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# SERIES ACTIVE POWER FILTER FOR MITIGATION OF DIFFERENT PQ PROBLEMS

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## ABSTRACT

*Due to the increase in the usage of Power Electronics based equipment modern power system is facing different power quality issues. To overcome different power quality problems Active Power Filters are gained more attention because of its modularity and flexibility in mitigating harmonics and compensation of reactive power. In this paper series active power filter is designed which provides voltage compensation to overcome the PQ problems like voltage sag, voltage swell and provide compensation for harmonics in supply voltage i.e when supply voltage is unbalanced and distorted. The unit vector templet method is used for control technique. The performance of series active filter is verified through exhaustive simulation on the MATLAB\ Simulink platform.*

***Keywords—Acive Power Filter(APF); Series Active Filter; Power Quality(PQ); Voltage Sag,Swell;Shunt Active Filter; Unified Power Quality Conditioner(UPQC).***

## I. INTRODUCTION

The term "Power Quality" (PQ) is most important aspects of any modern power delivery system today. Low quality power affects electricity consumers in many ways. Power quality problems can cause loss of production, damage of equipment or appliances, increased power losses, interference with communication lines and so forth. Due to widespread use of power electronics based equipment there is a significant impact on quality of electric power supply by generating harmonics in voltages and currents. Therefore, it is very important to maintain a high standard of power quality [1].

Conventionally Passive filters were used for mitigation of different Power quality problems. Passive filters were being used asa solution to solve harmonic current problems, voltage imbalance problems etc. but there are several disadvantage of passive filter like it can mitigate only few or selected harmonics andgives 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 presents the analysis of series active power filter and its characteristics. The detail discussion about power quality problems and there possible solutions are discussed in section II . Basic principle and circuit diagram of series active filter and is presented in section III. Section IV gives the control mechanism of Series APF and V gives the MATLAB Simulation results.

## II. POWER QUALITY AND SOLUTION TO DIFFERENT POWR QUALITY PROBLEMS

### A) Power Quality In Power Distrubution System

Power Quality problems exist if there is any bad operation or failure of electrical equipment. Power Quality is described by the extent of variation of voltage, current and frequency. It is defined as pure sinusoidal waveform of declared voltage and frequency.[6]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.

### B) Solution To Power Quality Problems

For the improvement of power quality there are two approaches. According to first approach the solution to the power quality problems can be done from the utility side .The first approach is called load conditioning, which ensures that the equipment is less sensitive to power disturbances, allowing the operation even under significant voltage distortion. The other solution is to install line conditioning systems that suppress the power system disturbances. In this approach the compensation device is connect to low and medium voltage distribution system in shunt or in series.

To overcome problem of passive filters a flexible and versatile solution is use of active power filters[1]. 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 abovediscussion 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 series active filter its control technique and performance for RL load is presented.

## III SERIES ACTIVE POWER FILTER

### 3.1 Basic Principle Of Series Active Filter

A series active filter is power electronic converter based compensator that can protect critical loads from all supply side disturbances other than outages.

A series active filter acts as controlled voltage source by imposing high impedance for the harmonic currents, blocking their flow from both loads to source and source to load directions.[4]

The series APF inserts a voltage, which is added at the point of common coupling (PCC) such that the load end voltage remains unaffected by any voltage disturbance. The series active power filter can compensate the supply voltage related problems by injecting voltage in series with line to achieve distortion free voltage at the load terminal. The series injected voltage can be represented by following equation:

$$Vinj(t)=VL(t)-VS(t) \qquad (2.1)$$

Where Vinj(t), VL(t), and VS(t) represent the series inverter voltage, load voltage, and actual source voltage, respectively.

As shown in fig 3.1 series APF is connected in between the supply and the load. The main function of the filter is to boost up the load side voltage so that load is free from any power disruption. Besides voltage sag compensation it also carries out other functions such as line voltage harmonic compensation, reduction of transients in voltage and fault current limitation.

