Active Power Filter For Power Quality Improvement

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Abstract- *This paper tells the contamination issues created in power systems due to the non-linear features and fast changing of power electronic equipment. Power quality issues are turning stronger because sensitive equipment will be sorer for market competition reasons, equipment will continue contaminating the system more and more due to cost increase caused by the built-in competition and sometimes for lack of enforced regulations. Active power filter have been developed over the year to solve these problems to improve power quality. Among which Shunt active power filter (SAPF) is used to control the load current harmonics and reactive power compensation. In this work both PI controllers based Fuzzy Logic checked three-phase SAPF to pay tones and reactive power by non-linear load to improve power quality is enforced for three-phased three wire systems. Fuzzy controller is based on linguistic description and does not require a mathematical model of the system. A MATLAB program has been formulated to stimulate the system operation. Various simulation results are demonstrated under steady state considerations and performance of fuzzy and PI controllers is equated. PWM pattern generation is based on carrier less hysteresis based current control to obtain the switching indicates to the voltage sourced PWM converter.*

Keywords- Active power filters, PWM, harmonics compensation, power factor correction, power quality.

1. Introduction-

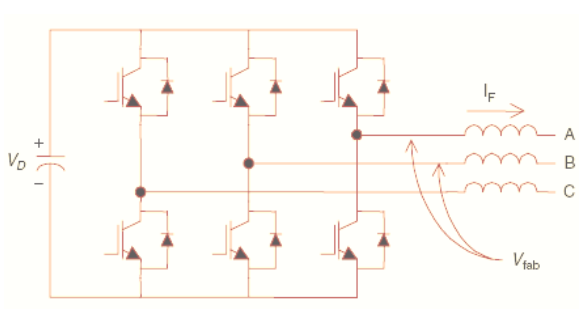
Increase in such non-linearity causes different undesirable features like low system efficiency and poor power factor. It also causes disturbance to other consumers and interference in nearby communication networks. The effect of such non-linearity may become sizeable over Early equipment was designed to withstand disturbances such as lightning, short circuits, and sudden overloads without extra expenditure. Current power electronics (PE) prices would be much higher if the equipment was designed with the same robustness. Pollution has been introduced into power systems by nonlinear loads such as transformers and saturated coils; however, perturbation rate has never reached the present levels. Due to its nonlinear characteristics and fast switching, PE create most of the pollution issues. Most of the pollution issues are created due to the nonlinear characteristics and fast switching of PE. Approximately 10% to 20% of today's energy is processed by PE; the percentage is estimated to reach 50% to 60% by the year 2010, due mainly to the fast growth of PE capability. A race is currently taking place between increasing PE pollution and sensitivity, on the one hand, and the new PE-based corrective *devices, which have the ability to attenuate the issues created by PE, on the other hand.*

the next few years. Hence it is very important to overcome these undesirable features.

Classically, shunt passive filters, consist of tuned LC filters and/or high passive filters are used to suppress the harmonics and power capacitors are employed to improve the power factor. But they have the limitations of fixed compensation, large size and can also exile resonance conditions.

Active power filters are now seen as a viable alternative over the classical passive filters, to compensate harmonics and reactive power requirement of the non-linear loads. The objective of the active filtering is to solve these problems by combining with a much-reduced rating of the necessary passive components.

Figure 1.1.Voltage source converter topology for active filters



Most of the active power filter topologies use voltage source converters, which have a voltage source at the dc bus, usually a capacitor, as an energy storage device. This topology, shown in Figure 1.1, converts a dc voltage into an ac voltage by appropriately gating the power semiconductor switches. Although a single pulse for each half cycle can be applied to synthesize an ac voltage, for most applications requiring dynamic performance, pulse width modulation (PWM) is the most commonly used today. PWM techniques applied to a voltage source inverter consist of chopping the dc bus voltage to produce an ac voltage of an arbitrary waveform. There are a large number of PWM techniques available to synthesize sinusoidal patterns or any arbitrary pattern. With PWM techniques, the ac output of the filter can be controlled as a current or voltage source device.

