NON-MODEL BASED CONTROL OF ACTIVE POWER FILTERS

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Abstract: This paper proposes a non-model based method formulated as an alternative to conventional PI control. This method has been applied to the problem of control of a shunt active power filter designed for reactive and harmonic current compensation. The amplitude of the current is controlled by the fuzzy system, which processes the error between the dc link voltage and a reference set voltage. The performance of the proposed method is examined by Matlab simulations and is found to have better dynamic behavior than PI control.

Keywords: harmonics, active power filter, fuzzy logic control

I. INTRODUCTION

The increase in loads consuming non-sinusoidal current, referred to as non-linear loads has resulted in the generation of harmonics in the power supply system. The major sources of harmonic currents are power electronic converters and controllers so also the switch mode power supplies in computers, computer terminals, data processors and other office equipments. The switching action of these loads draws a non-sinusoidal current from the supply. This current consists of the fundamental frequency component and the harmonic components. The harmonic components generate noise in the form of harmonic voltages and currents at audio / radio frequencies, which are inductively or capacitively, coupled into the communications and data lines. This noise is picked up by computer networks, communication equipment, telephone systems and other sensitive equipment. These systems get more and more affected as the speed of computer networks increases. Other effects of harmonics include heating of conductors, malfunctioning of relays, circuit breakers & sensitive electronic equipment. Active power filter (APF) is basically designed on the concept of injecting equal but opposite distortion to a system in order to compensate harmonic distortion. Shunt active power filters, using different control strategies have been widely investigated to provide a viable solution to the problems created by non-linear loads [1]-[3]. The controller in APF has two tasks:

(i) to generate the reference current and,

(ii) to regulate the generation of gating signals, for the inverter switches to maintain tracking of the reference current.

Reference current generation schemes utilizing current control principle either use: 1) a reactive volt-ampere calculator to set the filter current reference or 2) error between the dc- link voltage reference and the sensed dc-link capacitor voltage to set the amplitude of the source current reference. In type (1) the presence of a reactive volt-ampere calculator generates a delay in the process. The control logic and associated hardware in type (2) is relatively simple and compensation is achieved without either sensing the reactive volt-ampere demand or the load harmonics. The scheme requires only one current sensor and the compensation process is instantaneous [4], [5]. DC bus regulation is achieved using conventional PI algorithm. The PI model is derived by means of root locus or some other method, to develop an equation that describes the stable equilibrium state of the control surface, with coefficients being assigned to the proportional and integral aspects of the system. While the PI model may seem to be simple and hence economical, the contrary is more often true. Practically the tuning of PI parameters is mostly done by trial and error, which is a time consuming process. Thus it is desirable to develop a reliable auto-tuning method in order to automate this process. This paper proposes an intelligent auto-tuning method using fuzzy logic to overcome the disadvantages mentioned above.

II. PROBLEM IDENTIFICATION

An active power filter (APF) is a power electronic converter that is switched to maintain the mains current sinusoidal and in phase with the mains voltage irrespective of the load current. The active power filter configuration is shown in Fig.1. It consists of a single-phase voltage source inverter with an energy storage capacitor C_d at DC bus. This APF is connected in shunt with the load through a filtering inductor L_f. Due to the non-linear load, the load current i_L consists of a sinusoidal fundamental component i_1 and harmonic components i_h. The active power filter is used to prevent power system pollution due to these harmonic currents. The active power filter produces a current i_f that is equal to the harmonic current required by the load. The relationship between these currents is