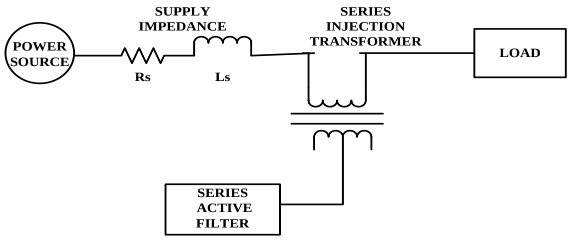



**Fig.3.1 Block Diagram of Series Active Filter**

### 3.2 System Configuration Of Series Active Filter

The series active filter is capable of generating or absorbing independently controllable real and reactive power at its AC output terminal. This device employs solid-state power electronic switches in a pulse-width modulated (PWM) inverter structure as shown in fig 3.2. It injects a set ofthree phase AC output voltages in series and synchronism with the distribution feeder voltages. The amplitude and phase angle of the injected voltages are variable thereby allowing control of the real and reactive power exchange between the device and the distribution system.

DC input to the inverter is given by battery input. The reactive power exchanged between the filter and the distribution system is internally generated by the filter without AC passive reactive components. The real power exchanged at the filter output AC terminals is provided by the filter input DC terminal.

The filter functions by injecting three single phase AC voltages in series with the three phase incoming network voltages during a dip, compensating the difference between faulty and nominal voltages. All three phases of the injected voltages are of controllable amplitude and phase. Voltage source inverter fed from the DC link supply the required active and reactive power.

In Fig 3.2. 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. Whereasila, ilb, ilc are the load currents. *Ls* and *Rs*represent the feederinductance and resistance, respectively. The interfacing inductance and filter capacitor of the series active filter are represented by *L*seand *C*se, respectively.The injected voltages of phase a, b, c are given by Vinja, Vinjb and Vinjc respectively. Vdc is the DC link voltage.

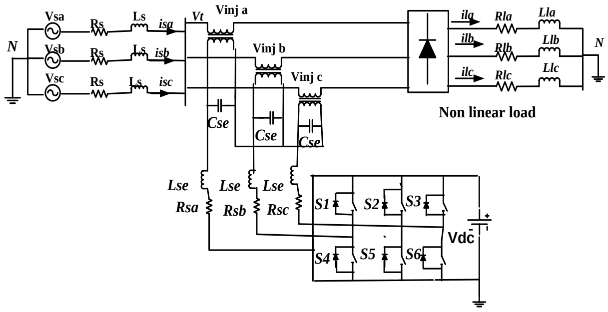



**Fig3.2 Schematic Diagram of Series active Filter**

### 3.3 Compensation Priciple

Equivalent circuit diagram of series active filter is shown in fig 3.3. in which Vs is source voltage Vc is compensation voltage of series active filter. iL is load current and Z is the load. The source voltage may contain zero negative and harmonic components.

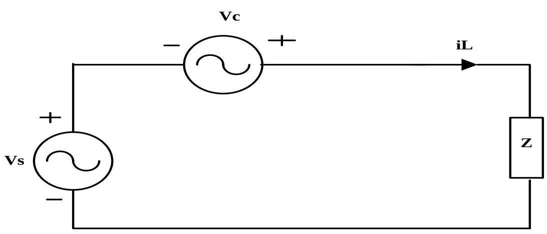



**Fig3.3 Equivalent Circuit of Series Active Filter**

The per phase voltage of the system can be expressed as

$V_a = Vlpa + Vlna + V_{l0a} + \sum_{K=2}^{\infty} Vkc$ (3.1)

where$V_{lpa}$ is the fundamental frequency positive sequence components, $V_{lna}$ and $V_{l0a}$ are negative and zero sequence components respectively.In order for the load voltage to be perfectly sinusoidal and balanced, the series filter should produce a voltage of

$V_{ah} = V_{lna} + V_{l0a} + \sum_{K=2}^{\infty} Vkc$ (3.2)

Thus series filter do the compensation.

## IV. CONTROL STRATEGY

The control of VSI based series APF is realized using hysteresis band PWM technique. The hysteresis band control is used very often among various PWM techniques available because of its simplicity of implementation, fast response and does not need any knowledge of load parameters. The basic implementation of hysteresis control is based on deriving the switching signals from comparison of the signal error with a fixed tolerance band. The control strategy has been implemented in two parts[4]:

• Derivation of reference signals

• Generation of PWM patterns with hysteresis controller

*A. Series Filter Control Using Unit Vector Templet Method*

The series filter is controlled by similar hysteresis band voltage control. A series active filter acts as controlled voltage source by imposing high impedance for the harmonic currents, blocking their flow from both loads to source and source to load directions. The zero, negative sequence as well as harmonic component, contained by source voltage are need to be eliminated by series compensator. In order for the load voltage to perfectly sinusoidal and balanced, the series filter should produce a voltage equal to equation (3.2). For obtaining reference load voltages PLL based unit vector templets are multiplied by a constant equal to peak amplitude of fundamental input voltage. Unit vector templates for different phases are obtained with proper phase delay as follows:

