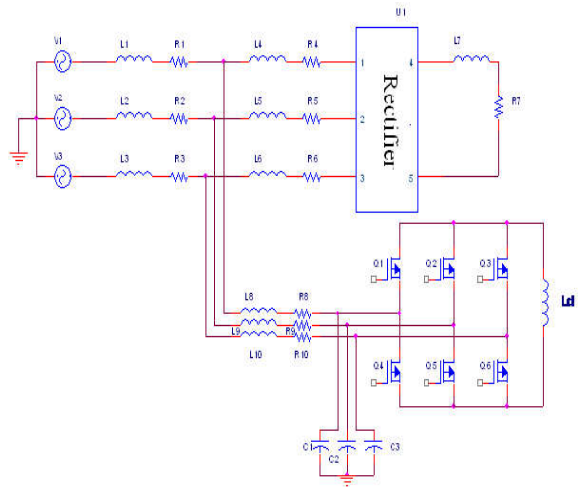

Figure-2: *A typical three phase voltage source active filter*

A shunt active filter is capable of removing harmonics from supply of commercial and industrial sites. The new technique based on sinusoidal subtraction by using filter to make an inverter which is more responsive to harmonics.

One of the most serious problems facing on active filter rating that is required to compensate harmonics from particular load. A parallel connected active filter able to limit of harmonics cancellation provided and the size can be selected accordingly to achieve any desired level of cancellation. One good thing of using parallel connected active filter is that it can provide enough compensation so that the load or filter compensation will be within some specified guidelines for harmonic generation.

The shunt active power filter based on Voltage Source Inverter (VSI) structure is an attractive solution to harmonic current problems. The shunt active filter is a PWM voltage source inverter that is connected in parallel with the load. Active filter injects harmonic current into the AC system with the same amplitude but with opposite phase as that of the load. The principal components of the APF are the VSI, DC energy storage device, coupling inductance and the associated control circuits.

The power system is conFigureured with four wires. The AC source is connected to a set of non-linear loads. Voltages V_{sa}, V_{sb}, V_{sc} and current I_{la}, I_{lb}, I_{lc} indicate the phase voltages and currents at the load side respectively. I_{ln} is the neutral current of the load side. The APF consists of three principal parts, a three phase full bridge voltage source inverter, a DC side capacitor and the coupling inductance L_f. The capacitor is used to store energy and the inductance is used to reduce the ripple present in the harmonic current injected by the active power filter. The shunt active filter generates the compensating currents to compensate the load currents I_{la}, I_{lb}, I_{lc} so as to make the current drawn from the source (I_{sa}, I_{sb}, I_{sc}) as sinusoidal and balanced. The performance of the active filter mainly depends on the technique used to compute the reference current and the control system used to inject the desired compensation current into the line. In this chapter, the instantaneous symmetrical components theory is used to determine the current references (I_{fa}*, I_{fb}*, I_{fc}*).

The primary goals of DSTATCOM are to cancel the effect of poor load power factor such that the current drawn from the source has a near unity power factor and to cancel the effect of harmonic contents in loads such that the current drawn from the source is nearly sinusoidal. In addition, it can also eliminate dc offset in loads.

III. CONTROL STRATEGY FOR SAF

The control strategy is basically the way to generate reference signals for shunt active filter. The compensation effectiveness of the SAF depends on its ability to follow with a minimum error and time delay to calculate the reference signals to compensate the distortions, unbalanced voltages or currents or any other undesirable condition. The basic of the hysteresis current control is based on an error signal between an injection current (I_{inj}) and a reference current of APF (I_{ref}) which produces proper control signals. The hysteresis band current controller decides the switching pattern of APF. The conventional hysteresis band current control scheme used for the control of APF is shown in Figure 3 . There are bands above and under the reference current. When the error reaches to the upper limit, the current is forced to decrease. When the error reaches to the lower limit, the current is forced to increase.

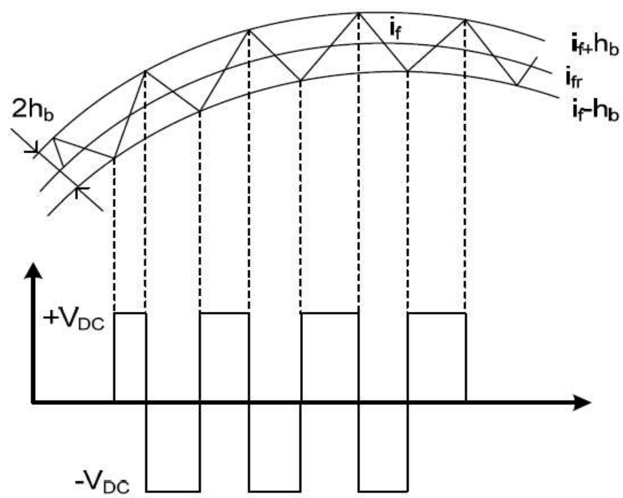

Figure-3: *Voltage and current waveforms of hysteresis band controller*

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IV.GENERATION OF REFERENCE CURRENT