Figure 1.2 shows the way PWM works by means of one of the simplest and most common techniques: the triangular carrier technique. It forces the output voltage v_a *over a switching cycle, defined by the carrier period of* V_{car}*, to be equal to the average amplitude of the modulating wave* V_a *ref. The resulting voltages for a sinusoidal modulation wave contain a sinusoidal fundamental component* $V_a(1)$ *and harmonics of unwanted components. These unwanted components can be minimized using a frequency carrier as high as possible, but this depends on the maximum switching frequency of the semiconductors (IGBTs, GTOs, or IGCTs).*

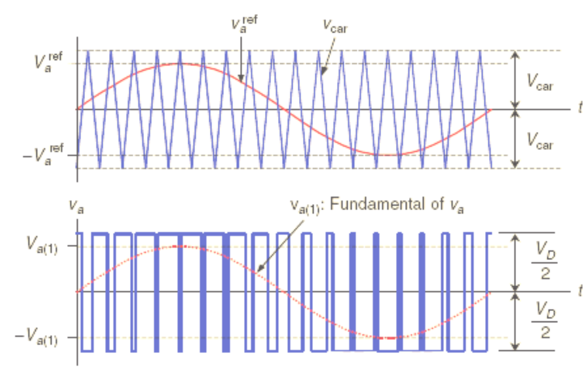


Figure.1.2. The PWM carrier Technique (triangular carrier).

The modulation strategy shown in Figure 1.3 uses a triangular carrier, which is one of many strategies applied today to control power inverters. Depending on the application (machine drives, PWM rectifiers, or active power filters), some modulation strategies are more suitable than others. The modulation techniques not only allow controlling the inverters as voltage sources but also as current sources. Figure 1.3 shows the compensating current generated for a shunt active *power filter using three different modulation techniques for current-source inverters. These three techniques are periodical sampling (PS), hysteresis band (HB), and triangular carrier (TC). The PS method switches the power transistors of the active filter during the transitions of a square wave clock of fixed frequency: the sampling frequency. The HB method switches the transistors when the error exceeds a fixed magnitude: the hysteresis band. The TC method compares the output current error with a fixed amplitude and fixed triangular wave: the triangular carrier. Figure 1.3 shows that the HB method is the best for this particular waveform and application because it follows more accurately the current reference of the filter. When sinusoidal waves are required, the TC method has been demonstrated to be better.*

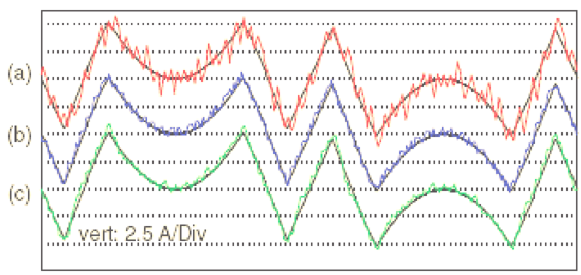


Figure.1.3. Current waveforms obtained using different modulation techniques for an active power filter: (a) PS method, (b) HB method, (c) TC method

1.1 Power Quality- *The PQ issue is defined as "any occurrence manifested in voltage, current, or frequency deviations that results in damage, upset, failure, or mis-operation of end-use equipment." Almost all PQ issues are closely related with PE in almost every aspect of commercial, domestic, and industrial application. Equipment using power electronic devise are residential appliances like TVs, PCs etc. business and office equipment like copiers, printers etc. industrial equipment like programmable logic controllers (PLCs), adjustable speed drives (ASDs), rectifiers, inverters, CNC tools and so on. The Power Quality (PQ) problem can be detected from one of the following several symptoms depending on the type of issue involved.*

- *Lamp flicker*
- *Frequent blackouts*
- *Sensitive-equipment frequent dropouts*
- *Voltage to ground in unexpected*
- *Locations*
- *Communications interference*
- *Overheated elements and equipment*