$u_a$= sin(  t)

$u_b$= sin(  t-120)

$u_c$=sin(  t+120)  (4.1)

The compensation signals for series filter are thus obtained by comparing these reference load voltages with actual source voltage using equation (4.1).

$$V^*_{fa} = V_{sa} - V_m . u_a$$
$$V^*_{fb} = V_{sb} - V_m . u_b$$
$$V^*_{fc} = V_{sc} - V_{m.} u_c \quad (4.2)$$

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. The control block diagram of series filter is shown in Figure 3.4

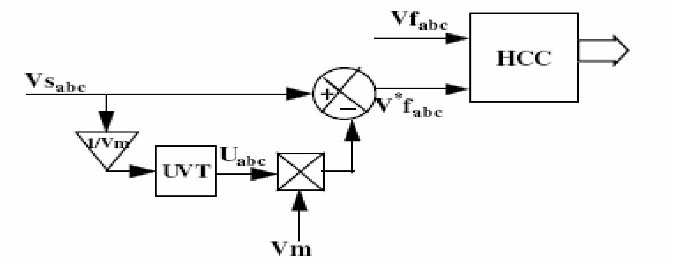



**Fig4.1 Control Block Diagram**

### 4.2 Extraction Of Unit Vector Tempalet

**Fig 3.5 gives the block diagram of series active filter.**

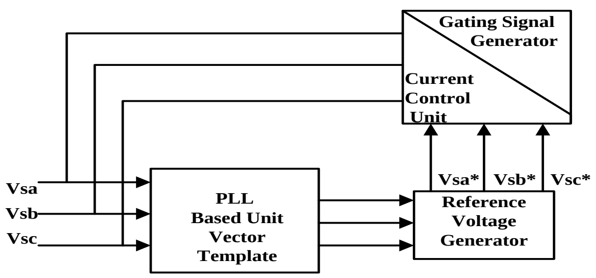



**Fig 4.2 Block Diagram of Series Active Filter**

Fig 4.3 gives the block diagram for extraction of unit vector templet. Vsa, Vsb, Vsc are the input supply voltages which are multiplied by gain K=1/Vm before passing through an phase locked loop. Thus unit vector templets Ua, Ub, Uc are generated. For getting the reference voltages these unit vector templets are compared by pick amplitude of fundamental input voltage. For gating Gate signals for inverter these reference voltages and actual load voltages are compared in hysteresis control loop as shown in fig 3.4.

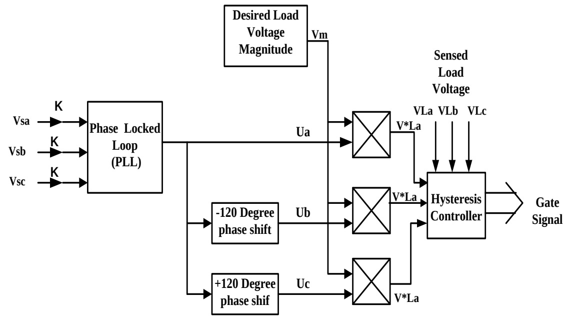



**Fig.4.3 Control Diagram**

Thus series filter injects the voltage in the system through injection transformer for making the load voltage balanced and distortion free.

## V. COMPENSATION BASED ON SIMULATION RESULTS

To verify the performance, VSI based Series APF model is developed using above equations in MATLAB / SIMULINK. A three–phase diode rectifier with an RL load is employed as nonlinear load. All the compensators are implemented using equivalent discrete blocks. Series filter is switched on at 0.1 sec to verify the performance of indusial filters. Controlled switches are assumed ideal. The system parameters are selected as given in table below.