$$i_s = i_L - i_f = i_1 + i_h - i_f \qquad (1)$$

$$\text{if} \quad i_f = i_h \text{ then } i_s = i_1$$

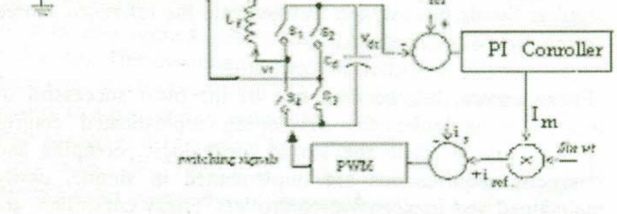

Figure-1: Configuration of Active Power Filter

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. From the above equation it can be inferred that if the source current is made to follow a current reference which is equal to the active component of load current and in phase with the supply voltage, the filter current would be equal to the harmonic and reactive component of load current. The average voltage of the capacitor can supply the real power information and the desired amplitude of the mains current can be obtained by using a voltage regulation circuit of the DC capacitor. The DC bus voltage is compared with a reference setting voltage maintained at more than twice the peak supply voltage. The compared result is fed to a PI controller to generate the desired amplitude of mains current. The output of the PI controller is multiplied by a unit amplitude sine wave derived from the mains voltage. This constitutes the reference current for switching the active power filter. This is then compared with the actual supply current and fixed frequency PWM is used to generate the switching signals for the inverter.

A single-phase bridge rectifier with RC (R=430Ω & C = 1000μF) is modeled as a non-linear load (NLL). The supply voltage and current drawn by this load are shown in Fig. 2(a). From the harmonic spectrum shown in Fig.2(b), it is evident that the load draws a distorted current from the supply and the total harmonic distortion is found to be 149.7%

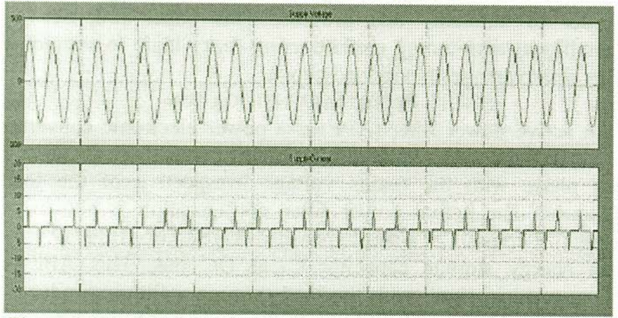

Figure-2 (a): Simulation Results: Nonlinear Load; Supply voltage & supply current before compensation

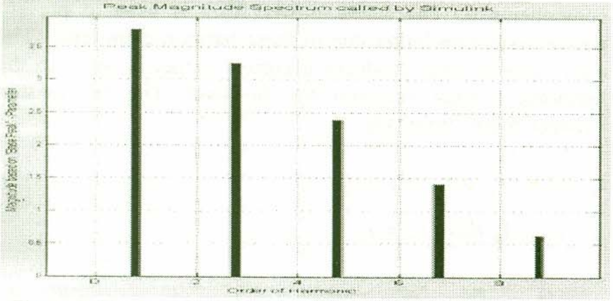

Figure-2 (b): Harmonic spectrum of uncompensated supply current

In this paper the authors have designed a fuzzy controller to regulate the dc bus voltage and generate the reference source current for switching the APF.

II. FUZZY LOGIC

Fuzzy control has become one of the most successful of today's technologies for developing sophisticated control systems [6]-[7]. With the aid of fuzzy logic, complex and imprecise requirements are implemented in simple, easily maintained and inexpensive controllers. Fuzzy controllers are easier to prototype and implement, simpler to describe and verify and can be maintained and extended with greater accuracy in less time. The availability of fast and custom built fuzzy logic controller IC's has also made its implementation practically feasible. Fuzzy theory can be integrated into control theory by using IF-THEN rules. A set of such rules can be used to create a functional controller. Using linguistic correlation (small, medium, large) the input variables to a system can be partitioned into overlapping sets to form a membership function. Fuzzy logic is thus a system of logic in which the system of sets has a degree of membership associated with each variable. The basic components of a fuzzy rule based system are shown in Fig.3. First a crisp to fuzzy transform (fuzzifier) changes crisp inputs into degrees of membership or truth-values. Next, an inference mechanism determines actions to be taken by applying the truth-values as conditions to rules. Finally a fuzzy to crisp transform (defuzzifier) converts fuzzy actions into crisp actions and combines them to form a single executable action. Fuzzy membership functions can take many shapes triangular, trapezoidal, sigmoid and bell shape etc. Triangular fuzzy membership shape is commonly employed in control applications due to primarily low computational costs of creating and integrating triangular fuzzy sets. However they are less robust. The sigmoid function and bell shaped fuzzy numbers are better in robustness since their center value is not a single point.

