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Unbalanced Nonlinear Loads Harmonic Compensation Using Fuzzy Based Control of Series Active Filters

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ABSTRACT

The indiscriminate use of non-linear loads has given rise to investigation into new compensation equipment based on power electronics. The aim of this equipment is the elimination of harmonics in the system and reduction in reactive power flow.

Depending on application type, series or parallel configurations or combination of active and passive filters are used. Active power filters can be used in conjunction with passive filters improving compensation characteristics of the passive filter and to avoid the possible occurrence of the generation of series or parallel resonance. This paper presents a fuzzy logic controlled series active power filter used to compensate for harmonic distortion due to unbalanced non liner loads in three-phase four-wire systems.

1. Introduction:

Non-linear loads, especially power electronic loads, create harmonic currents and voltages in the power systems.

If the mains voltage is undistorted, but non linear loads are connected to the electrical grid, the current harmonics produced will cause voltage distortions in the line impedances, and the voltage at the load terminals will also be distorted.

For many years, various active power filters (APF) have been developed to suppress the harmonics, as well as compensate for reactive power, so that the utility grid will supply sinusoidal voltage and current with unity power factor [1].

Due to advancement in the technology, active power filters have become most habitual compensation methods. Shunt active power filters for three-phase three-wire and three-phase four-wire distribution systems have been presented [2-4]. This filter was widely used in transmission systems but has fewer effects on the distribution systems. In [5], author itself mentioned that shunt active filter compensation was not perfect solution. Improved solution to harmonic problem uses a hybrid active filter, which consists of shunt active and passive filter or series active and passive filters [6].

In many cases, non-linear loads consist of combinations of harmonic voltage sources and harmonic current sources, and may contain significant load unbalance (ex. single phase loads on a three phase system). To compensate for these mixed non-linear loads, a combined system of a passive filter (PF) and a series APF can be effective [7].

Recently, in order to improve the power quality and to correct the unbalance voltage in the distribution system, a series active power filter which is connected in series with the passive filter was proposed [8-9]. The above mentioned methods used various controllers like Instantaneous reactive power theory [10], Synchronous Reference Frame theory [11] and Sliding Mode control theory [12]. All these theories were able to extract and mitigate the harmonics under the balanced load conditions.

Recently, fuzzy logic controller has generated a great deal of interest in various applications and has been introduced in the power electronics field.

In this paper, the proposed fuzzy based control algorithm for series active power filters is applicable to harmonic voltage source loads as well as to harmonic current source loads.

2. Fuzzy Logic Current Controller

The desired switching signals for the filter inverter circuit are deter-

mined according to the error in the filter current using fuzzy logic controller.

The parameters for the fuzzy logic current controller used in this paper are as follow [13];

- The design uses centrifugal defuzzification method.
- There are two inputs; error and its derivative and one output, which is the command signal to the PWM of the filter inverter.
- The two input uses Gaussian membership functions while the output use triangle membership function.

Fig.1 shows the degree of membership for the error and its derivative and the command signal respectively.

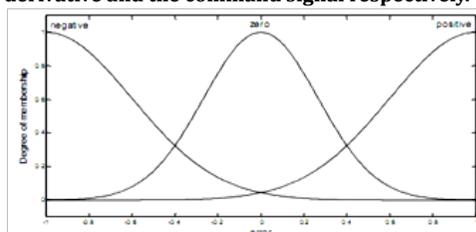


Fig.1-a

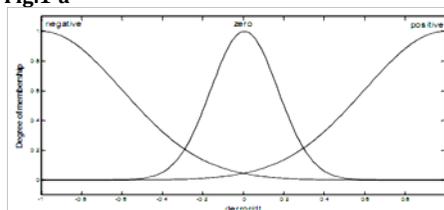


Fig.1-b

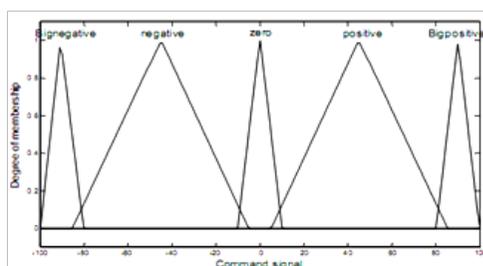


Fig.1-c

Fig. 1 The degree of membership for (a) the error, (b) the error derivative, and (c) the command signal

The above figures are the input and output variables for balanced load condition. Similar variable are used for unbalanced load condition but with different ranges; input 1 with range [-5,5], input 2 with range [-1,1], and the output with range [-250,250]. The fuzzy rules representation table is as Table 1:

Table 1: fuzzy rules sets

e(n)	Ce(n)						
	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

3. Series Active Filters

The combined filtering system of Fig.2 has already been introduced in reference [14]. It is composed of a shunt hybrid power filter in parallel with a passive power filter. The passive power filter consists of a set of tuned passive branches. The hybrid power filter is a series combination of an active filter (converter) and several tuned passive branches. Owing to the use of a parallel passive power filter, the power capacity of the converter is decreased and the performance and resonance problems of passive power filter are expected to improve.