PE are the most important cause of harmonics, interharmonics, notches, and neutral currents. Harmonics are produced by rectifiers, ASDs, soft starters, electronic ballast for discharge lamps, switched-mode power supplies, and HVAC using ASDs. Equipment affected by harmonics includes transformers, motors, cables, interrupters, and capacitors (resonance). Notches are produced mainly by converters, and they principally affect the electronic control devices. Neutral currents are produced by equipment using switched-mode power supplies, such as PCs, printers, photocopiers, and any triplets generator. Neutral currents seriously affect the neutral conductor temperature and transformer capability. Interharmonics are produced by static frequency converters, cyclo-converters, induction motors & arcing devices.

Equipment presents different levels of sensitivity to PQ issues, depending on the type of both the equipment and the disturbance. Furthermore, the effect on the PQ of electric power systems, due to the presence of PE, depends on the type of PE utilized. The maximum acceptable values of harmonic contamination are specified in IEEE standard in terms of total harmonic distortion.

Power electronics are alive and well in useful applications to overcome distribution system problems. Power electronics has three faces in power distribution: one that introduces valuable industrial and domestic equipment; a second one that creates problems; and, finally, a third one that helps to solve those *problems. On one hand, power electronics and microelectronics have become two technologies that have considerably improved the quality of modern life, allowing the introduction of sophisticated energy-efficient controllable equipment to industry and home. On another hand, those same sensitive technologies are conflicting with each other and increasingly challenging the maintenance of quality of service in electric energy delivery, while at the same time costing billions of dollars in lost customer productivity.*

1.2 Solutions to Power Quality Problems- *There are two approaches to the mitigation of power quality problems. The first approach is called load conditioning, which ensures that the equipment is made less sensitive to power disturbances, allowing the operation even under significant voltage distortion. The other solution is to install line-conditioning systems that suppress or counteract the power system disturbances. Passive filters have been most commonly used to limit the flow of harmonic currents in distribution systems. They are usually custom designed for the application. However, their performance is limited to a few harmonics, and they can introduce resonance in the power system. Among the different new technical options available to improve power quality, active power filters have proved to be an important and flexible alternative to compensate for current and voltage disturbances in power distribution systems. The idea of active filters is relatively old, but their practical development was made possible with the new improvements in power electronics and microcomputer control strategies as well as with cost reduction in electronic components. Active power filters are becoming a viable alternative to passive filters and are gaining market share speedily as their cost becomes competitive with the passive variety. Through power electronics, the active filter introduces current or voltage components, which cancel the harmonic components of the nonlinear loads or supply lines, respectively. Different active power filters topologies have been introduced and many of them are already available in the market.*

2. Shunt Active Power Filter- *The shunt-connected active power filter, with a self-controlled dc bus, has a topology similar to that of a static compensator (STATCOM) used for reactive power compensation in power transmission systems. Shunt active power filters compensate load current harmonics by injecting equal-but opposite harmonic compensating current. In this case the shunt active power filter operates as a current source injecting the harmonic components generated by the load but phase-shifted by 180°.*

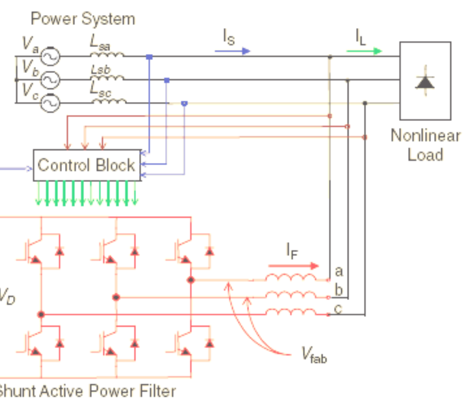


Figure.2.1 Shunt active power filter topology.

