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Design of Shunt Active Filter to Improve Power Quality using Pq Theory

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***Abstract*- Due to large amount of non-linear equipment, fluctuating loads (such as locomotive, arc-furnace, heavy merchant mill, welding equipment etc.), problems of power quality is becoming more and more serious with time. To overcome this APF (Active power filter) has gained more attention because of its modularity and flexibility in mitigating harmonics and compensation of reactive power. In this paper SAPF (shunt active power filter) is designed which compensates harmonics and load reactive power, by taking the reference of load current making the supply current balanced and distortion free when supply is balanced. Instantaneous "p-q" theory is used for control technique. The performance of shunt active filter is verified for RL load through exhaustive simulation on the MATLAB/Simulink platform.**

Keywords—APF(Active Power Filter); Shunt Active Power Filter(SAPF); "p-q" theory.

I. INTRODUCTION

Due to extreme use of power converters and other non-linear loads in industry it is observed that it deteriorates the power systems voltage and current waveforms. Static power converters such as single phase and three phase rectifiers, thyristor converters and large number of power electronic equipment are nonlinear loads which generate considerable disturbances in the ac mains. Mainly voltage harmonics and power distribution problems arise due to current harmonics [2] produced by nonlinear loads. As nonlinear currents flow through electrical system and the distribution-transmission lines, additional voltage distortion produce due to the impedance associated with the electrical network. The presence of harmonics in the power system cause greater power loss in distribution, interference problem in communication system and, sometimes result in operation failure of electronic equipments which are more and more sensitive because it contains microelectronic controller systems, which work with very low energy levels. It is noted that non-sinusoidal current results in many problems for the utility power supply company, such as low power factor, low energy efficiency, distortion of line voltage etc. Passive filters were being used as a solution to solve harmonic current problems, but because of the several disadvantage of passive filter like it can mitigate only few or selected harmonics and gives rise to resonance problem too. Additionally, passive filters have drawback of bulk size [2].To cope with these disadvantages, recent efforts have been concentrated in the development of active filters, which are able to compensate not only harmonics but also asymmetric currents which is caused by nonlinear and unbalanced loads. This paper performance on the analysis of shunt active power filter and its characteristics.

The detail discussion about power quality problems and there possible solutions are discussed in section II & III respectively. Basic principle and circuit diagram of shunt active filter is presented in section IV. Section V and VI gives the block diagram and control strategy for shunt active filter. Section VII and VIII gives the MATLAB simulation and results of simulation respectively.

II. POWER QUALITY IN POWER DISTRUBUSTION SYSTEMS

If there is any bad operation or failure of customer equipment then power quality problems exists there. The extent of variation of voltage, current and frequency describes the power quality. It is defined as pure sinusoidal waveform of declared voltage and frequency. The pure sinusoidal wave will become ideal now as it can only be seen in books.

The power quality in power system is analyzed as-

-any load connected to the power system will run satisfactorily and efficiently if power quality of system is good. Installation running cost and carbon footprints will be minimal.

- load connected to power system fail or have reduced life time if power quality of network is bad. This will reduce the efficiency of electrical installation. Installation running cost and carbon footprints will be high.

The most significant and critical power quality problems are voltage sags due to high economical losses that can be generated. The short term voltage drops (sags) can trip electrical drives or more sensitive equipment, leading to costly interruptions of production. Also the harmonics, voltage flickers, voltage notching, voltage unbalance, voltage distortions, current unbalance are the other power quality problems which are quite serious.

To overcome all these power quality problems there is a need to find out the solutions for power quality problems.

III. SOLUTION TO POWER QUALITY PROBLEMS

There are two methods for the mitigation of power quality problems called as line conditioning and load conditioning. In load conditioning equipment is made less sensitive to power disturbances which allow the operation even under significant voltage distortion. Line conditioning suppress the power quality disturbances.

