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INVESTIGATION OF SHUNT ACTIVE POWER FILTER FOR COMPENSATION OF CURRENT HARMONICS USING FUZZY LOGIC CURRENT CONTROLLER

P. Valarmathi

Lecturer (Senior Grade), Dept. of Electronics and Communication Engineering, Sakthi Polytechnic College, Erode, Tamil Nadu, India

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Abstract - *A 3 phase Shunt Active Power Filter (APF) controlled by fuzzy logic current controller is proposed for the harmonic currents compensation generated by nonlinear loads. Multilevel inverters are investigated and used for APF topologies. Today, a three level inverter is the most used converter in the major industrial applications. A new scheme is proposed to improve APF compensation capability based on fuzzy rules by regulating the current error. To develop three-level voltage inverter output and to avoid an unbalanced AC voltage waveform, a Proportional Integral (PI) controller is required in order to maintain the constant DC voltage. MATLAB/SIMULINK power system toolbox is used to simulate the proposed system in order to eliminate the harmonics and reactive power components. The results are obtained in various states under various operating conditions which show the efficiency of fuzzy controller based shunt active filter compared to the conventional scheme.*

Key Words: **Fuzzy logic current controller, Harmonic current compensation, Power quality, Shunt active Power Filter, Three-level (NPC) inverter.**

1. INTRODUCTION

Power pollution is obtained from nonlinear loads such as SMPS, electronic ballasts and adjustable speed drives results in the poor power quality in the grid system. The non-sinusoidal balanced or unbalanced currents generate harmonics, reactive power and extreme neutral current. The harmonic current cannot supply to active power and need to be eliminated to enhance the power quality [1]. Passive filters are used to eliminate current harmonics and increase the power factor. However, the passive filter has many disadvantages. Thus, active power filter [2] is the popular solution for the compensation of harmonic and reactive currents in power systems. The most powerful converter used in APF is the two-level voltage source inverter [3-5]. Due to power handling capabilities of power semiconductor devices, these inverters are imperfect for low power applications. Three-level inverters are applied in medium and high power applications in the past years [6-7]. The controller is the core of the active power filter operation and the subject of several researches in recent years [8-9].

The conventional scheme based on hysteresis or PWM logic control to generate pulses, presents numerous drawbacks. To improve the active power filter performance, intelligent control techniques, particularly fuzzy logic controllers are used. The principal advantages of these controllers are robustness, capability to control nonlinear systems, absence of accurate mathematical model, etc.

In this paper, the three-phase three-level shunt active filter based on fuzzy logic current controller is proposed for the current harmonics compensation. The new controller is designed to improve compensation capability of APF by adjusting the current error using a fuzzy rule. The reference current signals required to compensate current harmonics use the synchronous reference detection method. The performances of the proposed system for transient and steady-state conditions are analyzed with different nonlinear loads using Matlab/Simulink program and Sim Power System toolbox.

2. SHUNT ACTIVE FILTER

The circuit design of the shunt active filter is shown in Fig. 1. It is controlled to cancel AC side current harmonics and make the source current in phase with the source voltage. After compensation, the source current becomes sinusoidal and in phase with the source voltage [10-11][23].

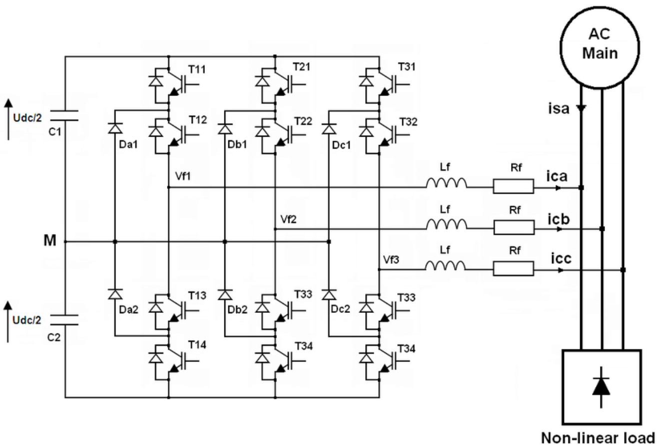


Fig -1: Three level shunt active filter

3. THREE-LEVEL (NPC) INVERTER

Multilevel inverters are currently used for active filter topologies. Three-level inverters are the most popular converters employed in medium and high power applications. It can reduces the harmonic content generated by the active filter and can reduce the voltage or current ratings of the semiconductors [12].