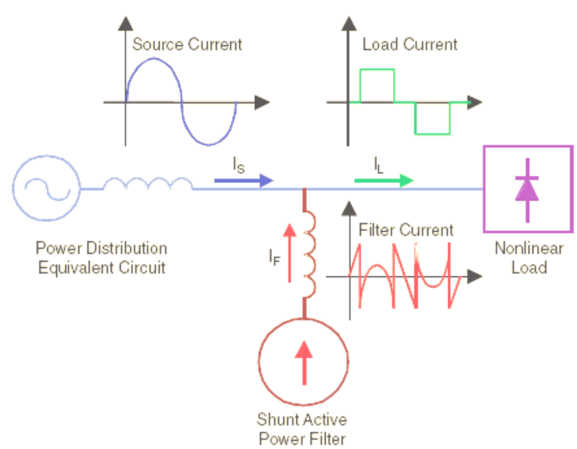


Figure 2.2 Filter current IF generated to compensate load-current harmonics

Figure 2.1 shows the connection of a shunt active power filter and Figure 2.2 shows how the active filter works to compensate the load harmonic currents.

2.1 PI Control Scheme- *The complete schematic diagram of the shunt active power filter is shown in figure 2.1.1. While figure 2.1.2.gives the control scheme realization. The actual capacitor voltage is compared with a set reference value.*

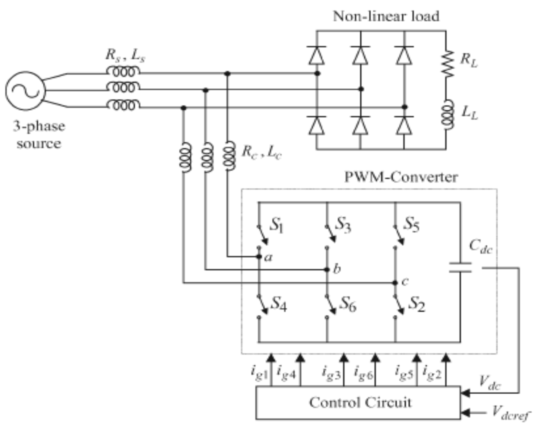


Figure 2.1.1 Schematic diagram of shunt active filter.

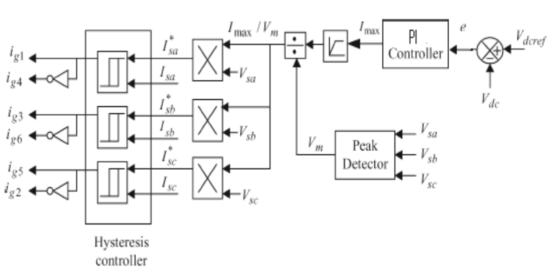


Figure .2.1.2 APF Control scheme with PI controller.

The error signal is fed to PI controller. The output of PI controller has been considered as peak value of the reference current. It is further multiplied by the unit sine vectors (u_{sa}, u_{sb}, and u_{sc}) in phase with the source voltages to obtain the reference currents (i_{sa}^*, i_{sb}^*, and i_{sc}^*). These reference currents and actual currents are given to a hysteresis based, carrierless PWM current controller to generate switching signals of the PWM converter[2]. The difference of reference current template and actual current decides the operation of switches. To increase current of particular phase, the lower switch of the PWM converter of that particular phase is switched on, while to decrease the current the upper switch of the particular phase is switched on. These switching signals after proper isolation and amplification are given to the switching devices. Due to these switching actions current flows through the filter inductor L_c, to compensate the harmonic current and reactive power of the load, so that only active power drawn from the source.

