An Adaptive Fuzzy Logic Based Harmonic Suppression In Power Electronic Hybrid System

P. Kripakaran[1], **R.Gopi Krishna**[2]

[1, 2] Asst.Prof, Dept. of EEE, Rajiv Gandhi College of Engineering and Technology, Puducherry, India

[1]kripa_pt@yahoo.co.in, [2]gopi_pec@yahoo.com

Abstract

This paper proposes an Adaptive Fuzzy Logic Control (AFLC) Technique in a Power Electronic Hybrid System for reactive power compensation and harmonic suppression. The Power Electronic Hybrid System consists of a Thyristor-Controlled Reactor (TCR) and a Resonant Impedance-Type Hybrid Active Power Filter (RITHAPF). The phase of the RITHAPF compensating current would be shifted, since the impedance of a filter inductor and passive power filters according to the harmonic current is inductive. This impact of phase shift on the RITHAPF is eliminated by the use of adaptive fuzzy logic controller and the Total Harmonic Distortion (THD) value is also reduced in the system. The performance of adaptive fuzzy logic controller is compared with the performance of hysteresis controller in the Power Electronic Hybrid System and are evaluated using MATLAB/SIMULINK and the obtained results are presented.

Key words : *Active filters, Power electronics, Adaptive Fuzzy logic, Hysteresis controller, Thyristors.*

I. INTRODUCTION

In recent years, there has been an increased emphasis and concern for the quality of power delivered to factories, commercial establishments and residences. This is due to the increasing usage of harmonic-creating non-linear loads such as speed drives, switched mode power supplies, arc furnaces, electronic fluorescent lamp ballasts etc.The development of power electronic devices and their related control technologies have given rise to more and more installation of power electronic equipment in grids. These have also deteriorated the quality of the power mains system [1]-[3]. Harmonic disturbances come generally from equipment with a non-linear voltage/current characteristic. Nowadays a large part of industrial, commercial and domestic loads is non-linear, making the distortion level on the low-voltage supply network a serious concern. As time goes on, more and more equipment is being used that creates harmonics in power systems. Therefore, attention is given to improve such power quality problems [4]-[6]. Power line conditioners, such as Static Var Compensators (SVCs) and Active Power Filters (APFs), improves the quality of power or the proper level of power to electrical equipment. They locally compensate reactive power and harmonics which can effectively improve the power quality and power factor (PF) of the system [7]. The nonlinear loads generate current harmonics that can be asymmetric and can cause voltage drops on the supply network impedance resulting in unbalanced conditions. These effects can be worse in the case where the loads change randomly. Hence, a Power Electronic Hybrid System (PEHS) consisting of a Thyristor-Controlled Reactor (TCR) and a Resonant Impedance-Type Hybrid Active Power Filter (RITHAPF) is proposed which is used for compensating reactive power and harmonic current. SVCs are a combination of fixed capacitors and TCR. They compensate the negative-sequence current caused by asymmetrical loads and also stabilize voltage at the point of common coupling. But TCR produces harmonic current during dynamic operation [8], [9]. However, Fixed capacitors connected in series with the inductors called the Passive Power Filters (PPFs) can suppress the harmonic current generated by TCR. This is return causes series–parallel resonance between the fixed capacitors and grid. Active Power Filters (APFs) are used to overcome this problem as they have good filtering performance [10], [11]. However, APFs application is limited because of its limitations in capacity and voltage level. Thus, the combination of the advantages of APFs and PPFs called the Hybrid Active Power Filters (HAPFs) are used. Hence HAPFs along with SVCs would effectively compensate reactive power and harmonic current. The use of hysteresis controller for non-linear or harmonic current control has the advantage of simplicity but leads to varying switching frequency in a wide range. This drawback has been developed with variable hysteresis band switching strategies but it needs a complex controller to achieve satisfactory performance. Another control called the Predictive current control offers the best potential for precise current control, although the implementation of a system in practical can be complex and difficult.