The reference current for DSTATCOM is calculated by instantaneous symmetrical component theory. It is assumed that source voltages are balanced and are given by

$$v_{sa} = \sin \omega t$$

$$v_{sb}=\sin(\omega t-120^{\circ})$$

The symmetrical component theory

$$v_{sc}=\sin(\omega t+120^{\circ})$$

originally defined for steady state analysis of 3-phase unbalanced systems. This transformation is the result of multiplying the transformation matrix by the phasor representation of unbalanced 3-phase system.

$$\begin{aligned}&(\mathbf{v_{sb}} - \mathbf{v_{sc}} - 3\beta\, \mathbf{v_{sa}})\mathbf{i_{sa}}\\ &+ (\mathbf{v_{sc}} - \mathbf{v_{sa}} - 3\beta\, \mathbf{v_{sb}})\mathbf{i_{sb}} + (\mathbf{v_{sa}} - \mathbf{v_{sb}} - 3\beta\, \mathbf{v_{sc}})\mathbf{i_{sc}} = \mathbf{0}\end{aligned}$$

The instantaneous power in a balanced three-phase circuit is constant while for an unbalanced circuit it has a double frequency component in addition to a dc value. In addition, the presence of harmonics adds to the oscillating component of the instantaneous power .The objective of the compensator is to supply the oscillating component such that the source supplies the average value of the load power. Therefore,

$$i_{fa}^{*} = i_{la} - \frac{v_{sa} + (v_{sb} - v_{sc})\beta}{v_{sa}^{2} + v_{sb}^{2} + v_{sc}^{2}} p_{lav}$$

$$i_{fb}^{*} = i_{lb} - \frac{v_{sb} + (v_{sc} - v_{sa})\beta}{v_{sa}^{2} + v_{sb}^{2} + v_{sc}^{2}} p_{lav}$$

$$i_{fc}^{*} = i_{lc} - \frac{v_{sc} + (v_{sa} - v_{sb})\beta}{v_{sa}^{2} + v_{sb}^{2} + v_{sc}^{2}} p_{lav}$$

By using these Equation, reference compensator currents are calculated.

V. SWITCHING CONTROL OF DSTATCOM

The shunt component of UPQC can be controlled in two ways,

a)Tracking the shunt converter reference current, when the shunt converter current is used as feedback control variable. The load current is sensed and the shunt compensator reference current is calculated from it. The reference current is determined by calculating the active fundamental component of the load current and subtracting it from the load current. This control technique involves both the shunt active filter and load current measurements.

b)Tracking the supply current, when the supply current is used as the feedback variable. In this case the shunt active filter ensures that the supply reference current is tracked. Thus, the supply reference current is calculated rather than the current injected by the shunt active filter. The supply current is often required to be sinusoidal and in phase with the supply voltage.

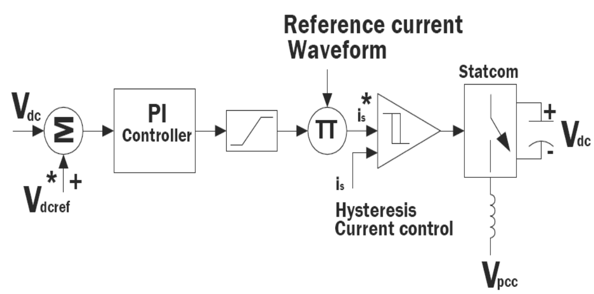

Figure- 4:*DC voltage control using PI controller*

Since the waveform and phase of the supply current is known, only its amplitude needs to be determined. Also, when used with a hysteresis current controller, this control technique involves only the supply current measurement. Thus, this is a simpler to implement method. Therefore it has been used in the UPQC simulation model.

In Figure 4, assume S and S1 are the status of the switch in top and bottom half of an inverter leg. The switch status, S=1 and S1=0 implies that the top switch of the inverter leg is closed and it connects the inverter leg to $V_{c1}=V_{dc}$ while the bottom switch in the same leg is open. Similarly for S=0 and S1=1, the bottom switch connects the inverter leg to $V_{c2}= -V_{dc}$ and the top switch in the inverter leg is open. Therefore, through the inverter switching arrangements the inverter supplies a voltage $\pm V_{dc}$. We now have to choose the control signal S=1 or 0 and S1=0 or 1, such that appropriate inverter connection is achieved. DC voltage control using PI controller is shown in Figure 4.2.Any deviation of the capacitor voltage from the reference is due to losses. The PI controller loops draws the loss from the ac system to hold the voltage constant.

In hysteresis control, the controlled current is monitored and is forced to track the reference within the hysteresis band. The inverter switches are made to change their states at instances when the controlled current touches the upper or lower limit of the hysteresis band. The controlled current is forced to decrease when it reaches the upper limit and to increase when it reaches the lower limit.