To overcome problem of passive filters a flexible and versatile solution is use of active power filters[6]. There are three types of active power filters shunt active power filter, series active power filter, hybrid active power filters. Shunt active power filter acts as controllable current source. It injects the current in the system. Series active filter acts as controllable voltage source and injects the voltage in the system. Hybrid active power filter is combination of active and passive filter in which the passive filter is in series or shunt with the active filter. Series and shunt active filters gives the solution for different power quality problems. Shunt active filters do the current harmonic filtering and reactive current compensation. Also they provide solution for current unbalance and voltage flicker. Series active filters do current harmonic filtering, reactive current compensation and gives solution for power quality problems like current unbalance voltage flicker, voltage sag/ swell, voltage unbalance etc. From above discussion it is observed that series active filters maintains balanced, distortion free nominal voltage at the load side where as shunt active filters balance the load current there by making the source current balanced and distortion free with unity power factor. For solution of different power quality problems there is a need of both shunt and series active filters. Unified PQ conditioner (UPQC) is a versatile custom power device which consists of two inverters connected back-to-back and deals with both load current and supply voltage imperfections[4]. UPQC can simultaneously acts as shunt and series active filters and gives the best solution for different power quality problems.

In this paper design of shunt active filter its control technique and performance for RL load is presented.

IV. SHUNT ACTIVE POWER FILTER

A. *Basic principle of shunt active filter*

Basic principle of shunt active filter is it compensates current harmonics by injecting equal but opposite harmonic compensating current. Here SAPF operates as a current source injecting the harmonic components generated by the load but phase shifted by 180^0. For any type of load this principle is applicable. Active power filters can also compensate the load power factor by applying the proper control technique. Thus power distribution system seems like non linear load and active power filter as ideal resistor. Fig.1. shows the current compensation characteristics of shunt active filter.

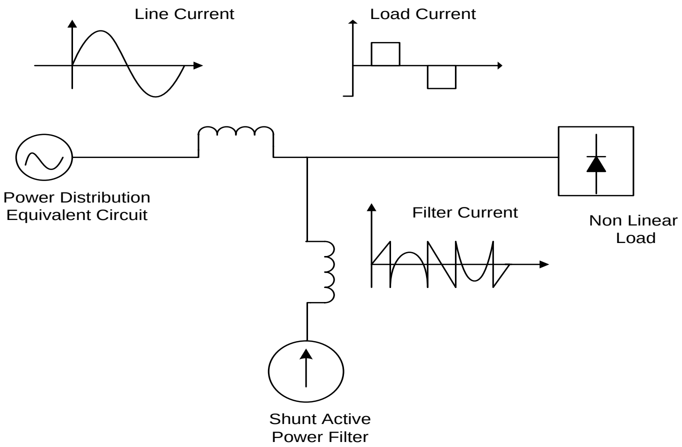


Fig.1. Compensation characteristics of shunt active power filter

B. *Equivalent circuit of system*

In Fig.2. the equivalent circuit diagram of our system is shown where Vsa, Vsb, Vsc are source voltages and isa, isb, isc are the source currents of three phase supply. Where as ila, ilb, ilc are the load currents which is variable frequency drive. *ifa*, *ifb*,*ifc* are the shunt active filter currents. Ls and Rs represents feeder inductance and resistance respectively.

The interfacing resistance, inductance and capacitance of the system are denoted by *Rf*, *Lf* and *Cf* respectively. *Cdc* is the dc link capacitor and voltage across it is *Vdbus*. The passive capacitor *Cf* has the capability to supply a part of the reactive power required by the load, and the active filter will compensate the balance reactive power and the harmonics present in the load. The addition of capacitor in series with the interfacing inductor of the shunt active filter will significantly reduce the dc-link voltage requirement and consequently reduces the average switching frequency of the switches. Voltage rating of dc-link capacitor largely influences the compensation performance of an active filter [4].