Figure 2 shows the power circuit of a diode-clamped three-level inverter based on the six main switches (T_{11}, T_{21}, T_{31}, T_{14}, T_{24}, T_{34}) of the traditional two-level inverter, addition of two auxiliary switches (T_{12}, T_{13}, T_{22}, T_{23}, T_{32}, T_{33}) and two neutral clamped diodes on each bridge arm. The diodes are having connection with reference point to get midpoint voltages. This structure permits the switches to endure larger DC voltage input on the premise that the switches will not raise the level of their withstand voltage. Any phase, for example phase-A, three kinds of voltage level can be obtained for corresponding three kinds of switching states. As a result, 27 kinds of switching output exist in three-phase three-level inverter [13-15] [20].

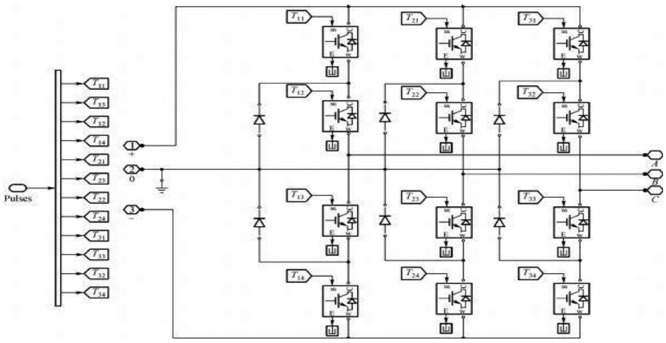


Fig -2: Three-level NPC inverter

4. CONTROL STRATEGY

Different control algorithms are proposed for APF but a Synchronous detection method is used for harmonic detection to calculate reference current for shunt active power filter due to its simplicity [16-17]. The balanced three phase source currents can be obtained after compensation. The equal current distribution method of this control scheme is implemented in this research work. Figure 3 shows the block diagram of SDM filter.

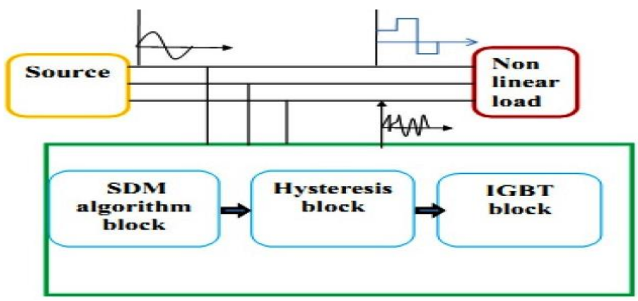


Fig -3: SDM filter block [22]

The expression of reference current for shunt active power filter in each phase (i^*_{ca}, i^*_{cb}, i^*_{cc})

$$i^*_{ca} = I_{La} - I_{Fa}$$

$$i^*_{cb} = I_{Lb} - I_{Fb}$$

$$i^*_{cc} = I_{Lc} - I_{Fc}$$

Where, I_{La}, I_{Lb}, I_{Lc} are 3 phase currents drawn by the load and I_{Fa}, I_{Fb}, I_{Fc} are fundamental currents.

After getting the reference current, it is compared with the actual current by using hysteresis current comparator to generate six switching pulses, which are used to control the IGBT either by turning ON or OFF.