VI. SIMULATION RESULTS

This section presents the details of the simulation carried out to demonstrate the effectiveness of the proposed control strategy for the active filter for harmonic current filtering, reactive power compensation, load current balancing, load voltage compensation and neutral current elimination. In the proposed work, the reference compensator currents and voltages are generated using the instantaneous symmetrical component theory to achieve the load current compensation and reactive power compensation. The switching control of the voltage source inverter based on hysteresis current controller used in the DSTATCOM is presented.The simulation results before and after the compensation is presented

The simulation result is carried for distribution system with and without shunt active filter. Figure 5. shows the three phase voltage of the system with out shunt active filter. It can be seen that harmonics is disturbed in voltages.Active filter is connected to three phase voltage supply via non-negligible transmission impedance .

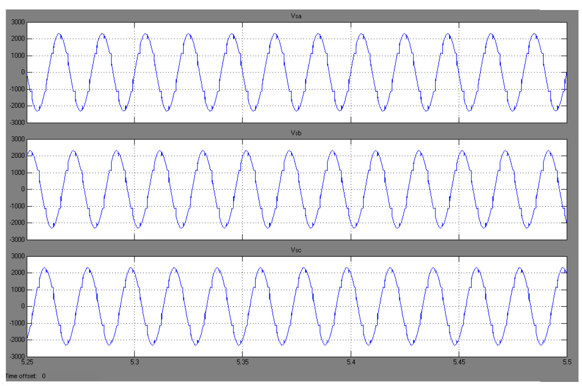

Figure-5: *Voltages of distribution system without SAF*

Figure 6. shows the three phase current of distribution system without shunt active filter. It can be seen that wave shapes are non-sinusoidal .Figure 7 shows the three phase current of distribution system with shunt active filter. The wave shapes are almost nearly sinusoidal.Three phase source voltage with SAF is shown in Figureure 8.Three phase load voltages with filter is shown in Figureure 9.

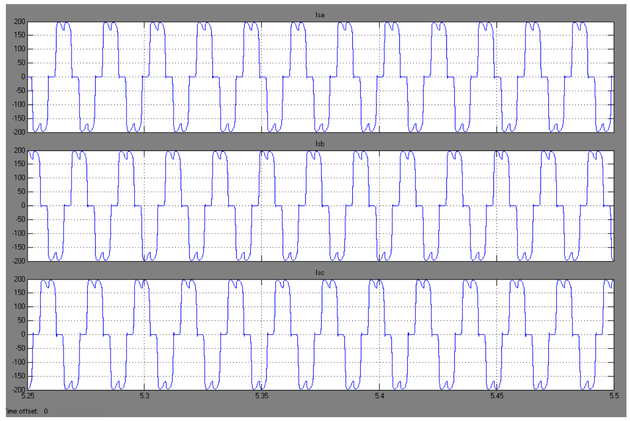

***Figure.6.** Currents of distribution system without SAF*

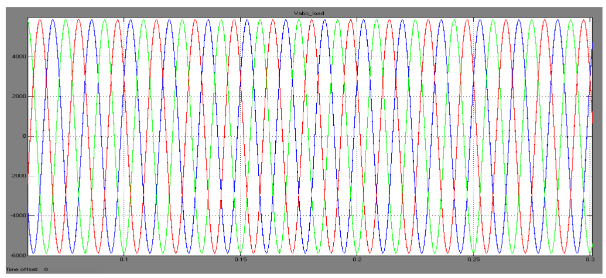

***Figure-7 :**Three phase source current with filter*

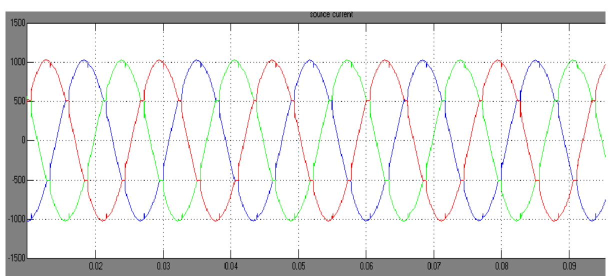

***Figure- 8:** Three phase source voltage with filter*

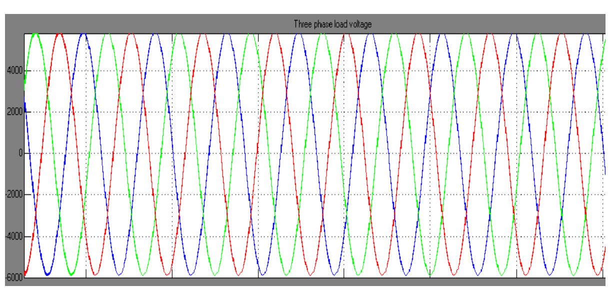

***Figure-9:** Three phase load voltage with filter*

VII. CONCLUSIONS

A new three-phase four-wire shunt active filter has been proposed for three-phase four-wire distribution system to improve the power quality. The performance of shunt active filter system has been demonstrated for neutral current compensation along with reactive power compensation, harmonic elimination and load balancing for both linear and non-linear loads. The shunt active filter has been found to meet IEEE 519-1992 standard recommendations of harmonic levels.

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