Artificial Neural Network Controlled Shunt Active Power Filter For Power Quality Improvement

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Abstract- ***Most of the pollution issues created in power systems are due to the non-linear characteristics and fast switching of power electronic equipment. Power quality issues are becoming stronger because sensitive equipment will be more sensitive for market competition reasons, equipment will continue polluting the system more and more due to cost increase caused by the built-in compensation and sometimes for the lack of enforced regulations. Efficiency and cost are considered today almost at the same level. Active power filters have been developed over the years to solve these problems to improve power quality. Among which shunt active power filter is used to eliminate and load current harmonics and reactive power compensation. In this paper the study is carried out on both PI controller based and Artificial Neural Network (ANN) controlled, three-phase shunt active power filter to compensate harmonics and reactive power by nonlinear load to improve power quality is implemented for three-phase three wire systems.***

Key Words: PI controller, ANN controller, Shunt active filter.

1. INTRODUCTION

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 creates 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. 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 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.

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 disoperation 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
- Communications interference
- Overheated elements and equipment.

PE are the most important cause of harmonics, inter-harmonics, 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 triplet's generator. Neutral currents seriously affect the neutral conductor temperature and transformer capability. Inter-harmonics are produced by static frequency converters, cyclo-converters, induction motors & arcing devices.

1.2 Control Strategies

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A new scheme has been proposed in which the required compensating current is generated using simple synthetic sinusoid generation technique by sensing the load current. This scheme is further modified by sensing line currents only. An instantaneous reactive volt-ampere compensator and harmonic suppressor system is proposed without the use of voltage sensors but require complex hardware for current reference generator. The generated reference current is not a pure sine wave but stepped sine wave. Also, without the use of voltage sensors, the scheme generates balanced sine wave reference currents but do not compensate reactive power completely (if source voltage is unbalanced/distorted) due to waveform difference between voltage and current.

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°.

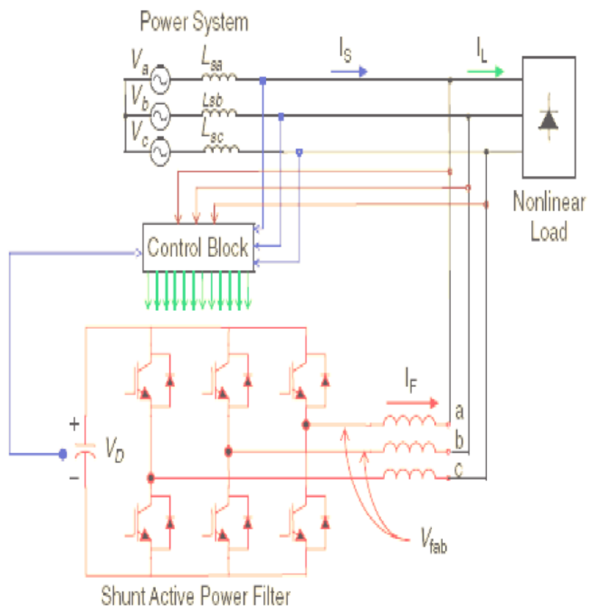

Fig-1 : Shunt active power filter topology

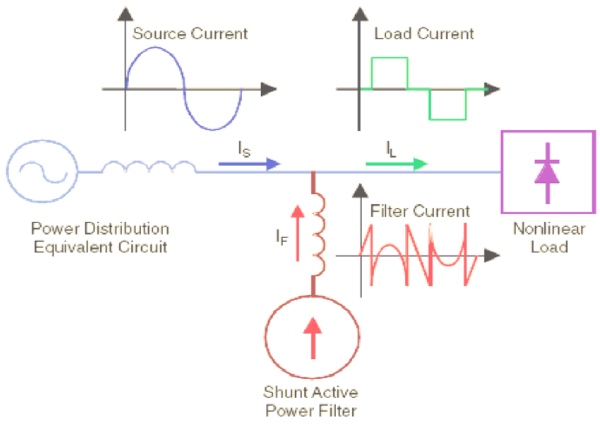

Fig-2 : Filter current IF generated to compensate load-current harmonics

2.1 Basic Compensation Principle

Figure 3 shows the basic compensation principle of a shunt active power filter. It is controlled to draw / supply a compensating current ic from/to the utility, so that it cancels current harmonics on the AC side, and makes the source current in phase with the source voltage. Figure.4 shows the different waveforms. Curve A is the load current waveform and curve B is the desired mains current. Curve C shows the compensating current injected by the active filter containing all the harmonics, to make mains current sinusoidal.