In general, the dc-link voltage for the shunt active filter has much higher value than the peak value of the line-to-neutral voltage. This is done in order to ensure a proper compensation at the peak of the source voltage. In [4], the authors mentioned about the current distortion limit and loss of control limit, which states that the dc-link voltage should be greater than or equal to √6 times the phase voltage of the system for distortion free compensation. In general, if the filter current (*If*) flows from the inverter terminal to the PCC, the

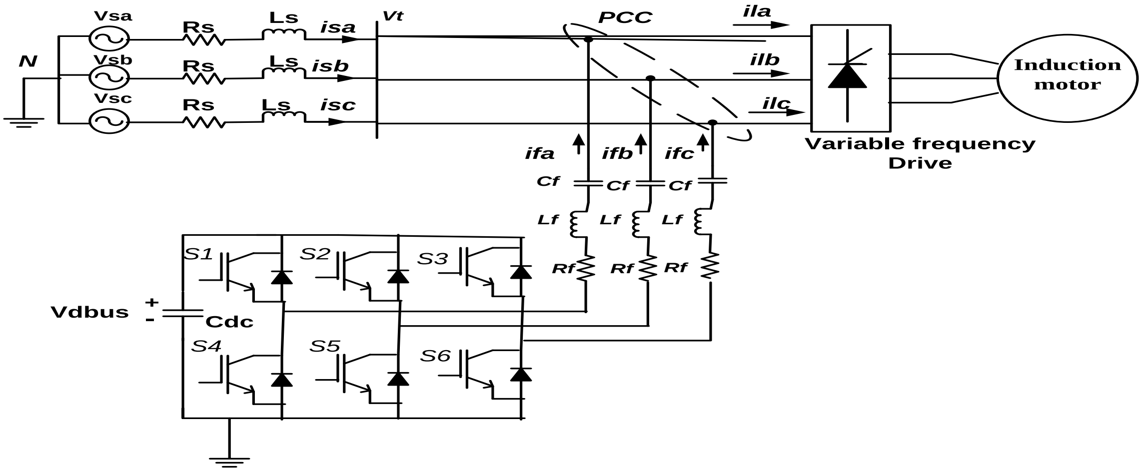


Fig. 2. Circuit diagram of proposed system

voltage at the inverter terminal should be at a higher potential. Equations (1)and (2) give the KVL along the filter branch for the proposed topology,

$$uV_{dc}- v_1=L_f\,(di_f/dt)+R_f\,i_f \qquad (1)$$

$$(uV_{dc}-1/C_f\int i_f\,dt)-v_1=L_f\,di_f/dt + R_f\,i_f$$

$$(uV_{dc}-v_{cf})-v_1= L_f\,(di_f/dt)+R_f\,i_f \qquad (2)$$

where u attains value from 1 or -1 depending upon the switching of the inverter. In (1), the fundamental voltage across the capacitor (*vcf*1) adds to the inverter terminal voltage (*uV*dc) when the load is inductive in nature. This is because, when the load is inductive in nature, the fundamental of the filter current leads the voltage at the PCC by 90◦ for reactive power compensation, and thus the fundamental voltage across the capacitor again lags the fundamental filter current by 90^0. Therefore, the fundamental voltage across the capacitor will be in phase opposition to the voltage at the PCC. Thus, the fundamental voltage across the capacitor adds to the inverter terminal voltage. This allows us to rate the dc-link voltage at lower value. The designer has a choice to choose the value of dc- link voltage to be reduced, such that the LC filter in the active filter leg of each phase offers minimum impedance to the fundamental frequency and higher impedance for switching frequency components. In the topology along with the series capacitor in the shunt active filter, the system neutral is connected to the negative terminal of the dc bus capacitor. This will introduce a positive dc voltage component in the inverter output voltage. This is because, when the top switch is “ON,” +*Vd*bus appears at the inverter output, and 0 V appears when the bottom switch is “ON.”