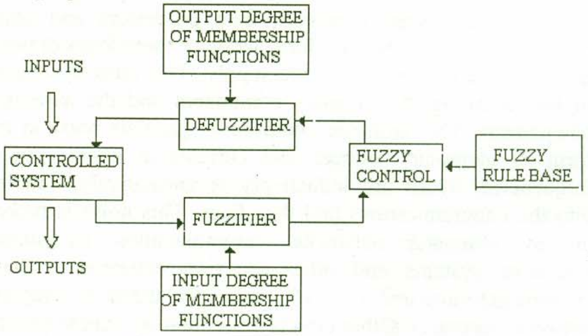

Fig.3: Block diagram of fuzzy feedback controller

The trapezoidal number is slightly different from the triangular and sigmoid number shapes because the set does not pivot around a single central number. In the present study considering all the above features of fuzzy membership functions we have considered triangular, trapezoidal, gaussian bell, psigmoid and gaussian membership functions.

III. FUZZY CONTROL SCHEME FOR APF

The fuzzy control algorithm for regulation of DC capacitor voltage implements a 49 rule [7×7, 9] Fuzzy Inference System (FIS). The 49 rule FIS accepts error and change of error in the capacitor voltage as inputs and gives the required magnitude of supply current I_m as output. The error between the reference generated by the fuzzy logic controller I_s*and the sensed supply current I_s is fed directly to the PWM generator, which uses it to generate the APF switching signals. The two inputs are represented by sets of seven membership functions and the output by a set of nine membership functions. The range for the 'error' input was set as [-30 30] and that for 'change of error' was set as [-10 10]. A limiting block was introduced before the fuzzy block in order to truncate values beyond these ranges before supplying them to the fuzzy logic controller. The 49 fuzzy if-then weighted rule base was designed using the pendulum analogy. The output was represented by a set of 9 membership functions whose shape was taken similar to the shape of the input membership functions. The range of output was set to [-35 35]. Rule Base was designed to maintain the Capacitor voltage constant by providing the required reference current amplitude. Rule generation and weighting was decided based on the Pendulum Analogy shown in Fig.4.

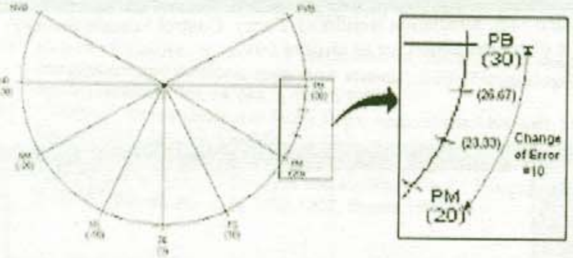

Fig.4: Pendulum analogy for fuzzy rule-base

From Fig.4 it can be inferred that if error is NB (negative big) & change of error is NS (negative small) then it has to countered with a PVB (positive very big) output with a relative weight of 0.83. On the other hand if error is NB and change of error is PB then the output would be PM with a relative weight of 1. The rule matrix formed based on the above logic is shown in Table I.

Table I: Fuzzy Rule Base

		ERROR						
		NB	NM	NS	ZE	PS	PM	PB
CHANGE OF ERROR	NB	PVB	PB	PM	PS	ZE	NS	NM
	NM	PVB	PB	PM	PS	NS	NM	NB
	NS	PVB	PB	PM	PS	NS	NM	NB
	ZE	PB	PM	PS	ZE	NS	NM	NB
	PS	PB	PM	PS	NS	NM	NB	NVB
	PM	PB	PM	PS	NS	NM	NB	NVB
	PB	PM	PS	ZE	NS	NM	NB	NVB

The AND method used during interpretation of the If-then rules was 'min' and the OR method used 'max'. Also 'min' was used as the implication method whereas 'max' method was used for aggregation.

IV. SIMULATION RESULTS

The active power filter with conventional PI control was first simulated in MATLAB and the simulation results are shown in Fig.5 (a)-(f). Though the response to step change in load is quite satisfactory it has been observed that there is a tendency to over shoot (Fig. 5(f)) with a large negative error. With a change in load at 0.1ms and 0.3ms the supply current is found to settle to the new steady state value within one cycle.