At the harmonic frequencies, power converter operates like a resistor in series with the mains impedance. Therefore, the effective harmonic impedance of mains is increased and the resonance of passive power filter is suppressed. In addition, filter performance is improved by imposing a voltage harmonic waveform at its terminals:

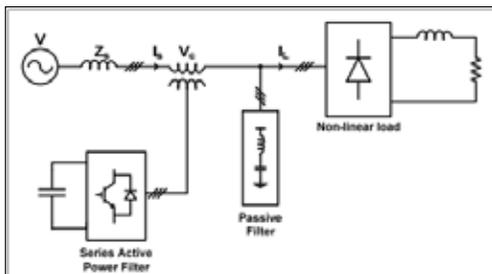


Fig.2. System with series active filter and passive filter

4. Simulation and Results:

The system was simulated using MATLAB/SIMULINK software in order to validate the efficiency of the presented control algorithm for unbalanced load condition.

The power circuit is a three-phase system supplied by a sinusoidal balanced three phase 100-V source with a source inductance of 5.8 mH and a source resistance of 3.6 ohm. The inverter consists of an IGBT bridge. On the dc side, two 100-V dc sources are connected. An LC filter has been included to eliminate the high frequency components at the output of the inverter. The passive filter is constituted by two LC branches tuned to the fifth and seventh harmonics. Each element value is listed as Table 2.

Table 2- Test system parameters

	Parameters value
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Source	LS=5.8 mH, RS=3.6 Ω
Passive filters	L5=13.5 mH, C5=30 μF L7=7.5 mH, C7=30 μF
Ripple filters	Lr=13.5 mH, Cr=50 μF

In this case, the three-phase load is built with three single phase uncontrolled rectifiers with capacitors and resistors connected in parallel at the dc side.

The simulated test power system with presence of unbalanced non linear load is indicated in Fig.3. As shown in this figure the hybrid series active filter is not considered.

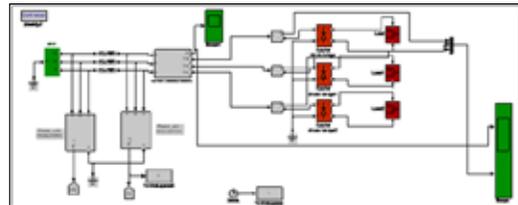


Fig.3. Simulated test system without series active filter

The simulated model of a hybrid series active filter which is connected to unbalanced load is shown in Fig.4.

As shown in this figure, the combination of series active filter and two traditional passive filters are considerable. The passive filter consists of two LC branches tuned to 5th and 7th current harmonics.

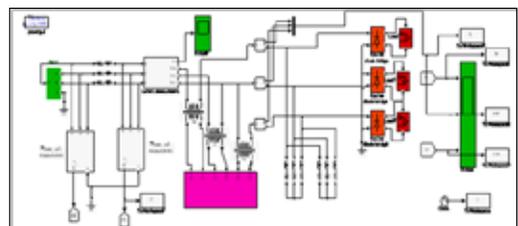


Fig.4. Simulated test system with hybrid series active filter

The configuration of series active filter is presented in Fig.5.

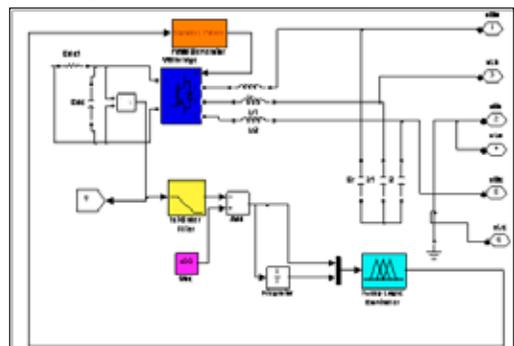


Fig.5. The circuit of series active power filter

As presented in Fig.5, the output of fuzzy logic controller is feed to PWM generator signal which applied to converter of series active filter. In Fig.6, the circuit of PWM signal generator of convert used in series active filter is presented.

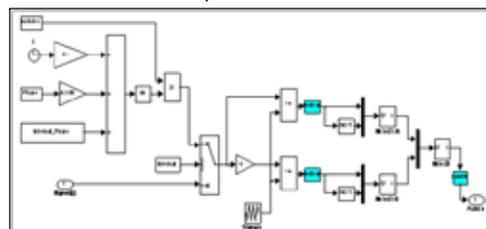


Fig.6. The circuit of PWM signal generation used in convert-

er of series active filter

The source current with and with\out filters as shown in Figs.7-8.

