Shunt Active Filter Based Voltage Regulation and Harmonic Damping

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ABSTRACT

This paper discusses a shunt active ûlter intended for installation on a power distribution system. The active ûlter has an additional capability to regulate the distribution line voltage by means of adjusting reactive power. Theoretical analysis investigates the dynamic performance of combined harmonic damping and voltage regulation. As a result, harmonic damping makes it possible to improve the stability of the control loop for voltage regulation, and the combined harmonic damping. Experimental results are shown to verify the effectiveness of the combined harmonic damping and voltage regulation.

IndexTerms – Digital control, distributed generators, power distribution systems, shunt active ûlters, voltage regulation.

I. INTRODUCTION

Harmonic problems have been serious in industrial and utility power distribution systems. "Harmonic ampliûcation" is one of the most serious problems. It is caused by harmonic resonance between line inductance and power factor correction (PFC) capacitors installed by consumers. Active ûlters for damping out harmonic resonance in industrial and utility power distribution systems have been researched [1], [10]. The authors have proposed a voltage detecting shunt active ûlter for

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installation on a power distribution system [1], [2]. The main purpose of installing the active ûlter is to damp out the harmonic ampliûcation. The active ûlter is characterized by behaving like a resistor for harmonic frequencies, resulting in damping out the harmonic ampliûcation throughout a distribution line. Since a real distribution system consists of four to eight distribution lines, installing the active ûlter on the end bus of each line is effective in harmonic damping. On the other hand, distributed generators such as solar cells, wind turbines and soon have been developed and installed on utility power distribution systems. A distributed generator produces an amount of active power, and injects it into the distribution system. The active power inûuenced by weather and/or wind velocity causes voltage ûuctuations in the distribution line, because it changes independently of power demand from loads. Moreover, distributed generators may produce the following problem in a utility distribution system: Some newly developed towns, apartments and buildings are being equipped with solar cells. This may make difûcult voltage regulation throughout

Multiple distribution lines. A static synchronous compensator (STATCOM) [11]–[13] is one of the most effective solutions to regulate the line voltage. The STATCOM consists of a voltage source converter connected in shunt with the power system, and enables to control a leading or lagging reactive power by means of adjusting its ac voltage. A STATCOM for installation on a distribution system, or the so - called D-STATCOM,

has been researched and put into commission to solve voltage ûuctuations and / or voltage ûickers [14], [15]. It is possible to use a shunt active ûlter as a D-STATCOM, because they have the same circuit conûguration. However, no literature has addressed the dynamic behavior of the active ûlter when it performs both harmonic damping and voltage regulation at the same time. This paper discusses a shunt active ûlter intended for installation on a power distribution system, with focus on voltage regulation capability. Theoretical analysis as well as computer simulation provides the dynamic performance of harmonic damping and voltage regulation. As a result, harmonic damping has the capability to improve the stability of voltage regulation. Thus, adjustment of the feedback gains makes it possible to reduce voltage ûuctuation in transient states, when the active ûlter has the function of combined harmonic damping and voltage regulation. Experimental results are shown to verify the effectiveness of the active ûlter capable of both harmonic damping and voltage regulation.

II. ACTIVE FILTER FOR HARMONIC DAMPING

A. System Configuration

Fig.1 shows a 200 V simpliûed power distribution feeder under no- load conditions, where a shunt pure active ûlter for damping out harmonic propagation is connected by a LC filter. The purpose of the capacitor in LC filter is to impose a high impedance to the fundamental frequency so that the fundamental voltage appears exclusively across the capacitor. This means that no fundamental voltage is applied across the active ûlter. Fig.2. shows the detailed power circuit of the active ûlter, which consists of a three – phase voltage fed PWM inverter, and a series connection of L and C per phase. Note that the tuned frequency of L and C is not the ûfth – harmonic frequency but around the seventh - harmonic

frequency. The reason is that the seventh - tuned LC ûlter is less bulky than the ûfth - tuned LC ûlter as long as both ûlters have the same inductor as L . The dc-bus of the PWM inverter has only a capacitor without external supply, and the dc – bus voltage is controlled by the Active ûlter. The Active ûlter is controlled so as to draw the compensating current from the distribution line.
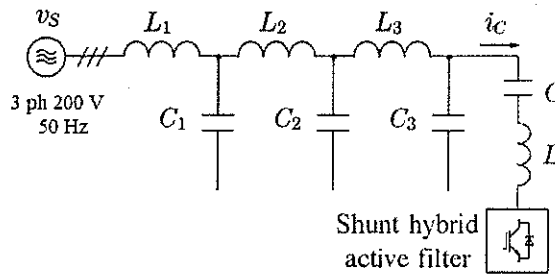