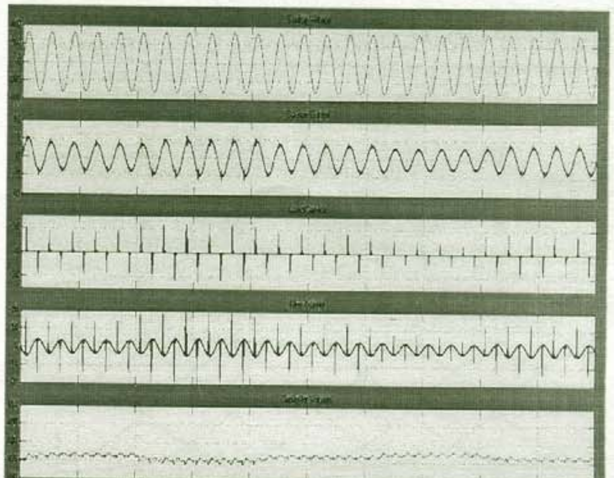

Figure-5: Simulation Results of PI Control Scheme for APF: (a) supply voltage, (b) compensated supply current, (c) load current, (d) filter current, (e) voltage across dc capacitor

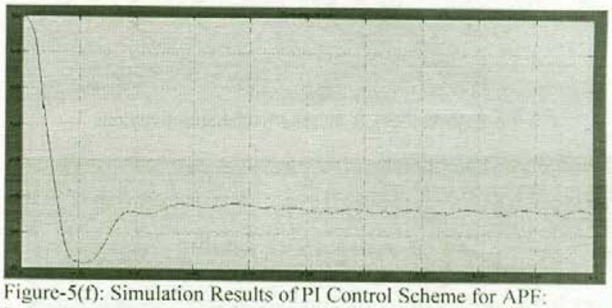

Figure-5(f): Simulation Results of PI Control Scheme for APF: Rate of compensation for an error of 50V

Extensive simulation study considering triangular, trapezoidal, gaussian bell, psigmoid and gaussian membership functions for FIS was carried out to control the APF. However gaussian membership function provided the best harmonic compensation and hence was finalized to implement the fuzzy scheme. The PI controller block in the control scheme of APF (Fig. 1) was replaced by the designed fuzzy inference system (FIS). The input and output membership functions of the FIS are shown in Fig.6. The APF was then simulated for the same fixed and variable load. The rate of compensation for a large error was also studied. The simulation results are shown in Fig. 7(a)-(e). The dynamic response for addition and removal of load may be observed from Fig.7(b). Supply current settles smoothly to a new steady state value within a quarter cycle of change in load at 0.1ms and 0.3ms. There is a small change in DC bus voltage (Fig.7 (e)) at the instant of disturbance in load to balance extra energy due to increased or decreased level of compensation. DC bus voltage settles to its steady state value within a few cycles. Also with a large deviation the capacitor voltage is found to reach steady state without overshooting the set value as is evident from Fig.7(f). Harmonic spectrum of the compensated supply current is shown in Fig. 7(g). It was observed that the supply current after compensation becomes sinusoidal with a 97.88% reduction in total harmonic current distortion. Fuzzy controller compensates for a large error faster and the APF is found to give a better and robust performance under transient and varying load conditions when compared to a conventional PI controller compensating the same error.

