FUZZY LOGIC CONTROLLER FOR THREE-LEVEL SERIES ACTIVE POWER FILTER TO COMPENSATE VOLTAGE HARMONICS

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Abstract: *In this paper, the three-level inverter is used as a series active power filter to suppress harmonic voltage drawn from a nonlinear load. This filter acts as zero impedance for the fundamental frequency and as high resistor for harmonic frequencies. Most previously reported three-phase series active power filters are based on two-level inverters with conventional controllers requiring a complex and a complicated mathematical model. To overcome this problem a fuzzy logic controller is used and extended to a three level series active power filter.*
This work presents principles of operation and design of a fuzzy logic controller algorithm to control the harmonic voltages. The viability of the proposed algorithm is validated with computer simulation. The obtained results showed that source voltage is sinusoidal and in phase with source current as well as a reduced total harmonic distortion.

Keywords: *Active power filter, passive power filter, power quality compensator, fuzzy controller, conventional controller.*

1. Introduction

Power quality deterioration generally results from the intensive use of static converters and other non-linear loads. The reduction of harmonic and reactive currents becomes an increasingly required issue. Passive LC filters have been used [1] to remove line current harmonics and to improve the power factor. However, when implemented, these passive filters present many drawbacks such as tuning problems, series and parallel resonance.

Recently active power filters have been widely used, studied and presented as a solution to harmonic problems. These filters are classified into shunt active power filter, injecting compensating currents [2,3,4,5]; the series active power filter, injecting compensating voltages through a transformer [2,3,6,7]; the hybrid filters (parallel passive filters and series active power filter) [8,9] acting as zero impedance for the fundamental frequency and as high resistor for harmonics frequencies and finally, Unified Power Quality Conditioner UPQC (series active power filter and shunt active power filter) compensating supply voltage and load current [10].

The series active power filter is appropriate for harmonic voltage compensation, which has sufficient capacitor component in the DC link of the rectifier. The solution of, harmonic voltage become a great issue and a field of interest because the loads that act as harmonic voltage sources (copiers, fax machines, fluorescent lamps, air conditioners etc.), continue to increase.

Therefore, hybrid filter topology has been developed achieving the desired performance with a significant reduction in the kVA-rating [8, 9].

Due to power semi-conductors handling capabilities, two levels voltage source inverters are limited to medium power applications. Hybrid topologies shunt passive filter and series active filter were proposed to obtain high power filters.

Recently, there has been an increasing interest in using multilevel inverters for high power drives, reactive power and harmonics compensation [10,11,12,13,14,15]. Multilevel pulse width modulation inverters can be used as series active power filter for high power applications solving the problem of power semiconductor limitation. The use of neutral-point-clamped (NPC) inverters is suitable to series connected devices.

Two level three-phase series active power filters with conventional controllers were employed to reduce harmonic voltages generated by nonlinear loads.

This paper presents a three level NPC voltage source inverter as series active power filter and fuzzy logic controller for harmonic voltage control.

The PWM technique [16] is used to generate inverter switching signals and *p-q* theory [17, 18] for harmonic voltage identification.

A SIMPOWERSYSTEM Matlab /simulation model based on proposed control strategy is given and the simulation results are discussed and analysed.

2. Series APF topology description and modeling

A- Description of the APF topology

Fig.1 shows the topology of combined series APF and shunt passive filter, acting as zero impedance for fundamental frequency and as high resistor for harmonics frequencies.

The APF is supplied by low power PWM inverter connected in series with the main supply and the non-linear load through current transformer. The passive filter connected in parallel to the load is used to damp the 5th and the 7th harmonic of *Vl* because of their high amplitudes.

The series APF acts as a voltage source and injects compensating voltage in order to obtain sinusoidal load voltage. The developments in digital electronics, communications and process control system have made the loads very sensitive, requiring ideal sinusoidal supply voltage for their operation. Simultaneous and accurate acquisition of reference voltage signal is very important.
In this paper fuzzy logic controller is proposed as a solution to improve the compensating harmonic voltages.

The control method is aimed to control a PWM inverter to produce the desired compensating voltage, in the output of the series APF.