Thus, the inverter output voltage will have dc voltage component along with the ac voltage. The dc voltage is blocked by the series capacitor, and thus the voltage across the series capacitor will be having two components, one is the ac component, which will be in phase opposition to the PCC voltage, and the other is the dc component when a four-leg topology is used for shunt active filter with a single dc capacitor, the inverter output voltage varies between +*Vd*bus and −*Vd*bus. Therefore, this topologies does not contain any dc component in the inverter output voltage.

V. BLOCK DIAGRAM OF PRAPOSED SYSTEM

Shunt active filter generally consist of two distinct main blocks: As shown in Fig. 3.

1) Hysteresis current control unit for giving the gate pulses to inverter (power processing Unit), and
2) Active filter controller (Signal Processing Unit).

The Hysteresis control is responsible for processing power signal in synthesizing the compensating current that should be drawn from the power system. The active filter controller is responsible for signal processing in determining in real time the instantaneous compensating current references, which are continuously passed to the Hysteresis converter. Fig.3. shows the basic configuration of a shunt active filter for current compensation of a specific load. It consists of a voltage fed converter with a Hysteresis current controller and an active filter controller that realize an almost instantaneous control algorithm. The shunt active filter controller works in a closed loop manner, continuously sensing the load current *iL*, and calculating the instantaneous values of the compensating current reference *ic** for the Hysteresis converter.

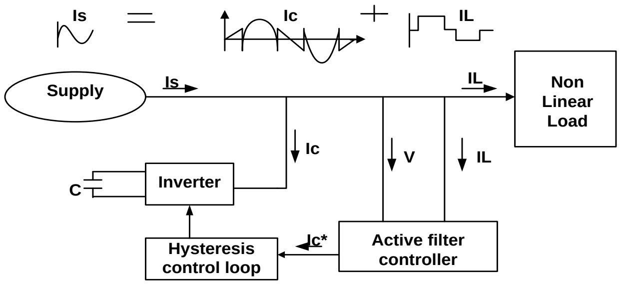


Fig.3. Block diagram of praposed system

VI. CONTROL STRATEGES FOR SHUNT ACTIVE FILTER

The control of shunt active filter is realized in three stages.

i) In the first stage, the essential current signals are sensed.

ii) In the second stage, compensating commands in terms of current are derived based on instantaneous PQ theory

iii) In the third stage of control, the gating signals for the Three phase two level inverter are generated using the Hysteresis current control method.

In shunt active filter load current is sensed for comparison with reference current generated by PQ theory.

A. Generation of referance compensator current using PQ theory

The control strategies to generate compensation commands are based on frequency domain or time-domain correction techniques. In our proposed system we are using ‘PQ’ theory for the generation of current compensating command which is a time domain analysis method.

The p-q theory first transforms voltage and currents from the abc to αβ0 coordinates, and then defines instantaneous power on these coordinates[3]. The compensated real and imaginary part of the power are denoted by p* and q*. Then, the inverse transformation from αβ to abc is applied to calculate the instantaneous values of the three phase compensating current references ica*,icb*,icc*. The Fig.4. shows the generation of compensation currents for shunt active filter using ‘PQ’ theory.

B. Hysteresis current control loop

Once the reference quantities and the actual quantities are obtained from the measurements, the switching commands for the VSI switches are generated using hysteresis band current control method [1].

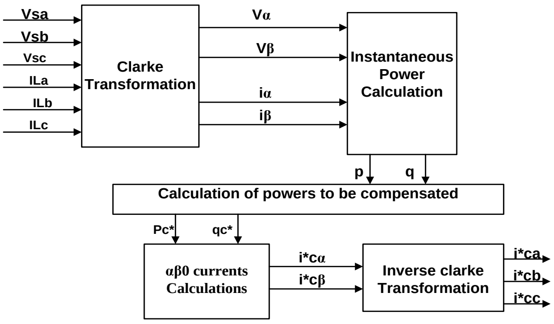


Fig.4. Block diagram of referance current generator using PQ theory

Hysteresis current controller scheme is based on a feedback loop, generally with two-level comparators. The switching commands are issued whenever the error limit exceeds a specified tolerance band “±*h*.” Unlike the predictive controllers, the hysteresis controller has the advantage of peak current limiting capacity apart from other merits such as extremely good dynamic performance, simplicity in implementation and independence from load parameter variations. The disadvantage with this hysteresis method is that the converter switching frequency is highly dependent on the ac voltage and varies with it. The switching control law for shunt active filter is given as follows.