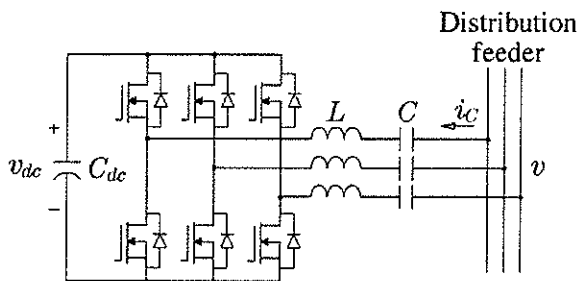**Figure 1: Shunt Active Filter with LC filter.**

Figure 2 : Power circuit of the Active filter

A. Experimental System

Fig.3 shows the experimental system under no-load conditions. A three phase power distribution feeder simulator rated at 200V, 50Hz, and 20kW is used for the laboratory experiments. In the feeder simulator harmonic is generated by a non linear load connected at bus, which produces an amount of harmonic voltage. Table I summarizes the line simulator parameters. When a lossless line is assumed, the characteristic impedance of the feeder simulator, can be calculated as

$$Z_0 = \sqrt{\frac{L}{C}} = 0.8\,\Omega \qquad (2)$$

A. Operating principle

The hybrid filter with current control is based on voltage detection. The compensating current of the Active ûlter consists of a fundamental component and harmonic components. The fundamental component is determined by the impedance of the LC filter while the harmonic components are controlled by the active ûlter. Three-phase voltages and currents are detected at the installation bus. The harmonic voltage in each phase is extracted from the detected three phase voltage, and then the harmonic voltage is ampliûed by a control gain K_V. Thus the harmonic current reference I^*_{Ch} is given by
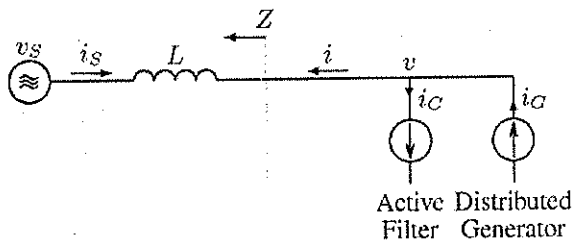
$$i^*_{Ch} = K_V * V_h \qquad (1)$$

Figure 3 : Simplified circuit of the distribution system.

The actual harmonic compensating current is extracted from the detected compensating current. Assuming that is equal to its reference , the hybrid ûlter behaves as a damping resistor of $1/K_V$ [V/A] for harmonic frequencies. The optimal value of is equal to the inverse of the characteristic impedance of the distribution feeder. With this value, the hybrid ûlter can damp out harmonic propagation effectively.

3. CONTROL SCHEME

A. Harmonic Damping

There are several methods to extract the harmonic components from the detected three-phase waveforms. Among them, the so-called p - q theory based on time domain has been widely applied to the harmonic extraction circuit of active ûlters. The detected three-phase voltage is transformed into the D - Q0 coordinates as shown in Fig.4. Two ûrst order digital high pass ûlters (HPFs) with the same cut off frequency as 17 Hz extract the dc component V_{hd}^*, V_{hq}^* and V_0 which corresponds to the fundamental frequency in the coordinates.
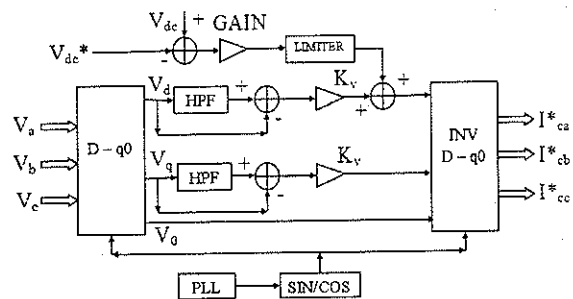

Fig.4. Block diagram of the control circuit equipped with the function of voltage regulation and harmonic damping.