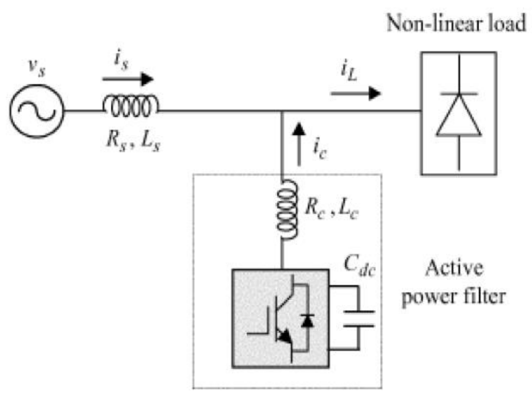

Fig-3 : Shunt active power filter Basic Compensation Principle.

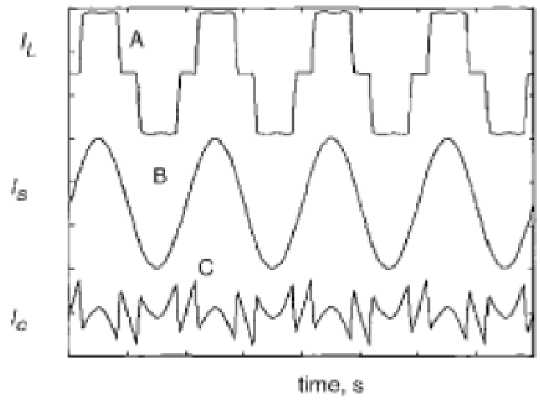

Fig- 4 : Shunt active power filter-shapes of load, source and desired filter current waveforms

2.2 Role Of Dc Side Capacitor

The DC side capacitor serves two main purposes: it maintains a DC voltage with small ripple in steady state, and serves as an energy storage element to supply real power difference between load and source during the transient period. In the steady state, the real power supplied by the source should be equal to the real power demand of the load plus a small power to compensate the losses in the active filter. Thus, the DC capacitor voltage can be maintained at a reference value. However, when the load condition changes the real power balance between the mains and the load will be disturbed. This real power difference is to be compensated by the DC capacitor. This changes the DC capacitor voltage away from the reference voltage. In order to keep satisfactory operation or the active filter, the peak value of the reference current must be adjusted to proportionally change the real power drawn from the source. This real power charged/discharged by the capacitor compensates the real power consumed by the load. If the DC capacitor voltage is recovered and attains the reference voltage, the real power supplied by the source is supposed to be equal to that consumed by the load again.

3. ARTIFICIAL NEURAL NETWORK

Figure 5 shows the block diagram of the implemented fuzzy logic control scheme of a shunt active power filter. 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 C_e (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.

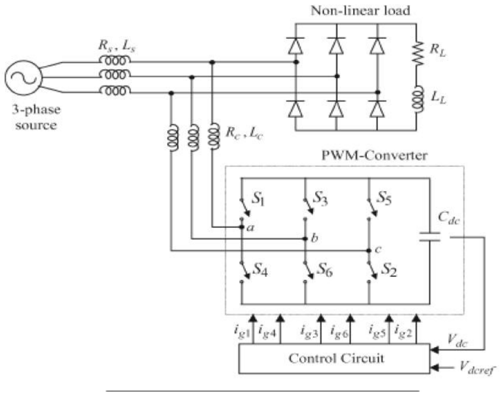

Fig-5 : Schematic diagram of closed loop ANN Controlled shunt active power filter.