If $ifa \geq i{*}fa + h1$, then bottom switch is turned ON whereas top switch is turned OFF ($S1 = 0$, $S2 = 1$).

If $ifa \leq i{*}fa - h1$, then top switch is turned ON whereas bottom switch is turned OFF ($S1 = 1$, $S2 = 0$).

Thus six switching commands are generated.

VII. MATLAB SIMULATION

The simulation for proposed system is carried out in MATLAB software. The simulation diagram is shown in Fig.6. the first sub system block ie controller block consists of hysteresis current control loop, reference current generator circuit and PI controller block for the control of voltage Vdbus across the DC link capacitor.

Three phase breaker is used in simulation for showing the simulation after and before compensation.

Voltage across the DC link capacitor is maintained constant using the PI controller.

In hysteresis current controller reference current generated using PQ theory and actual load currents are taken for comparison and switching commands are generated for VSI.

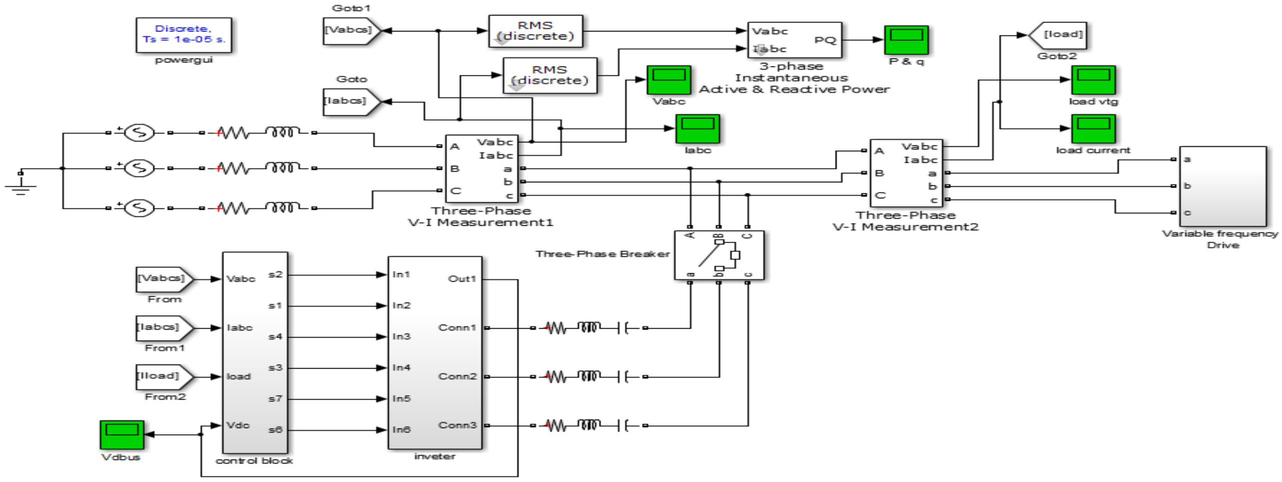


Fig. 5. MATLAB Simulation of Shunt active filter

The values for interfacing inductor(Lf), capacitor(Cf) and resistor(Rf) and other system parameters are given in table