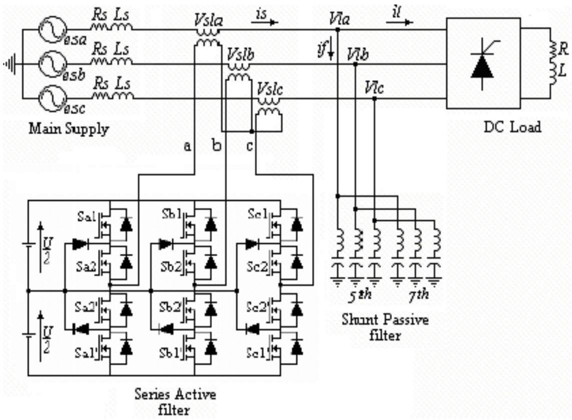


Fig.1. General Configuration of hybrid active power filter

b- Modelling

Fig.2. shows the per-phase equivalent scheme of the studied topology.

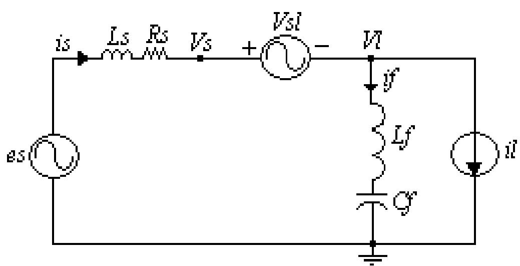


Fig.2. Per-phase equivalent scheme.

Where:
es, is, Ls, Rs: source voltage, source current, source inductance, and source resistance,
Vs: line voltage,
Vl, il : load voltage and load current,
Vsl: controllable voltage source representing the series active power filter,
if, Cf, Lf: shunt passive filter current, passive filter capacitance, and passive filter inductance.

This equivalent scheme is modeled by (1) and (2):

$$Vsl = Vs - Vl \tag{1}$$

$$is = if + iL \tag{2}$$

Where,

$$Vs = es - Rs \cdot is - Ls\frac{dis}{dt} \tag{3}$$

The voltage error is given by:

$$\Delta Vsl = Vslref - Vsl \tag{4}$$

Vslref is expressed by:

$$Vslref = Vsh - Vlh \tag{5}$$

$$Vsh = k.\, ish \tag{6}$$

Vsh, Vlh, ish: represent, respectively, the harmonic components present in *Vs, Vl*, and *is*.
k: is a current sensor gain.

3. APF voltage references determination

The harmonic current identification is controlled using various schemes, which may be based on time- or frequency-domain. In this work time-domain Instantaneous active and reactive power (*p-q*) scheme is employed. This method is preferred because, it provides fast response to changes in the power system, easy to implement and have less computational burden [19].

The harmonic component *Vslh* of *Vsl* is defined by:

$$Vslh = Vsl - Vslf \tag{7}$$

First, we extract the *p-q* components of *Vsl*:

$$\begin{bmatrix} Vslp \\ Vslq \end{bmatrix} = Cpq.C32 \begin{bmatrix} Vsl_a \\ Vsl_b \\ Vsl_c \end{bmatrix} \tag{8}$$

*Cpq, C*32 representing the Park matrix and Concordia matrix given respectively by:

$$Cpq = \begin{bmatrix} sin(\omega t) & -cos(\omega t) \\ -cos(\omega t) & -sin(\omega t) \end{bmatrix}$$

$$C32 = \sqrt{2/3}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix}$$

Next, decomposition of *Vslp* and *Vslq* into continuous components $\overline{V}slp$, $\overline{V}slq$ and alternative components $\tilde{V}slp$,$\tilde{V}slq$:

$$Vslp = \overline{V}slp + \tilde{V}slp \tag{9}$$

$$Vslq = \overline{V}slq + \tilde{V}slq \tag{10}$$

$\overline{V}slp$, $\overline{V}slq$ are obtained via a second order low-pass filter.

Then, the obtained three-phase fundamental components are presented below:

$$\begin{bmatrix} Vslf_a \\ Vslf_b \\ Vslf_c \end{bmatrix} = C23.\,Cpq^{-1} \begin{bmatrix} \overline{V}slp \\ \overline{V}slq \end{bmatrix} \qquad (11)$$

Finally, this algorithm can be represented as shown in the block diagram of Fig.3.