5. FUZZY LOGIC CURRENT CONTROLLER

Fuzzy logic scheme is like a human being's feeling and inference process. It need not require an accurate mathematical model, can work with inaccurate inputs. It can handle non-linearity and more robust than other conventional type controllers [18-19].

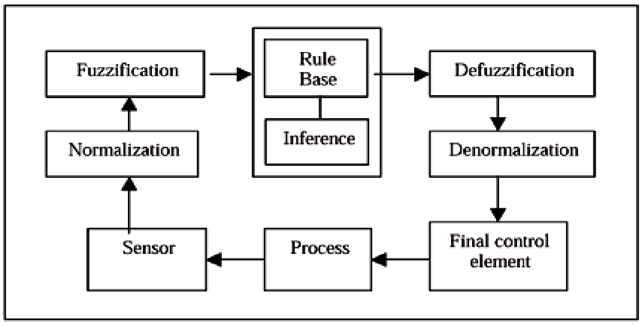
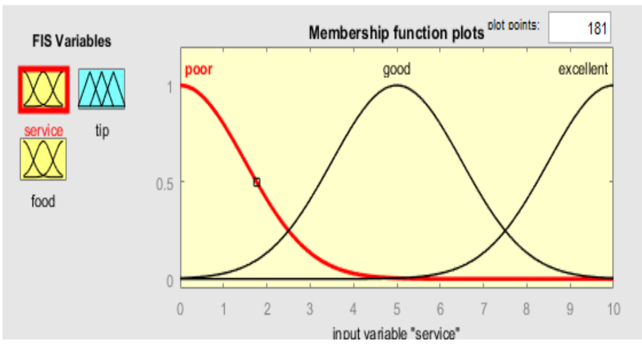


Fig -4: Block diagram of Fuzzy Logic controller

Fuzzy logic control is the evaluation of a set of simple linguistic rules to determine the control action. The fuzzy logic current controller design has two inputs, error *e*, change of error *de* and one output *s*. Here the error *e* and change of error *de* are the input variable for real system. Both inputs and output have five membership functions such as NB-Negative Big, NS-Negative Small, Z-Zero, PS-Positive Small, and PB-Positive Big [21]. The membership functions used in fuzzification are shown in figure 5. Table 1 shows the fuzzy rules.



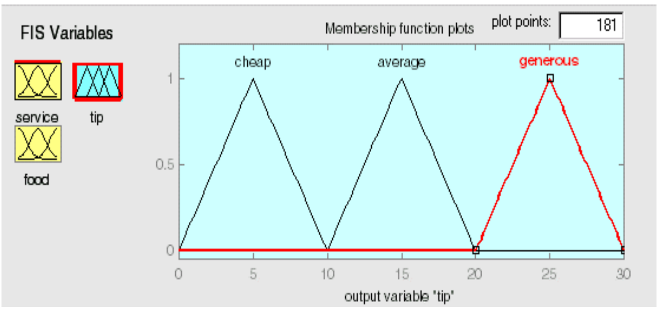


Fig -5: Membership functions

Table -1: Fuzzy Rules

Error/Change in Error	NB	NS	Z	PS	PB
NB	NB	NS	NS	Z	PS
NS	NB	NS	NS	PS	PB
Z	NB	NS	Z	PS	PB
PS	NB	NS	PS	PS	PB
PB	NS	Z	PS	PS	PB

Each phase errors are discredited by the zero order hold blocks. The error rate is error derivative and obtained by unit delay block. The saturation block requires upper and lower bounds on a given signal. The input signal is within the range of lower and upper limit parameters, the input signal passes remains same.

When the input signal is outside these bounds, the signal is clipped to the upper or lower bound. The output of the saturation blocks are the input to fuzzy logic controllers. The outputs of these fuzzy logic controllers are used in the production of pulse switching signals of the three-level inverter. The switching signals are generated by comparing a two-carrier signal with the output of the fuzzy logic controllers. The Simulink model of the fuzzy logic switching signal generation is given in figure 6.

