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Fuzzy logic controller of a series active power filter for Power Quality improvement

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ABSTRACT
Here a control algorithm for a series active power filter is proposed. It is constituted by series active filter and shunt passive filter. The control strategy is based on instantaneous reactive power theory. So that the voltage wave form injected by active power filter is able to compensate the reactive power and the load current harmonics. The control algorithm was designed by using fuzzy logic controller for a better performance. Simulations have been carried out on the MATLAB-Simulink platform with different loads and variations in source impedance.

***Keywords* – Active power filter, Harmonics, Instantaneous reactive power theory, Power quality, fuzzy logic controller**

I. INTRODUCTION
Now a days Harmonic current is the major problem in electrical power system due to the increase of non-linear loads. Harmonic current drawn from a supply by waveform at the point of common coupling (PCC) due to the source impedance.
One traditional solution to mitigating the harmonics problems in the use of passive filters. In fact, this is a quite traditional solution to preventing load harmonic currents from flowing into the source or other loads. For the design of passive filter, it is necessary to know the source impedance, which is not constant and depends directly on system configuration.

This means that the filtering characteristics of the passive filter is strongly influenced by system impedance. In additional, there are several problems may occur.

1. The series and/or parallel resonance occurs between the source impedance and the shunt filter impedance.
2. The compensation characteristics heavily depend on the system impedance because the source impedance has to be greater than the shunt filter impedance in order to eliminate source current harmonics.
3. They are not suitable for variable loads

To avoid the above –mentioned problems regarding the applications of passive filters, it would be interesting to combine the shunt passive filter with series active filter.

An active power filter, APF, typically consists of a three phase pulsewidth modulation (PWM) voltage source inverter. Which is connected in series to the ac source. It is possible to improve the compensation characteristics of the shunt filters. This topology is as shown in fig.1, where v_c is the voltage that the inverter should generate to achieve the objective of the proposed control algorithm.

There are several different techniques have been applied to obtain a control signal for the active filter.

In this paper, a control strategy based on instantaneous reactive power theory is proposed, it is applied by considering a balanced and resistive load as ideal load. Thus, the strategy obtains the reference voltage is obtained to achieving ideal behavior for the set of hybrid filer-load. When the source voltages are sinusoidal and balanced the power factor is unity, in other words, the load reactive power is compensated and the source current harmonics are eliminated. By this means, it is possible to improve the passive filter compensation characteristics with our depending on the system impedance, since the set load-filter would present resistive behavior. It also avoids the danger that the passive filter behaves as a harmonic drain of closed loads, and like wise, the risk of possible series and/or parallel resonances with the rest of the system. In addition, the compensation is also possible with variable loads, not affecting the possible the passive filter detuning.

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

The advantages of fuzzy logic controllers over the conventional PI controller are that they do not need an accurate mathematical model; they can work with imprecise inputs, can handle nonlinearity, and may be more robust than the conventional PI controller.

The control algorithm was designed by using fuzzy logic controller for a better performance. Simulations have been carried out on the MATLAB-Simulink platform with different loads and variations in source impedance.

II. SERIES ACTIVE POWER FILTER
It is well known that series active power filters compensate current system distortion caused by non-linear loads by imposing a high impedance path to the current harmonics which forces the high frequency currents to flow through the LC passive filter connected in parallel to the load. The high impedance imposed by the series active power filter is created by generating a voltage of the same frequency that the current harmonic component that needs to be eliminated. Voltage unbalance is corrected by compensating the

fundamental frequency negative and zero sequence voltage components of the system.

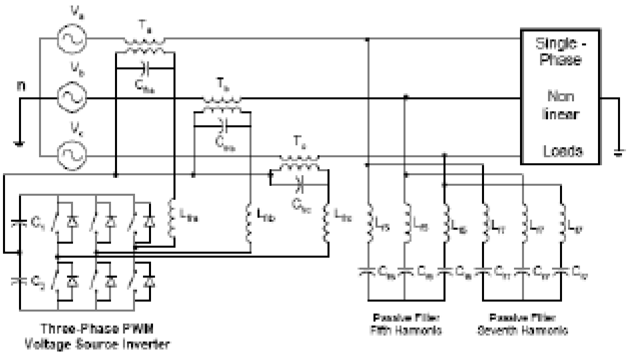

Fig.1.The proposed series active power filter topology with shunt passive filter.