3.1 ANN Based Control

Various attempts have been carried out to use ANN for control purposes. Based on the learning method, the ANN based controllers can be divided in two categories. The first categories are the controllers with off-line learning. Here, first the learning is performed, and then the trained ANN is implemented to the process which is under control. Nguyen and Windrow have shown in a novel approach the use of this method for backing up a trailer in a two dimensional plane. Kong and Kosko tried also the same approach, but used the truck kinematic equation instead of truck emulator as used by Nguyen. Beau- fays et al. have used this method for load frequency control in power systems. Generally, the off-line method is applicable to a process with explicit mathematical formulation. The second category includes the controllers that use on-line learning. Chen has investigated on-line learning for adaptive control, although his method is only applicable to single input, single output linearized systems. It is shown that the learning process makes this controller an adaptive one. On-line learning has been successfully used for underwater vehicle control as reported. The proposed learning algorithm and the net-work architecture provide stable and accurate tracking performance. For the on-line learning method, the mathematical formulation of the process under the control is needed. Schiff Mann et al. have reported a comparative study for an ANN on-line controller and a P-I controller. The results show that the ANN controller is very effective. In their study the plant is treated as an additional and non-modifiable layer of the network and only simple qualitative knowledge of the plant is necessary. The on-line training makes an ANN controller an adaptive controller. The learning process based on the back propagation, adjusts the ANN parameters (weights) such that the output follows its reference value.

4. MODELLING SYSTEM

A program is developed to simulate the 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.

4.1 Modelling Of Nonlinear Load

A three-phase diode rectifier with input impedance and R-L load is considered as a nonlinear load. Due to the presence of source inductance, six overlapping and six non-overlapping conduction intervals occur in a cycle. During a non-overlapping interval only two devices will conduct while during an overlapping interval three devices of the bridge will conduct simultaneously. The dynamic equations during non-overlap and overlap intervals are given in (1) and (2) respectively:

$$pi_d = (V_o - (2R_s + R_L)\, i_d - 2V_d)/(2L_s + L) \quad \text{.... eq.4.1.1}$$
$$pi_d = (V_o - (1.5R_s + R_L)\, i_d - 2V_d)/(1.5L_s + L) \quad \text{... eq.4.1.2}$$

Where R_s and L_s are the elements of the source inductance, v_d is the voltage drop across each device, R_L and L are the elements of load impedance, i_d is the load current flowing through the diode pairs and ***p*** is the differential operator d/dt). V_0 is the AC side line voltage segment (v_{ac}, v_{bc}, v_{ba}, v_{ca}, v_{cb}, v_{ab} during non-overlap, and $v_{bc}+v_{ac}/2$, $v_{ba}+v_{bc}/2$, $v_{ca}+v_{ba}/2$, $v_{cb}+v_{ca}/2$, $v_{ab}+v_{cb}/2$, $v_{ac}+v_{ab}/2$ during overlap intervals) based on diode pair conduction. The phase currents i_{sa}, i_{sb}, and i_{sc} are obtained by i_d, considering the respective diode pair conduction.

4.2 Modelling Of PWM Converter

The PWM converter has been modelled as having a three phase AC voltage applied through a filter pedance (R_c,L_c) on its input, and DC bus capacitor on its output. The three phase voltages v_{fa}, v_{fb}, and v_{fc} reflected on the input side can be expressed in terms of the DC bus capacitor voltage V_{dc} and switching functions stating the on/off status of the devices of each leg S_a, S_b, and S_c as

$$V_{fa} = (V_{dc}/3)(2S_a - S_b - S_c)$$
$$V_{fb} = (V_{dc}/3)(-S_a + 2S_b - S_c) \quad \text{eq.4.2.1}$$
$$V_{fc} = (V_{dc}/3)(-S_a - S_b + 2S_c)$$