B. Voltage Detection

In line - voltage regulation part is performed by a feedback control. Two co - ordinates V_d and V_q is compared with harmonic extracted voltage V_{hd}^* and V_{hq}^*. A gain K_V ampliûes and to produce current references for harmonic damping I_{hd}, I_{hq}, and I_0 as shown in (1). The current reference for the voltage - source inverter is the sum of the current references from the three parts, as follows:

$$I^*_{cd}(s) = K_v (G_h V_{hd}^* - V_d) + (V_{dc}^* - V_{dc}) \qquad (1)$$

$$I^*_{cq}(s) = K_v (G_h V_{hq}^* - V_q) \qquad (2)$$

$$I^*_0(s) = 1/3 (V_a + V_b + V_c) \qquad (3)$$

The obtained current reference is converted three phase current reference by inverse D - Q0 transformation I^*_{ca}, I^*_{cb}, and I^*_{cc}. The three three phase reference compensating current is compared with the active filter compensating current extracted from ac system. Thus

three phase compensating current I_{ca}, I_{cb}, and I_{cc} are produced. The obtained reference current is given to a hysteresis current controller in order to generate controlled gate signal for shunt active filter.

C. DC – Bus Voltage Control

A critical issue in this hybrid active ûlter is the dc-bus voltage control. The dc bus consists of a single capacitor charged from the power supply. During operation, the active ûlter may absorb an amount of active power into, or release it from, the dc capacitor. Excessive active power absorption will increase the dc-bus voltage, and may damage the active ûlter. The strategy used to control the dc-bus voltage is based on active power control. According to the D – q0 theory, a dc component in the D –q0 coordinates corresponds to active power. No direct axis current on the D –q0 coordinates ûows in the LC ûlter. Thus, the active power is controlled by adjusting the quadrature axis component. The direct axis is set to zero. Fig.3 shows a block diagram for the dc bus voltage control. The dc-bus voltage is detected and compared with a reference, amplifying the error signal by a control gain of 0.12. A limiter is included in the dc-bus control loop. It is designed to ensure a smooth transient response and to avoid sudden increments or decrements in the dc-bus voltage. It is also designed to prevent the control loop from numerical saturation in the DSP signals. The limiter is set to ± 2.5 V in the digital controller which corresponds to 25% of the maximum control signal. For a 40-V dc-bus voltage, the maximum dc-bus control signal corresponds to a ± 10 V peak-to-peak fundamental voltage for the inverter. voltage for the inverter.

3. SIMULATION RESULTS

Table 1
Circuit Parameters used for the Simulation

Table II shows the circuit parameters used in the

Source voltage	$V_a = V_b = V_c$	200 V
power	p	20KVA
Frequency	F	50 Hz
Line inductance	$L_a = L_b = L_c$	22.7 mH
DC - Capacitor	c	4700µF
DC - voltage	$V_{dc\ ref}$	40V

simulation. The simulation is carried for distribution system with and without shunt active filter. Total harmonic distortion is calculated for the system voltage and current.

Table IV

Total Harmonic Distortion

Parameters	Source current Is			Voltage V		
	I_a	I_b	I_c	V_a	V_b	V_c
Without shunt active filter	16.99	18.03	17.86	25.31	25.90	25.22
With shunt active filter	2.95	2.89	2.72	4.84	4.79	4.74

Figure 5 : Three Phase voltage of distribution system without Shunt Active Filter
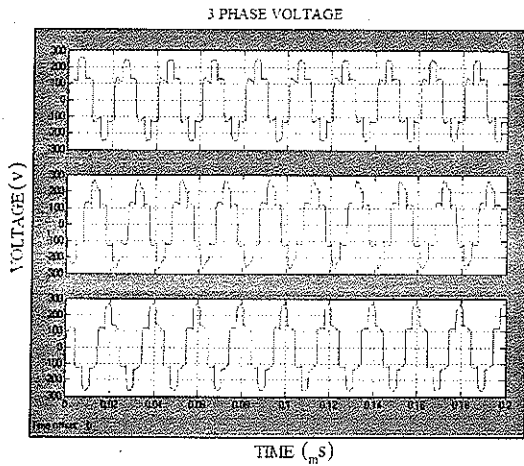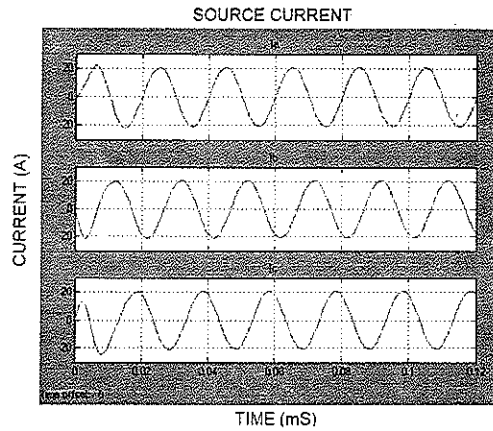