In this paper, an adaptive fuzzy control technique is used which overcomes the limitations of other control methods. It also decreases the tracking error and increases dynamic response and robustness. Thus the THD of the three phase source currents is reduced and the characteristic current harmonic components (3rd, 5th, 7th, 11th, 13th and 17th orders) are suppressed correspondingly

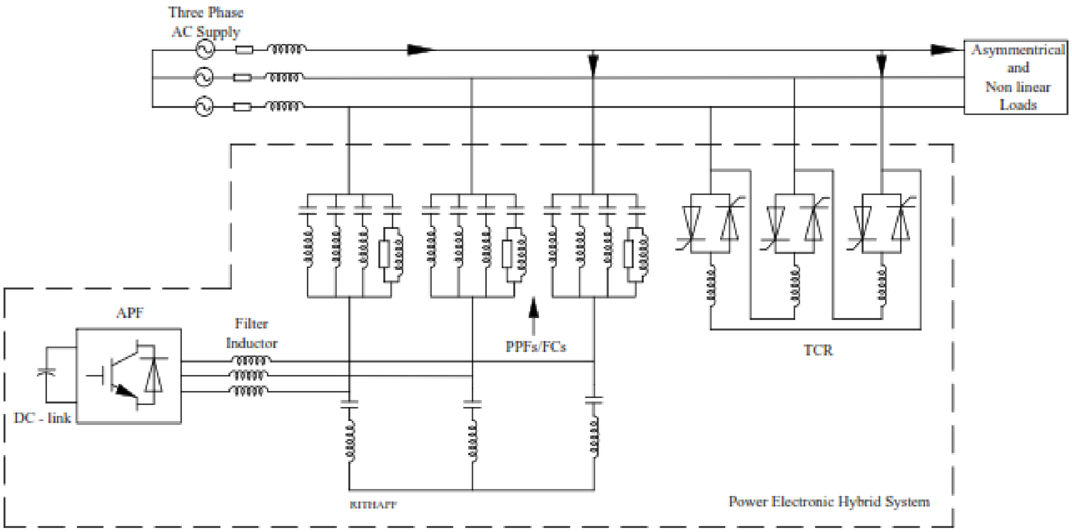

Fig.1 Configuration of the PEHS

II. SYSTEM CONFIGURATION

The Power Electronic Hybrid System consists of a RITHAPF and TCR. They are connected at the point of common coupling. The RITHAPF consists of active power filters and passive power filters. The APF is a voltage source converter (VSC) whose ac link is connected to a filter inductor and whose DC link is a capacitor. The PPFs can compensate a fixed capacity of capacitive reactive power, corresponding to fixed capacitors of SVCs. They mainly sustain the fundamental voltage at the point of common coupling whereas the APF only support harmonic voltage which greatly reduces the voltage level of power electronic devices of the APFs. The RITHAPF can be equipped in medium high voltage grids and its initial investments would be cut down. The TCR is connected near the asymmetrical and non–linear loads. It uses the delta connection [1].

The PEHS, depending on its configuration, could be effectual to compensate the reactive power and negative sequence current that are caused by asymmetrical and non–linear loads and to suppress the harmonic current generated by both the TCR and non–linear loads.

III. CONTROL METHODS FOR POWER ELECTRONIC HYBRID SYSTEM

A. Hysteresis current controller

A hysteresis current controller is implemented with a closed loop system. Active filters produce a nearly sinusoidal supply current by measuring the harmonic currents and injecting them back into the power system with a phase shift of 180°. A controlled current inverter is required to generate this compensating current. Hysteresis current control is a method of controlling a voltage source inverter so that an output current is generated which follows a reference current waveform.

The actual current signal is compared with the given current signal of the inverter by hysteresis current control. If the actual current signal exceeds the given current signal by a certain range, the switching state of the inverter is changed to control the change of the actual current signal in order to track the given current signal. Hysteresis current control is easy to implement but there is no limit to the switching frequency. This is one disadvantage of the hysteresis current controller.

B. Adaptive fuzzy logic controller (AFLC)

The conventional control methods such as PI controller, state feedback control etc.., may help in increasing the stability margin or in improving the dynamic response of the closed loop. Yet, these controllers will possibly present a poor steady-state error for the harmonic reference signal. An AFLC technique is used which can overcome these effects with better dynamic response and robustness [12].