The three phase currents i_{fa}, i_{fb}, and i_{fc} flowing through impedances (R_c, L_c) are obtained by solving the following differential equations:

$$P_{ifa} = (1/L_c)(R_c\, i_{fa} + (V_{sa} - V_{fa})$$
$$P_{ifb} = (1/L_c)(R_c\, i_{fb} + (V_{sb} - V_{fb})$$
$$P_{ifa} = (1/L_c)(R_c\, i_{fc} + (V_{sc} - V_{fc})$$

The DC capacitor current can be obtained in terms of phase currents i_{fa}, i_{fb}, and i_{fc} and the switching status (1 for on and 0 for off) of the devices $S_{a,}$ S_b and S_c

$$I_{dc} = i_{fa} S_a + i_{fb} S_b + i_{fc} S_c \quad \text{...... eq.4.2.2}$$

From this, the model equation of the DC side capacitor voltage can be written as

$$pV_{dc} = (1/C_{dc})(i_{fa} S_a + i_{fb} S_b + i_{fc} S_c) \text{.. eq.4.2.3}$$

5. SIMULATION AND RESULTS

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 modelled separately, integrated and then solved to simulate the system. Fig. 6 to Fig.12 shows the simulations results of the shunt active power filter controlled by fuzzy logic and a conventional PI controller with MATLAB program. 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.6 A load with highly nonlinear characteristics is considered for the load compensation. The THD in the load current is 28.05%. The phase-a load current is shown in figure 7. The source current is equal to the load current when the compensator is not connected.

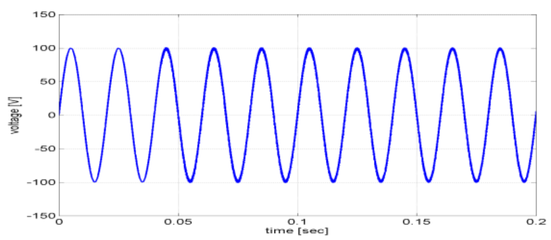

Fig-6 : Source Voltage

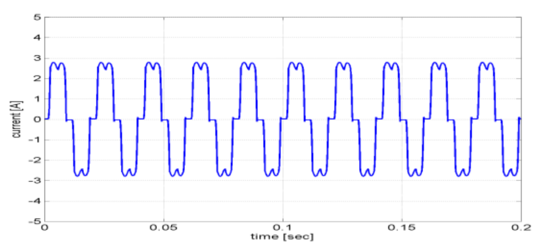

Fig-7 : Source current when the compensator is not connected

The compensator is switched ON at t=0.05s and the integral time square error (ITSE) performance index is used for optimizing the and coefficients of the PI controller. The optimum values (K_p and K_i) are found to be 0.2 and 1.5, respectively, which corresponds to the minimum value of ITSE. The source currents for PI and ANN controllers are shown in Figs.8 and 10 respectively. Compensating currents of PI and ANN controllers are shown in figures 9 and 11. The DC side capacitor voltage during switch on response is shown in figures 12 of PI and ANN controllers.