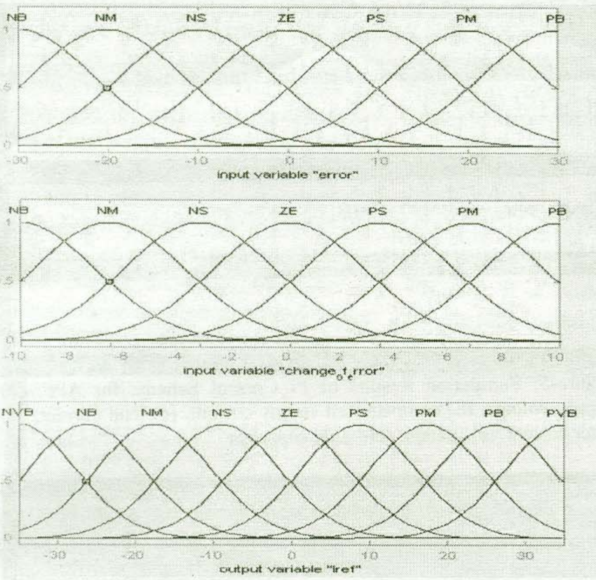

Fig.6: Gaussian input & output membership functions

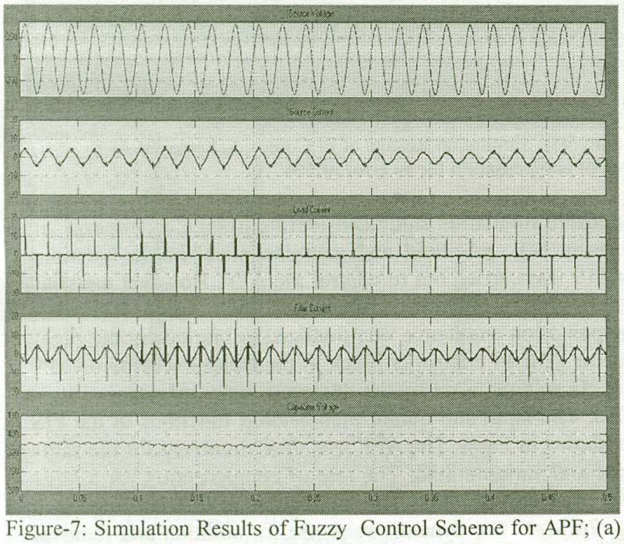

Figure-7: Simulation Results of Fuzzy Control Scheme for APF; (a) supply voltage, (b) compensated supply current, (c) load current, (d) filter current, (e) voltage across dc capacitor

The APF system controlled by the proposed fuzzy system was further applied to three more different loads to demonstrate its capability to compensate reactive and harmonic current. Fig.8 (a)-(e) shows the dynamic performance of APF system for an ac regulator fed inductive load. This regulator is commonly used to control temperature, light and speed of small ac motors. It is modeled as two thyristors connected back to back, with a series R-L load fed from a 230V, 50Hz supply. It is observed that the supply current is sinusoidal and the APF is able to feed reactive power and harmonic current components of the load. The system was also simulated for a single phase thyristor controlled DC motor load. From the results [Fig 9 (a)-(e)] it is observed that the fuzzy system works satisfactorily with the supply current sinusoidal and in phase with the supply voltage. Fig.10 (a)-(e) show the simulation results for a nonlinear load comprising of a diode bridge rectifier with series R-L load (R= 430Ω, L = 1.5 H). The fuzzy controlled APF system is seen to compensate reactive and harmonic power with the supply current being sinusoidal after compensation.

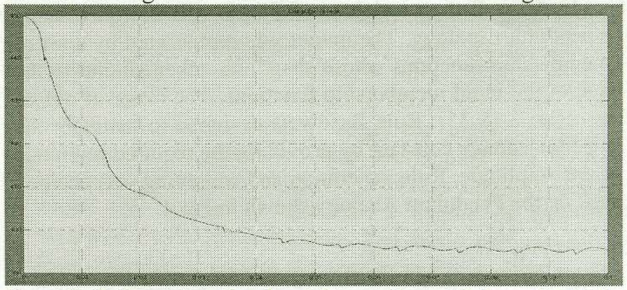

Figure-7 (f): Simulation Results of Fuzzy Control Scheme for APF: Rate of compensation for an error of 50V

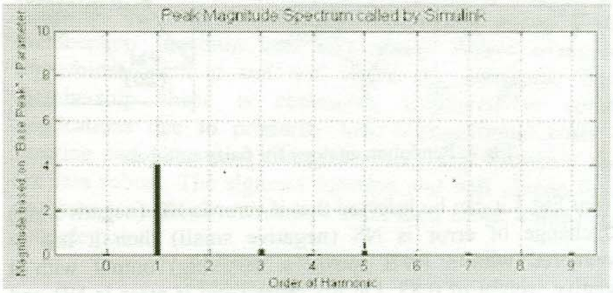

Figure-7 (g): Harmonic spectrum of compensated supply current with Fuzzy control scheme