2.2 Fuzzy Control Scheme- *Fig.2.2.1 shows the block diagram of the implemented fuzzy logic control scheme of a shunt active power filter. Fig.2.2.2 shows the schematic diagram of the control algorithm. In order to implement the control algorithm of a shunt active power filter in closed loop, thee DC side capacitor voltage is sensed and then compared with a reference value. The obtained error e (=$V_{dc,ref}$-$V_{dc,act}$) and the change of error signal ce(n)=e(n)-e(n-1) at the nth sampling instant as inputs for the fuzzy processing. The output of the fuzzy controller after a limit is considered as the amplitude of the reference current I_{max} takes care of the active power demand of load and the losses in the system.*

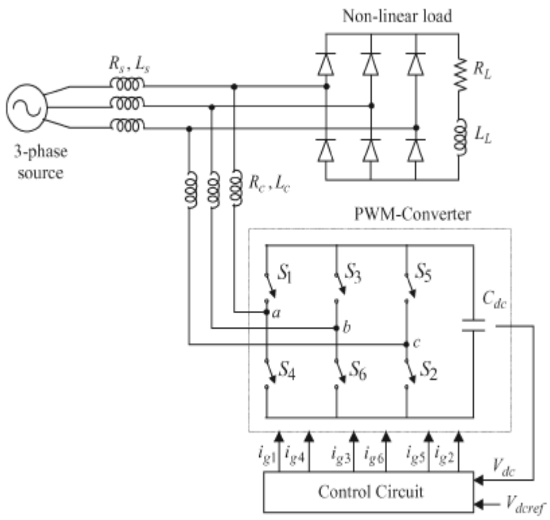


Figure2.2.1.Schematic diagram of closed loop fuzzy logic controlled shunt active power filter

The switching signals for the PWM converter are obtained by comparing the actual source currents (i_{sa}, i_{sb}, and i_{sc}) with the reference current templates (i^*_{sa}, i^*_{sb}, and i^*_{sc}) in the hysteresis current controller. Switching signals so obtained, after proper amplification and isolation, are given to switching devices of the PWM converter [6].

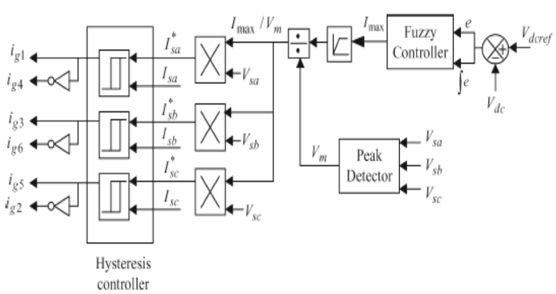


Figure2.2.2.Fuzzy Control scheme

3. Simulation Result-

A program is developed to simulate the both PI controller based and fuzzy logic based shunt active power filter in MATLAB. The complete active power filter system is composed mainly of three-phase source, a nonlinear load, a voltage source PWM converter, and a fuzzy controller or a PI controller. All these components are modeled separately, integrated and then solved to simulate the system.

Figures 3.1-3.3 show the simulations results of the proposed shunt active power filter controlled by fuzzy logic and a conventional PI controller with MATLAB program. The parameters selected for simulation studies are given in table 3.1. The three phase source voltages are assumed to be balanced and sinusoidal. The source voltage waveform of the reference phase only (phase-a, in this case) is shown in fig.3.1. A load with highly nonlinear characteristics is considered for the load compensation. The THD in the load current is 22.05%. The phase-a load current is shown in figure 3.2. The source current is equal to the load current when the compensator is not connected.

System Parameters	*Values*
Source voltage (V_s)	*100V (peak)*
System frequency (f)	*50 Hz*
Source impedance (R_s,L_s)	*0.015ohm;0.12mH*
Filter Impedance (R_c,L_c)	*0.32ohm;2.8mH*
Load impedance (R_l,L_l)	*5.3ohm;17.5mH*
DC Link capacitance	*2000uF*
Reference DC link voltage (V_{dcref})	*220V*

Table3.1.System parameters for simulation study.