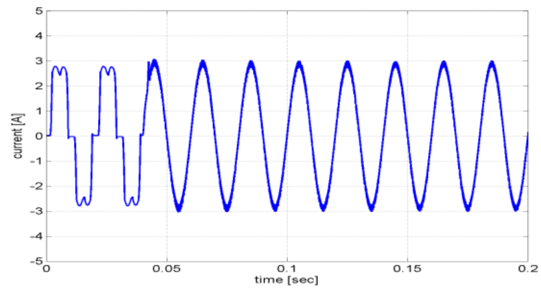

Fig-8 : Source Current with PI Control

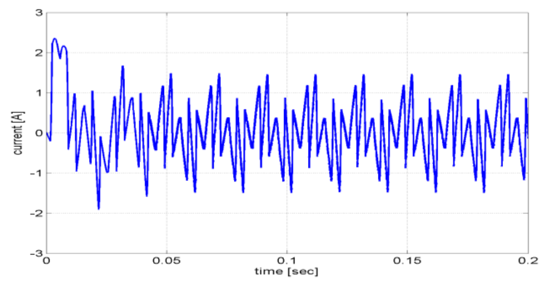

Fig- 9 : Compensating Current With PI Control

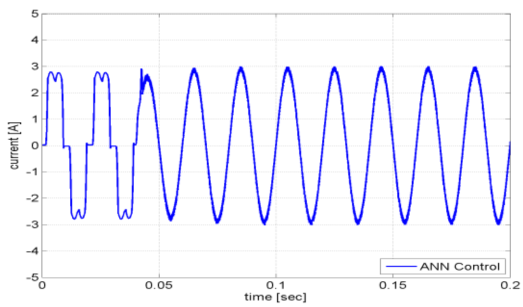

Fig-10 : Grid current with ANN Control

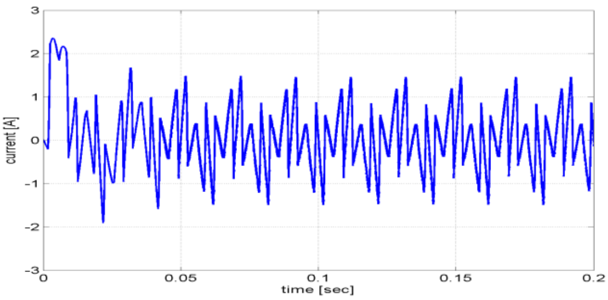

Fig-11 : Compensating current with ANN Control

From the wave forms it is clear that harmonic distortion is reduced after connecting compensator. Compared to PI controller fuzzy controller fuzzy controller gives better harmonic compensation.

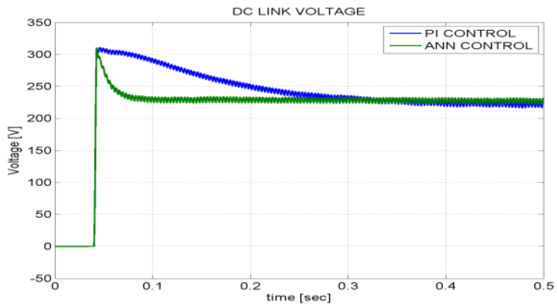

Fig-12 : The DC side capacitor voltage of PI and ANN

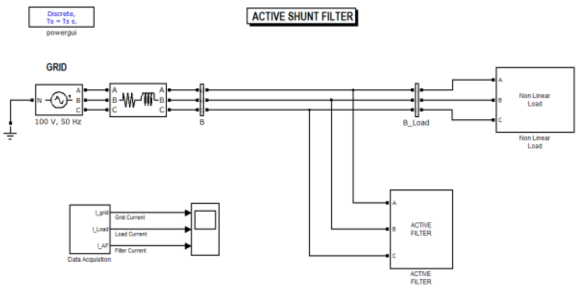

Fig-13 : Simulation model

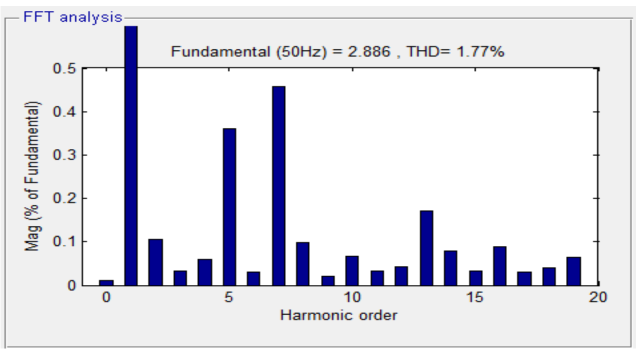

Fig-14 : Simulation Result with ANN control

The source current THD is reduced form 27.88% to 2.12% increase of PI controller and 1.77% increase of ANN controller which is below IEEE standard with both the controllers and ANN controller shows the improved performance than convention control.

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.

6. CONCLUSIONS

A shunt active power filter has been investigated for power quality improvement. Various simulations are carried out to analyses the performance of the system. Both PI controllers based and Artificial Neural Network 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 Artificial Neural Network 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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BIOGRAPHIES

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