V. CONCLUSION

The conventional PI algorithm for regulating the DC bus to generate the reference supply current for switching the active power filter was found to lack the capacity to adjust satisfactorily to large fluctuations. Though the response to step change in load was quite satisfactory it was observed that there is a tendency to over shoot. Also the fine-tuning of the PI parameters has to be done by trial and error and is time consuming. The fuzzy control algorithm for regulation of the DC capacitor voltage was designed to implement a 49 rule Fuzzy Inference System (FIS) that can replace the PI controller block in the control scheme of APF. It is observed that the filter responds to the changed load conditions within a quarter of a cycle. From the transient response it is clear that the fuzzy alternative to the conventional PI control provides better and fast dynamic response.

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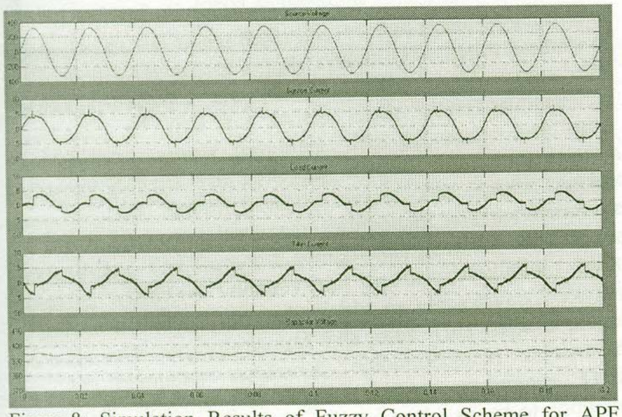

Figure-8: Simulation Results of Fuzzy Control Scheme for APF system under nonlinear ac voltage regulator fed inductive load (a) supply voltage, (b) compensated supply current, (c) load current, (d) filter current, (e) voltage across dc capacitor

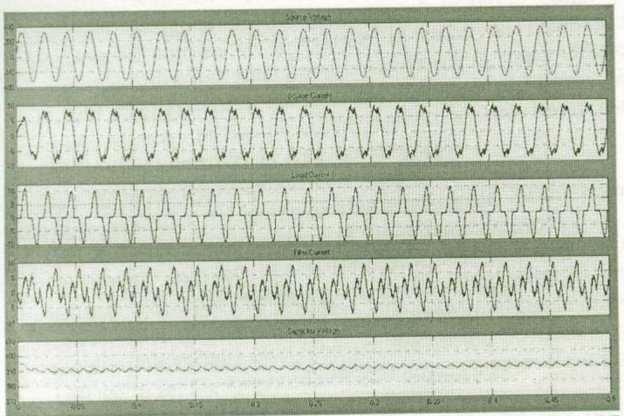

Figure-9: Simulation Results of Fuzzy Control Scheme for APF system under thyristor controlled DC motor load (a) supply voltage, (b) compensated supply current, (c) load current, (d) filter current, (e) voltage across dc capacitor

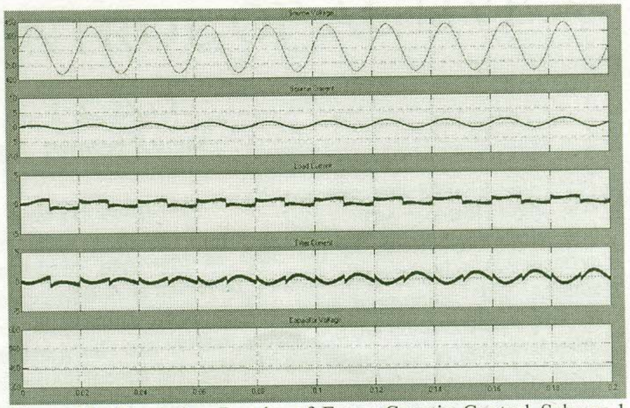

Figure-10: Simulation Results of Fuzzy-Genetic Control Scheme.1 for APF system under nonlinear rectifier fed inductive load; (a) supply voltage, (b) compensated supply current, (c) load current, (d) filter current, (e) voltage across dc capacitor