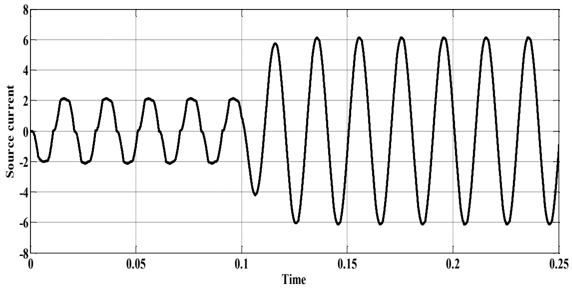
TABLE 1
SYSTEM PARAMETERS

SYSTEM QUINTITES	VALUES
System Voltages	230V (Line to neutral), 50Hz
Feeder impedance	Zs=1+j3.141Ω
Shunt VSI parameters	Cdc=2200μF,Lf=26mH, Rf=1 Ω V_{dbus}=560V
PI controller gains	Kp=6, Ki=5.5
Hysteresis band	h_1=±5.5 h_2=±6.9V

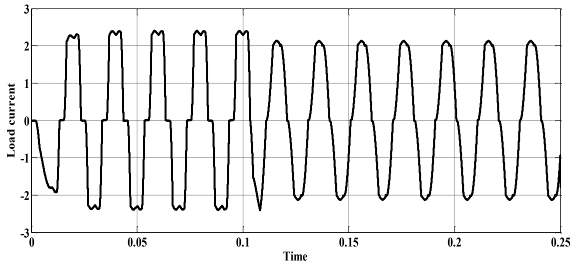
VIII. SIMULATION RESULTS

Up to 0.1second the simulation is carried out before compensation after that shunt active power filter provides the compensation current i.e. we get the waveforms after compensation.

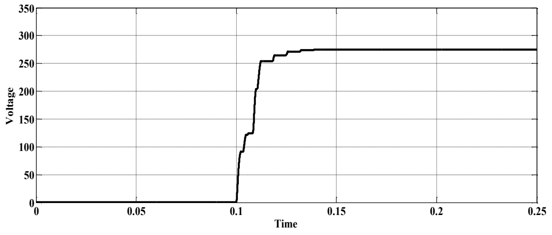
The waveforms of source current, load and compensation current and dc link capacitor voltage are observed. The dc link capacitor voltage and compensating currents are zero before compensation. They will increase as the compensation gets started.



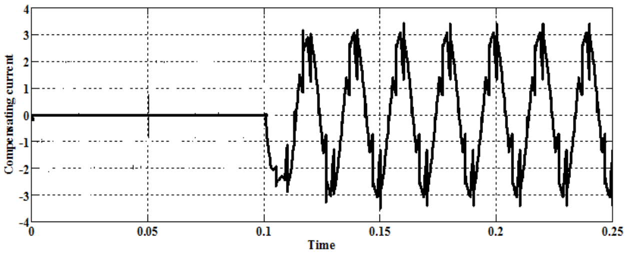
(a)



(b)



(c)



(d)

Fig.6. (a)source current after and before compensation, (b) load current before and after compensation, (c) dc link capacitor voltage before and after compensation, (d) compensating current before and after compensation

The THD of the source current without and with compensation are given in table 2

TABLE 2

SOURCE CURRENT WITHOUT AND WITH COMPENSATION

Source Current	(%THD)Without compensation	(%THD)With compensation
isa	10.12	1.13
isb	12.30	1.101
isc	14.98	1.14

Source current before compensation have the the percentage THD of 10.12, 12.30, 14.98 for phase a, b, c respectively which is beyond permissible limit. After compensation the THD are 1.13, 1.101, 1.14 respectively which is within permissible limit. The source current and dc link capacitor will take nearly 12 to 13 milliseconds to attend the steady state position after the compensation gets started.

VIII. CONCLUSION

The distribution system is very much distorted due to non linear loads. It will cause the system current to distort considerably. It was observed that by using SAPF the performance of system current improves drastically rrespective of harmonics in load current. Hence it is to be recommended that SAPF can be used in industry to improve system current.

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