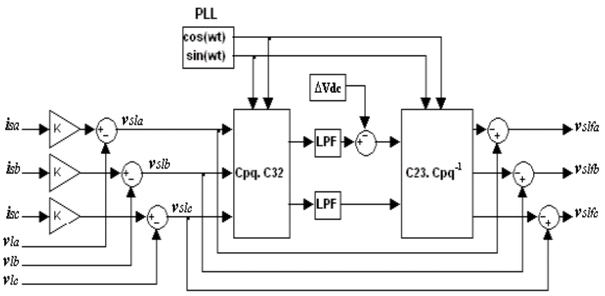


Fig.3. Block diagram of voltages references determination

4. Inverter control using PWM

The control method is aimed to control PWM inverter to produce the desired compensation voltage, in the output of series APF. The principle of this method is described in detail in [20]. The control is carried out by implementing a fuzzy logic controller [19,20,21] after finding the difference (error (e)) between the injected voltage (V_{inj}) and the calculated reference voltage (V_{slf}) that determines the reference voltage of the inverter (modulating wave). This reference voltage is compared with two carrying triangular identical waves shifted one from other by a half period of chopping producing the control signal to control the on-off of the IGBT. The general block diagram of voltage control is shown in Fig.4.

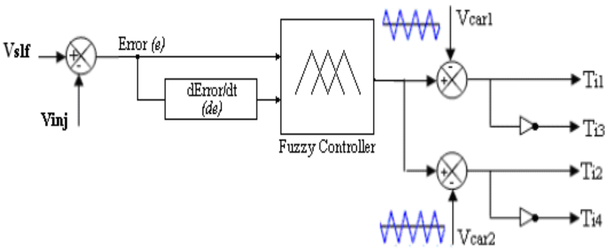


Fig.4. PWM synoptic block diagram of voltage control

5. Fuzzy Control Application

Fig. 5, as explained in [20], shows the synoptic scheme of fuzzy controller, which possesses two inputs (the error (*e*), (*e* = *Vslf* –*Vinj*) and its derivative (*de*)) and one output (the command (*cde*)).

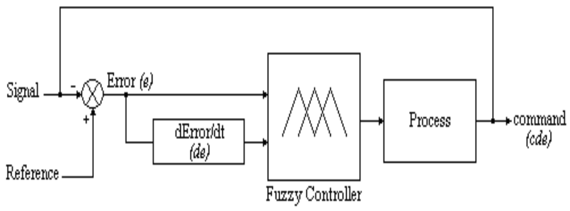
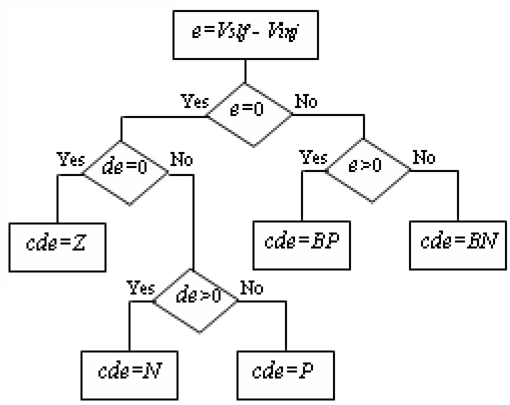


Fig.5. Fuzzy controller synoptic diagram

The purpose is to obtain sinusoidal source currents in phase with the supply voltages. The conventional controllers (P, PI…) are replaced by fuzzy logic controllers. The fuzzy controller algorithm is designed as described and explained in [20].

The establishment of the fuzzy rules illustrated and presented by the curves in Fig.6, is based on the error (*e*) sign, variation and knowing that (*e*) is increasing if its derivative (*de*) is positive, constant if (*de*) is equal to zero, decreasing if (*de*) is negative, positive if (*Vslf* > *Vinj*), zero if (*Vslf* = *Vinj*), and negative if (*Vslf* < *Vinj*), fuzzy rules are summarized in this algorithm:



(Z): Zero.
(P): Positive.
(N): Negative.
(BP): Big positive.
(BN): Big negative.