III. COMPENSATION STRATEGY

Electric companies try to generate electrical power as sinusoidal and balanced voltages so it has been obtained as a reference condition in the supply. Due to this fact, the compensation target is based on an ideal reference load which must be resistive, balanced and linear. It means that the source currents are collinear to the supply voltages and the system will have unity power factor. Therefore, at the point of common coupling (PCC), the following expression will be satisfied:

$$v = R_e i \quad (1)$$

Here,Re is the equivalent resistance, v is the voltage vectoron the connection point, and i is the supply current vector.

Fig. 2 shows the configuration active filter connected in series with passive filter connected in shunt with the load.

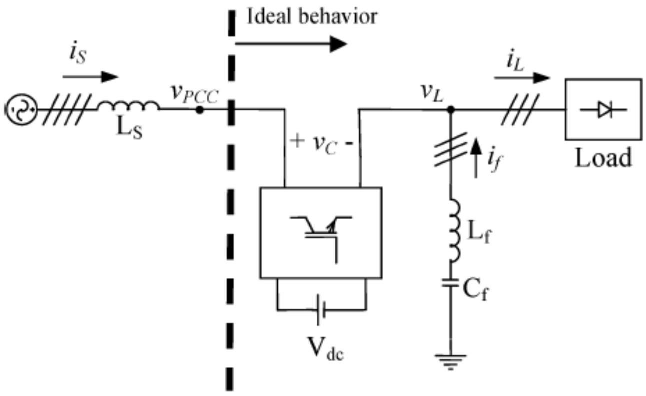

Fig.2. System with compensation equipment.

In low voltage distribution systems, there is usually the presence of single-phase loads. That produces severe unbalance voltages and currents in the system. For this reason, even if the voltage source is balanced, the PCC voltage cannot be balanced due to the presence of unbalanced three-phase loads and/or single-phase loads. A compensating system will have to avoid the propagation of the voltage imbalance from the PCC to other consumers.

In a three-phase system, The vector transformations from the phase reference system a-b-c to $\alpha - \beta - 0$ coordinates can be obtained, thus

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{2/3}\begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix}\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{2/3}\begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (3)$$

The instantaneous real power and imaginary power is defined by the equations as

$$p = v_\alpha i_\alpha + v_\beta i_\beta \quad (4)$$

$$q = v_\alpha i_\beta - v_\beta i_\alpha \quad (5)$$

The voltage vector can be calculated as

$$v_L = \frac{p}{i_{\alpha\beta}^2} i_{\alpha\beta} + \frac{q}{i_{\alpha\beta}^2} i_{\alpha\beta} \perp \quad (6)$$

The average power supplied by the source will be

$$P_s = I_1^2 R_e \quad (7)$$

$I_1^{\,2}$ is the square rms value of the fundamental harmonics of the source current vector. The compensator instantaneous power is difference between the total real instantaneous power required by the load (pL) and the instantaneous power supplied by the source (pS), i.e.,

$$p_c = p_l - p_s \quad (8)$$

When the average values are calculated in this equation and taking into account that the active power exchanged by the compensator has to be null, Eq(8) can be rewritten as follows:

$$0 = \frac{1}{T}\int p_l dt - I_1^{\,2} R_e \quad (9)$$

Therefore, the equivalent resistance can be calculated by

$$R_e = \frac{\frac{1}{T}\int p_l dt}{I_1^{\,2}} = \frac{P_L}{I_1^{\,2}} \quad (10)$$

Where PL is the load average power.

The aim is that the compensation equipment and load have ideal behaviour from the PCC. The upstream voltage of the active filter can be calculated as follows:

$$v_{pcc} = \frac{P_L}{I_1^{\,2}} i \qquad (11)$$

where i is the source current vector. Thus, the reference signal for the output voltage of the active filter is as follows:

$$v_c^* = v_{pcc} - v_L = \frac{P_L}{I_1^{\,2}} i - v_L \qquad (12)$$

That is, when the active filter generates this compensation voltage, the set load and compensation equipment will behave as a resistor with a Re value.