**Table 5.1 System Parameters**

| System Quantities | Values |
|---|---|
| System voltages | 230 V (L-L),50Hz |
| Feeder impedance | Zs=1+j3.141Ω |
| Non linear Load | Three phase full bridge rectifier with RLload of 150Ω, 300mH |
| Series VSI Parameters | Cse=80μF, Lse=5mH, |
| Interfacing Transformer | 1:1, 100V and 700 VA |
| Hysteresis band | h2= |

Fig 5.1 gives the simulation results for Series APF. The compensation starts at 0.1 sec. Waveforms before that are uncompensated waveforms. Simulation is carried out under two conditions. As shown in Fig 5.1 the 5$^{th}$ harmonic component is added in the source voltage and then compensation is done. In another condition voltage

sag and voltage swell of 50% are created in the supply voltage and then compensation is done. For these both conditions series APF provides compensation as shown in fig 5.1 and 5.2

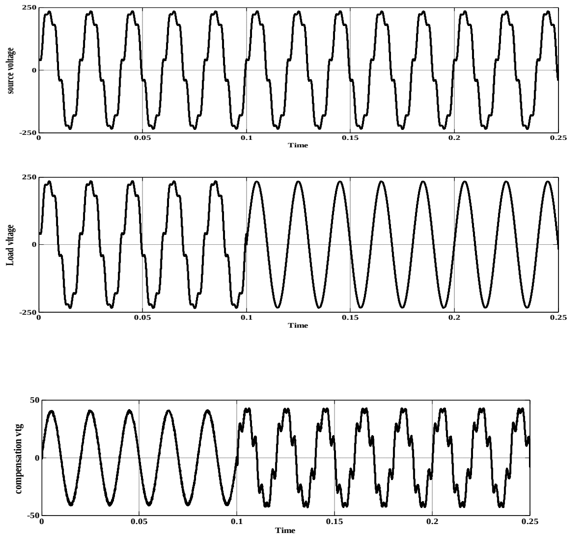


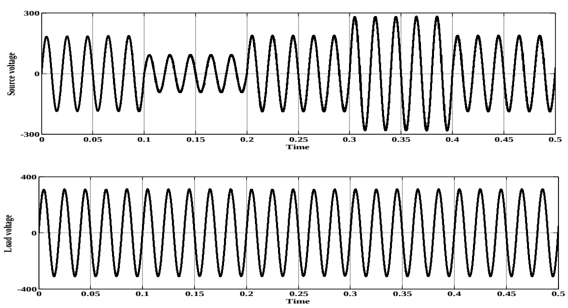
**Fig5.1 Source voltage, load voltage, compensation voltage**

From fig 5.1 it is clear that after compensation load voltage becomes sinusoidal with THD limits of IEEE 519 standards. Table below gives the %THD of source voltage and load voltage.

**Table 5.2 % THD Before and after compensation**

| Phase | % THD Without compensation | | %THD With Compensation |
|---|---|---|---|
| | Source Voltage | Load Voltage | Load Voltage |
| Phase a | 20.65 | 20.64 | 0.95 |
| Phase b | 20.64 | 20.65 | 0.90 |
| Phase c | 20.65 | 20.64 | 0.90 |

Fig 5.2 gives the compensation for voltage sag and swell.The source voltage with voltage sag from 0.1sec to 0.2 sec and voltage swell from 0.3 to 0.4sec and after compensation the resultant load voltage is sinusoidal with no voltage sag and swell.



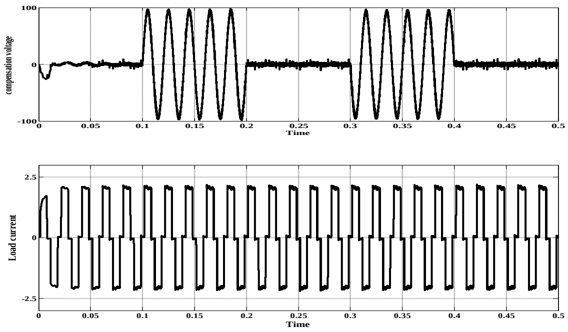



Fig5.2. Source voltage with voltage sag and swell, load voltage after compensation, compensation voltage, load current. Thus Series APF provides voltage compensation for different PQ problems.

## VI. CONCLUSION

This paper presents control technique based on unit vector template method for series APF. The MATLAB simulation results show that the voltage sag & swell and the distortions in source voltage due to $5^{th}$ and higher order harmonics can be compensated by proposed control strategy. The load voltage waveforms are constant during voltage sag, swell and harmonic distortion conditions. This is verified by taking 50% voltage sag & swell. Thus series APF provides voltage compensation.

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