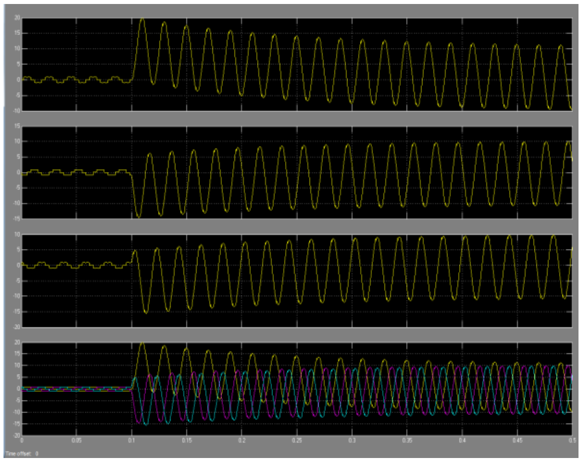


Fig.3.1 Result-1

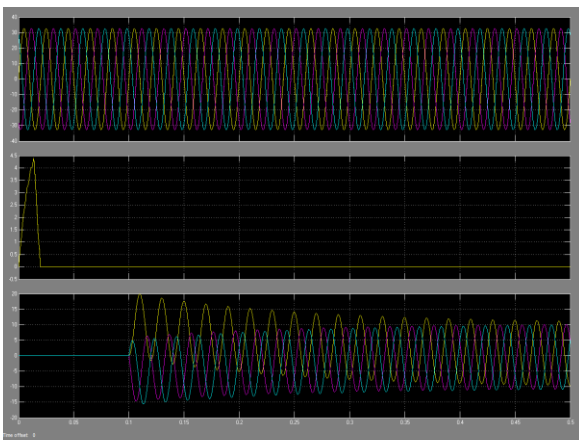


Fig.3.2 Result-2

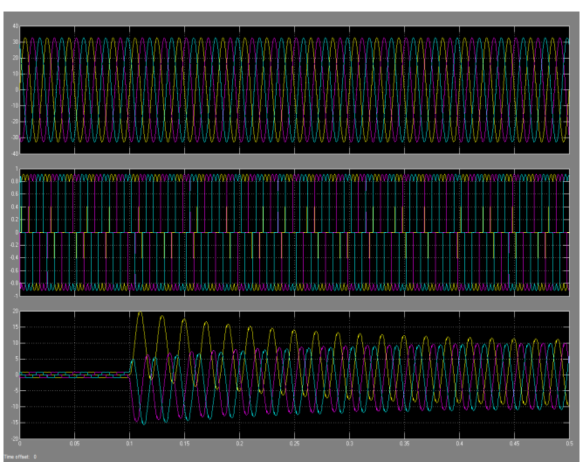


Fig.3.3 Result-3

From the responses it is depicted that the settling time required by the PI controller is approximately 10 cycles whereas in case of fuzzy controller is about 7.5 cycles. The peak overshoot voltage incase of PI controller is 880Volts (approx) whereas in case of fuzzy controller is 780volts (approx). The source current THD is reduced form 22.05% to 2.58% which is below IEEE standard with both the controllers. After compensation both source voltage and current are in phase with each other means that the harmonics are eliminated and reactive power is compensated to make power factor close to unity. As the source current is becoming sinusoidal after compensation power quality is improved.

4. Conclusions- *A shunt active power filter has been investigated for power quality improvement. Various simulations are carried out to analyze the performance of the system. Both PI controller based and fuzzy logic controller based Shunt active power filter are implemented for harmonic and reactive power compensation of the non-linear load. A program has been developed to simulate the fuzzy logic based and PI controller based shunt active power filter in MATLAB. It is found from simulation results that shunt active power filter improves power quality of the power system by eliminating harmonics and reactive current of the load current, which makes the load current sinusoidal and in phase with the source voltage. The performance of both the controllers has been studied and compared. A model has been developed in MATLAB SIMULINK and simulated to verify the results. The fuzzy controller based shunt active power filter has a comparable performance to the PI controller in steady state except that settling time is very less in case of fuzzy controller. The THD of the source current is below 5%, the harmonics limit imposed by IEEE standard.*

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