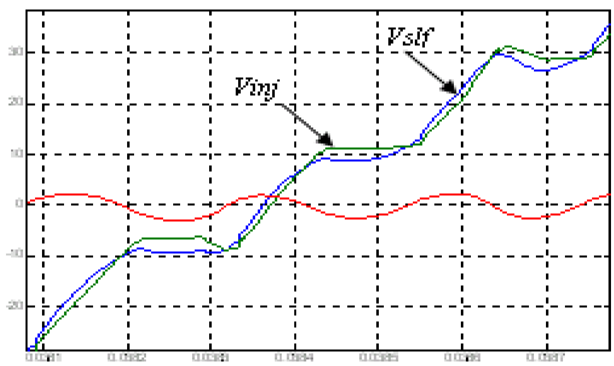


Fig.6 Fuzzy rules establishment

6. Simulation

The simulation is carried out using a program working in MATLAB Simulink environment. The simulation parameters are given in table.1, presented below.

Table 1
Simulation Parameters

1	Supply: *Vs*, *Rs*, *Ls*	220 V, 0.01Ω, 0.1 mH.
2	DC Load: *Rdc*, *Ldc*	10 Ω , 2 mH
3	DC supply voltage U	1000 V
4	Fifth harmonic filter Cf, Lf Seventh harmonic filter Cf, Lf	3.3 mH, 120 μ F 11 mH, 18 μ F
5	Switching frequency	10 K Hz
6	Current sensor gain k	5

Switching pulses of the three-phase three-level inverter are shown in the Fig.7.

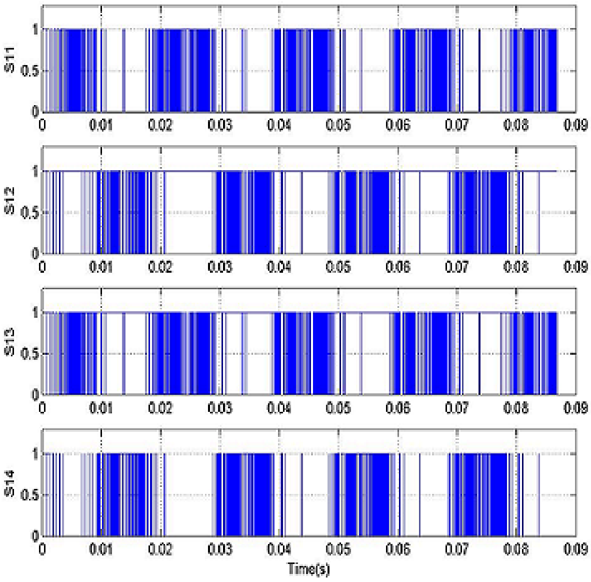


Fig. 7. Switching pulses of APF arm (S11, S12, S13, , S14)

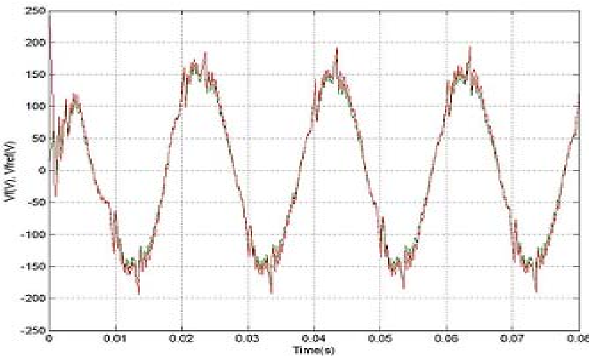


Fig.8. APF voltage output *Vsl* and its reference *Vslf.*

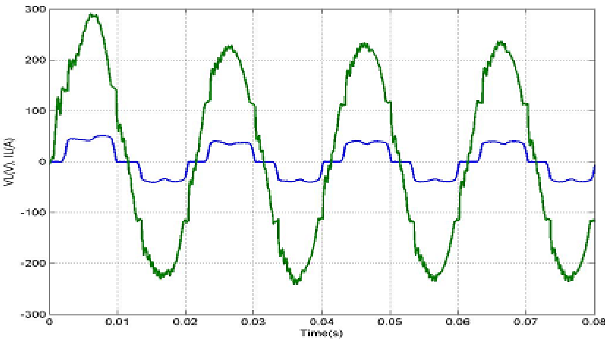


Fig. 9. Delay between Source current/voltage is_a and Vs_a.