Figure.6. Three Phase voltage of distribution system with Shunt Active Filter

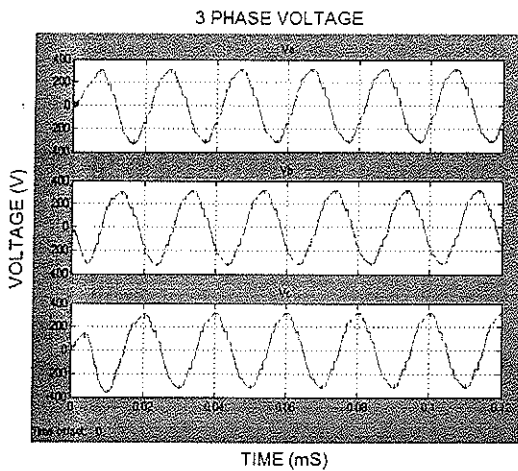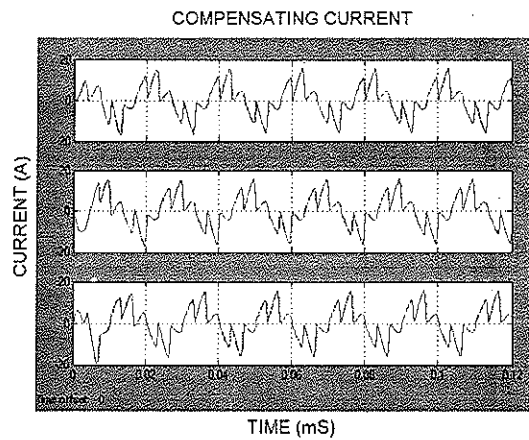**Figure 7 : Source current of distribution system without Shunt Active Filter (ₘs)**

Figure 8 : Source current of distribution system with Shunt Active Filter

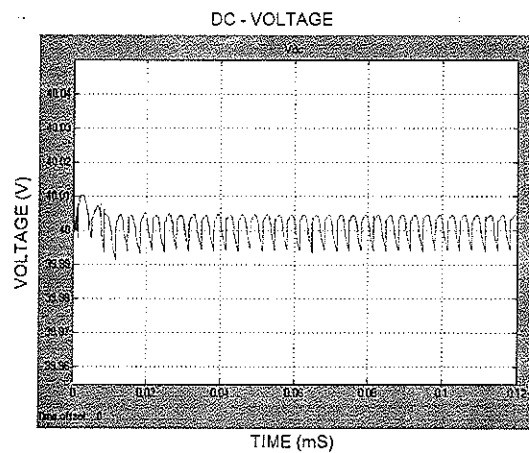**Figure.9. Compensating current with Shunt Active Filter**

Figure 10 : DC – Voltage of Shunt Active Filter

230

5. Conclusion

This paper has dealt with a shunt active filter for installation on a power distribution system, with focus on harmonic damping and voltage regulation performance. Harmonics present in the distribution system is significantly reduced by shunt active filter. Simulated results have demonstrated good voltage – regulation performance, and have verified stable operation. Total harmonic distortion is also measured and compared . the main disadvantage of this P – Q theory is selective harmonics cannot be damped.

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Author's Biography

Mr. K. Sureshkumar received his B.E., degree in Electrical and Electronics Engineering from the Government College of Technology, Coimbatore, affiliated to Bharathiar University, in 1999 and M.E., degree in Applied Electronics from the Coimbatore Institute of Technology, Coimbatore, affiliated to Bharathiar University, in 2002. He is currently a research scholar at the Anna University, Coimbatore and presently working as Assistant Professor in the Department of Electrical & Electronics Engineering, Velammal Engineering College, Chennai. He has around

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