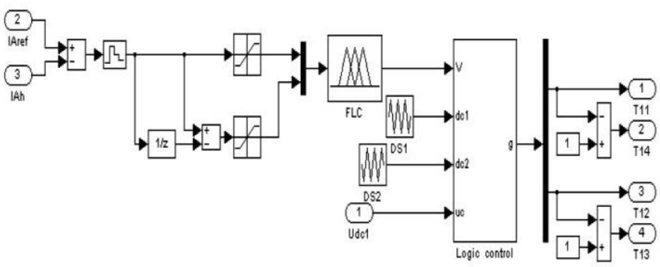


Fig -6: Three-level inverter switching signal generation

Figure 7 shows the block diagram of the proposed fuzzy current controller for the three-phase shunt active power filter.

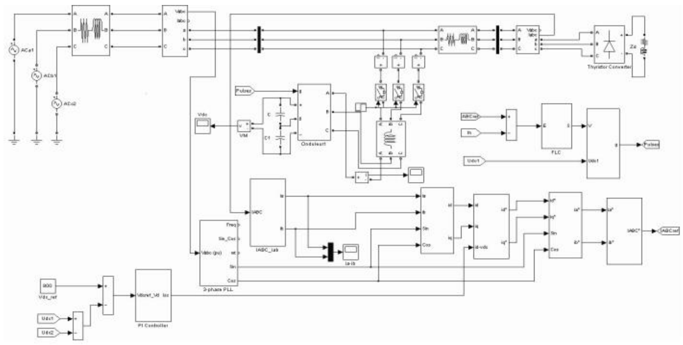


Fig -7: Three-level shunt active filter based on fuzzy current controller

6. SIMULATION RESULTS

Figure 8 shows the waveform of AC current source before compensation. Figure 9 shows the corresponding current source harmonic spectrum. Figure 10 and 11 shows respectively the source and injected current before and after APF application. The DC voltage is shown in figure 12. The waveforms of source voltage and source current after compensation are simultaneously shown in figure 13. The harmonic spectrum of the source current after compensation is shown in figure 14.

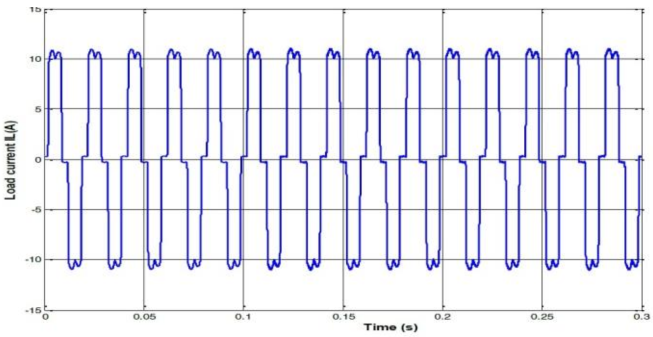


Fig -8: Source current without APF

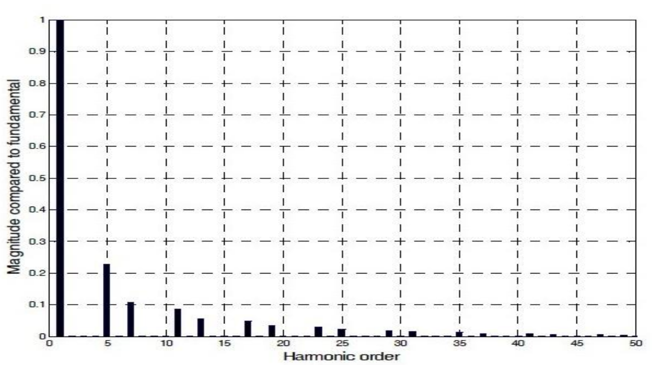


Fig -9: Source current spectrum without APF (THD 25.21%)