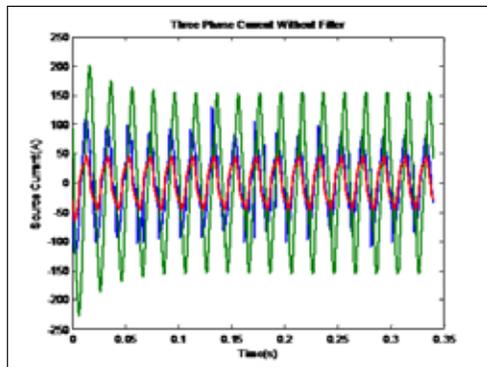


Fig.7.The three phase source current without hybrid series active filter

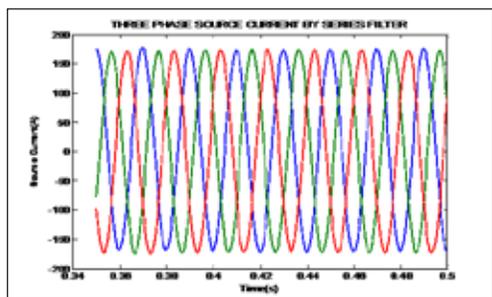


Fig.8.Three phase source current with series active filters

Due to harmonics injected by nonlinear load in each phase, the voltage phase to phase of system will be distorted which has been presented in Fig.9.

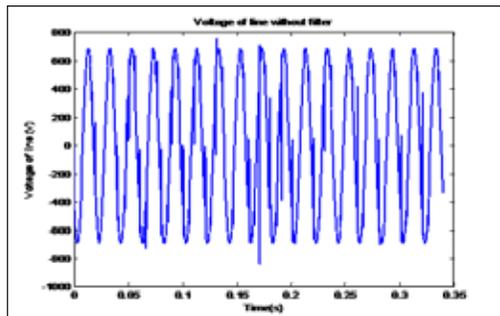


Fig.9.The distorted line voltage of system of balanced non-linear load without active filter

In order to analysis the effect of hybrid series active filter performance on total harmonic distortion and its improvement and also in order to make a comparison between the presence and absence the hybrid series active filter, the FFT analysis of source current has been implemented as shown in Figs.10-11 respectively for without and with presence of series active filter.

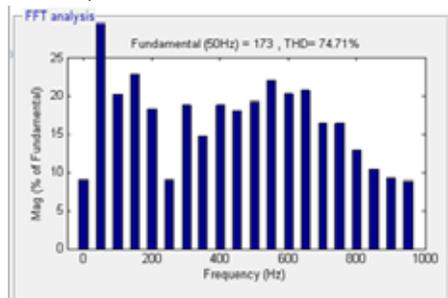


Fig.10.FFT analysis of source current of unbalanced load in absence of hybrid filter

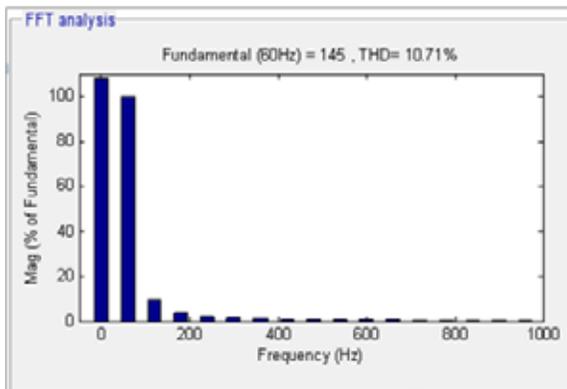


Fig.11.FFT analysis of source current of unbalanced load in presence of hybrid filter

As shown in Figs.10-11, it is clear that the THD of system when series active filter is connected to system decreases from 74.71% to 10.71%.

5. Conclusion

In this research the harmonic compensation of harmonic sources in electrical power system using fuzzy based control strategy of series active power filter is investigated.

In this study the unbalanced nonlinear load is considered as a harmonic source in simulation under MATLAB software.

Non-linear loads, especially power electronic loads, create harmonic currents and voltages in the power systems. In this case, the three-phase load is built with three single phase uncontrolled rectifiers with capacitors and resistors connected in parallel at the dc side.

Also a passive filter for 5th and 7th harmonics orders is considered as parallel with active filter. With this strategy is possible to improve the passive filter compensation characteristics without depending on the system impedance, since the set load filter would present resistive behavior.

The simulation results showed the good performance of proposed control strategy in harmonic compensation. This is found by FFT analysis.

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