Finally, if currents are unbalanced and nonsinusoidal, a balanced resistive load is considered as ideal reference load. Therefore, the equivalent resistance must be defined by the equation

$$R_e = \frac{p_L}{I_1^{+2}} \qquad (13)$$

Here, I_1^{+2} is the square rms value of the positive sequence fundamental component. In this case, (12) is modified, where I_1 is replaced by I_1^{+}, now eq(12)becomes

$$v_c^* = \frac{p_L}{I_1^{+2}} i - v_L \qquad (14)$$

IV. FUZZY LOGIC CONTROLLER

The fuzzy control algorithm is implemented to control the load phase voltage based on processing of the voltage error e(t) and its variation Δe (t) in order to improve the dynamic of SAF.

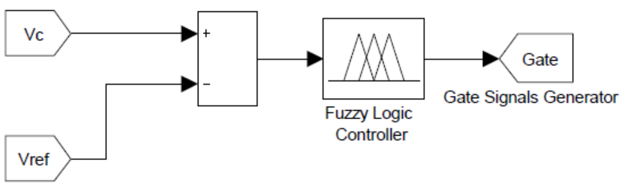

Fig.3. Fuzzy controller structure block diagram

The main advantages of fuzzy control are its linguistic description, independence of mathematical model, robustness, and its universal approximation. A fuzzy logic controller is consisting of four stages: fuzzification, knowledge base, inference mechanism and defuzzification. The knowledge base is composed of a data base and rule base and is designed to obtain good dynamic response under uncertainty in process parameters and external disturbances .The data base consisting of input and output membership functions, provides information for the appropriate fuzzificztion operations, the inference mechanism and defuzzification. The inference mechanism uses a collection of linguistic rules to convert the input conditions into a fuzzified output. Finally, defuzzification is used to convert he fuzzy outputs into control signals. In designing of a fuzzy control system, the formulation of its rule set plays a key role in improvement of the system performance.

V. SIMULATION RESULTS

The system shown in Fig. 1 has been simulated in the Matlab- Simulink platform to verify the proposed control. Each power device has been modeled using the SimPowerSystem toolbox library. 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 Insulated Gate Bipolar Transistor (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 as shown in below table.

source	Ls=5.8mH;Rs=3.6ohm
Passive filter	L5=13.5mH;C5=30 μF L7=7.5mH;C7=30 μF
Ripple filter	Lr=13.5mH;Cr=50 μF

A. Nonlinear Balanced load:

In this case, the nonlinear load consists of an uncontrolled three-phase rectifier with an inductance of 55 mH and a 25 resistor connected in series on the dc side.

Given below Fig.4 shows the simulink diagram of a series active power filter.The source current of a phase 'a' current wave form with and without filters as shown in below Fig.5.&6..

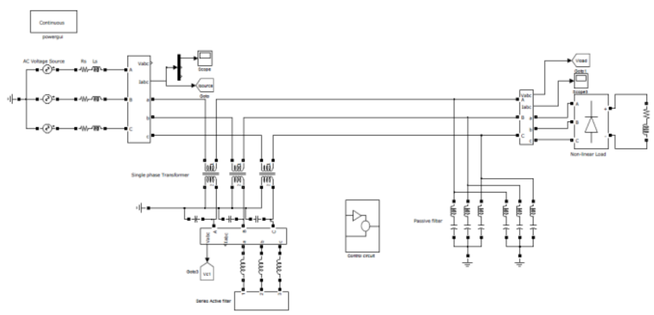

Fig.4. Simulik model diagram of a series active filter when it's connected to balanced load.