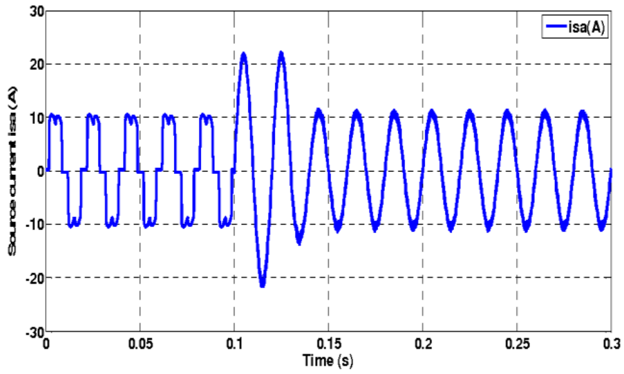


Fig -10: Source current before and after compensation using conventional controller

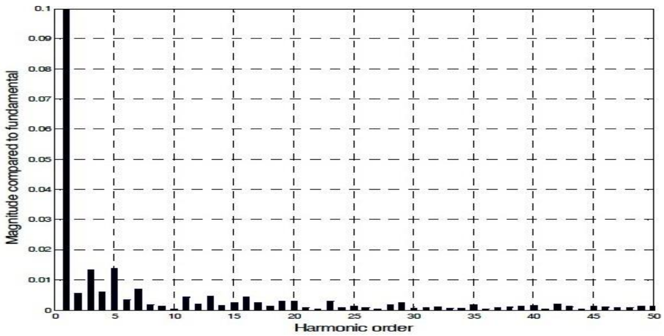


Fig -11: Source current spectrum with APF (THD = 3.51%)

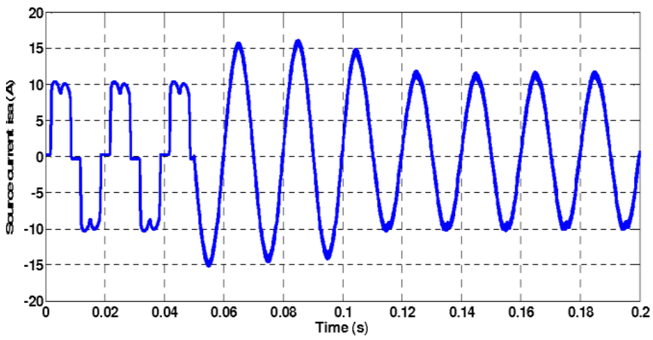


Fig -12: Source current before and after compensation using Fuzzy controller

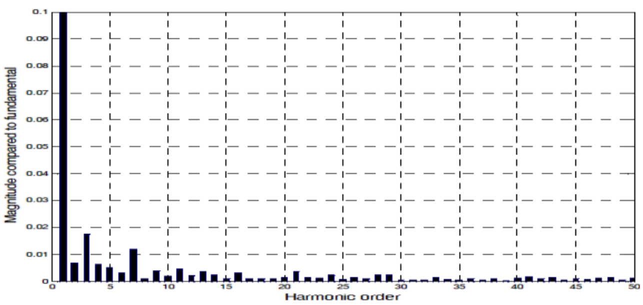


Fig -13: Source current spectrum with APF using fuzzy controller (THD 1.27%)

3. CONCLUSIONS

In this paper, a three-phase shunt active power filter with neutral-point diode clamped inverter based on fuzzy logic current controller is presented. Use of filter is achieving the harmonics elimination by the nonlinear loads. Simulations with different nonlinear loads (AC/DC converter with R,L or R,C) under various conditions are performed using the conventional PWM and fuzzy current controllers. The result shows the advantages and efficiency of the proposed fuzzy logic controller. The THD is significantly reduced from 25.21% to 3.51% by conventional PWM controller and to 1.27% for fuzzy controller with APF. For both controllers, the current source after compensation is sinusoidal and it is in phase with the input voltage. Hence, the proposed fuzzy logic current controller is efficient to control shunt active filters based on multilevel inverter topology in harmonic currents elimination and power factor improvement.

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