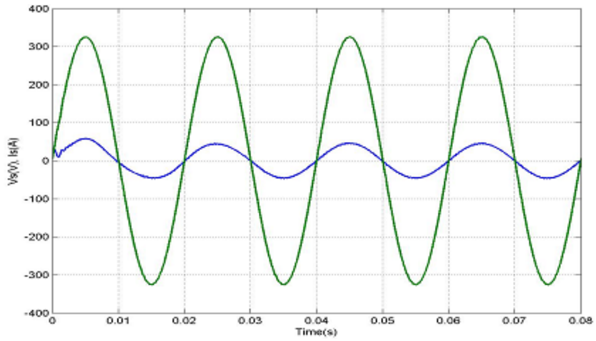


Fig. 10. Delay reduction between Source current/voltage is_a and Vs_a and power factor correction.

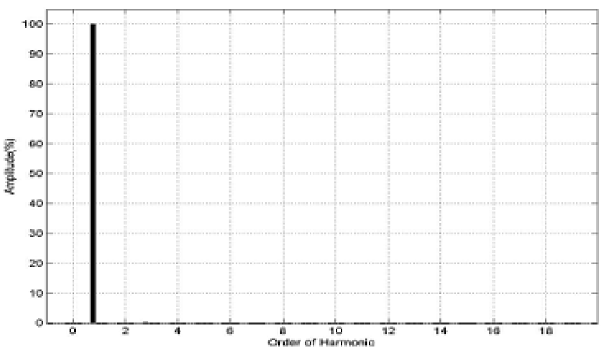


Fig.11. Source voltage spectrum when the filter is connected

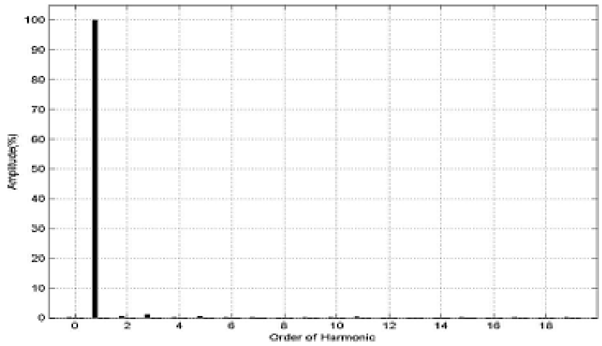


Fig. 12. Source current spectrum when the filter is connected

7. Results and discussions

The performance of the proposed hybrid active power filter is evaluated with system specifications and passive filter parameters presented in table 1. The sensor current gain is K= 5 and the switching frequency is equal to10Khz. The main voltage sources are assumed to be balanced and sinusoidal. The active filter voltage output of phase-a is shown in Fig. 8. A load with highly nonlinear characteristics is considered for load compensation.

Fig. 9 shows the delay between source current and source voltage *(is_a* and *Vs)*. Fig. 10, illustrates the delay reduction between Source current/voltage is_a and Vs_a and power factor correction when the hybrid filter is connected. The Fig.11 and 12, show the source voltage spectrum and the current source spectrum when the hybrid power active filter is connected (THD i_{sa} is reduced from 24,64 % to 2 %).

Simulation results show that the presented hybrid active power filter reduces THD percentage to 2 percent which is ideal for power network and also transient response is around 0.01s.

8. Conclusion

The goal of this work is to show the advantages of the multilevel series active filter when using fuzzy logic controllers instead of conventional controllers. In fact, not only the harmonics were reduced to an acceptable rate, but also the transient response time was minimized. Moreover, the utility power factor was corrected.

The fuzzy logic controller has improved the steady state performance of series active power filter. The effectiveness of the proposed scheme is proved by simulation.

In the future work, developed algorithms will be implemented experimentally in the dSPACE Board in order to show the efficiency and capability of the proposed scheme.

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