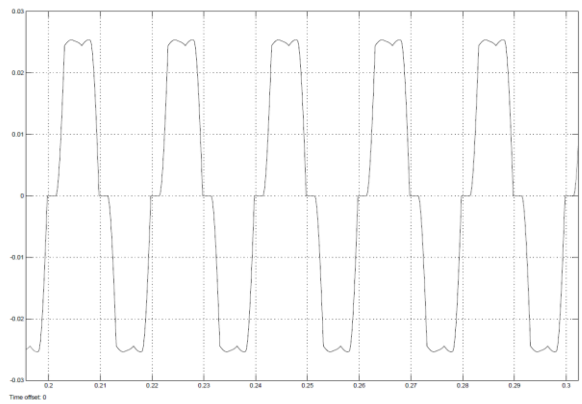

Fig.5.source current of the phase 'a' without filter

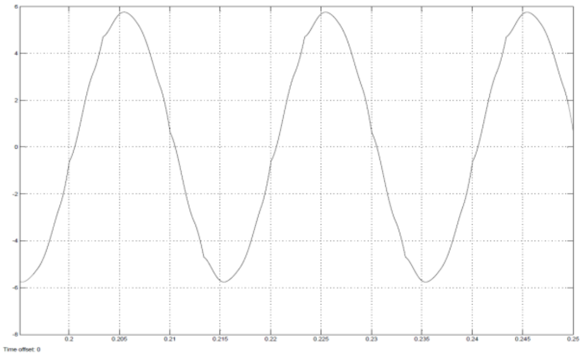

Fig.6.Source current when active filter connected.

B. Nonlinear unbalanced load:

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

The simulink model of a series active filter which is connected to unbalanced load as shown in Fig.7 and the source current with and with out filters as shown in Fig.8.&9.

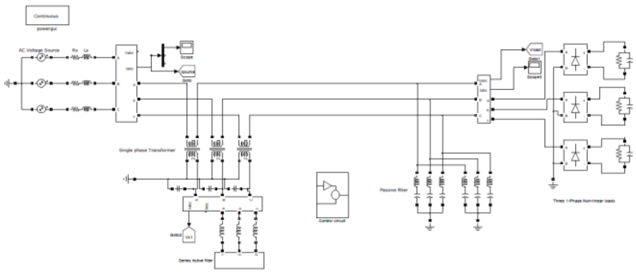

Fig.7. Simulik model diagram of a series active filter when it's connected to unbalanced load.

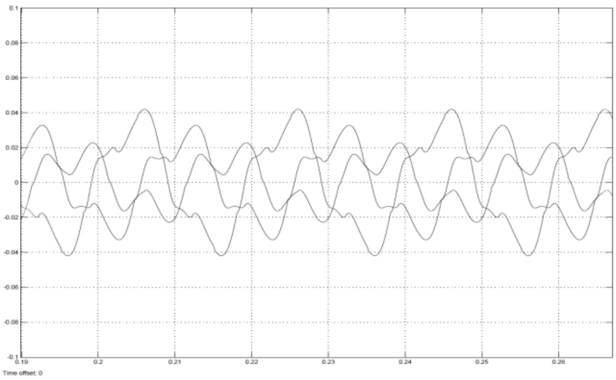

Fig.8.source current wave form without filter

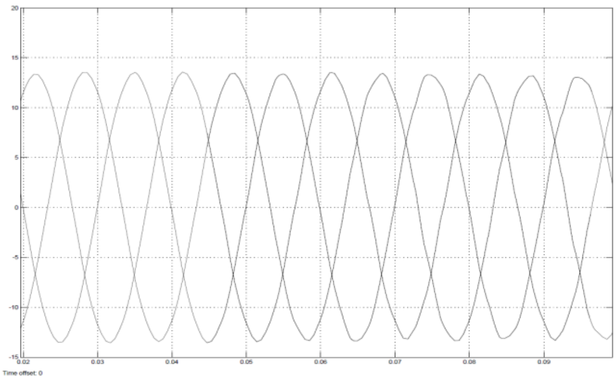

Fig.9.Source current when active filter connected.

VI. CONCLUSION

A novel control strategy based on the dual formulation of compensation system principles is proposed. It is applied by considering a balanced and resistive load as ideal load. Thus, the determined reference voltage is obtained to attain the objective of achieving ideal behavior for the set hybrid filter load. 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. It also avoids the danger that the passive filter behaves as a harmonic drain of close loads, and likewise, the risk of possible series and/or parallel resonances with the rest of the system. In addition, the compensation is also possible with variable loads, not affecting the possible passive filter detuning.

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