In an adaptive fuzzy logic controller, parameters and control rules are obtained from a model data file which contains summary of input-output pairs. The development of the rules requires well understanding of the process to be controlled. It does not require a mathematical model of the system [12].

The fuzzy logic controller contains four modules to be followed: input data is classified into suitable linguistic values or sets using fuzzification; the knowledge base possess the rule base and data base, containing knowledge of the linguistic labels and control rules; decision making is inferring control action from rule base; the conversion from the inferred fuzzy values to real crisp value or control action is the defuzzification.

The error e and change in error e_c are used as numerical variables from the real system. To convert these numerical variables into linguistic variables, the following seven fuzzy sets are chosen as: negative big (NB), negative medium (NM), negative small (NS), zero (ZE), positive small (PS), positive medium (PM) and positive big (PB) [13].

The fuzzy adjustor according to PEHS, shown in Fig.2 is used to adjust the parameters of proportional control gain K_P and integral control gain K_I, based on the error e and the change of error e_c.

$$K_P = K_P^* + \Delta K_P \tag{1}$$

$$K_I = K_I^* + \Delta K_I \tag{2}$$

Here the K_P^* and K_I^* are calculated offline based on the Ziegler-Nichols method [15]. The fuzzy logic controller has two inputs and single output. The fuzzy rules are in the IF-THEN form.

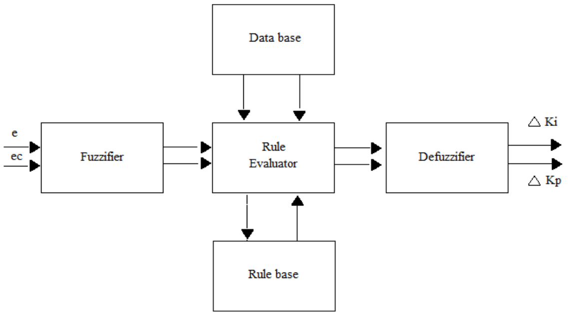

Fig.2 Block Diagram of Fuzzy Adjustor unit.

To ensure the sensitivity and robustness of the controller, the membership function of the fuzzy sets for e(k), $e_c(k)$, ΔK_P and ΔK_I acquired from the ranges of e, e_c, ΔK_P and ΔK_I. The membership functions are shown in Fig.3 respectively [12].

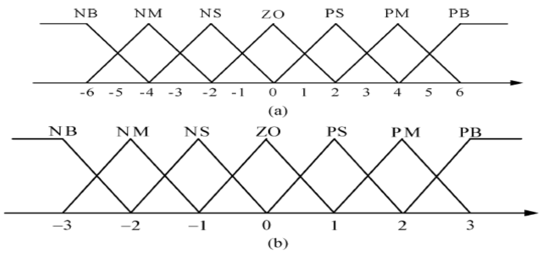

Fig.3 Membership Functions of the fuzzy variable (a) Membership function of e(k) and $e_c(k)$ (b) Membership function of ΔK_P and ΔK_I

The tuning rules of ΔK_P and ΔK_I are shown in Table.1 and Table.2 [13].

Table.1 ADJUSTING RULE OF THE ΔK_P PARAMETER

e\ec	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	NB	PM	PS	PS	Z
NM	PB	PB	NM	PM	PS	Z	Z
NS	PM	PM	NS	PS	Z	NS	NM
Z	PM	PS	Z	Z	NS	NM	NM
PS	PS	PS	Z	NS	NS	NM	NM
PM	Z	Z	NS	NM	NM	NM	NB
PB	Z	NS	NS	NM	NM	NB	NB

Table.2 ADJUSTING RULE OF THE ΔK_I PARAMETER

e\ec	NB	NM	NS	Z	PS	PM	PB
NB	Z	Z	NB	NM	NM	Z	Z
NM	Z	Z	NM	NM	NS	Z	Z
NS	Z	Z	NS	NS	Z	Z	Z
Z	Z	Z	NS	NM	PS	Z	Z
PS	Z	Z	Z	PS	PS	Z	Z
PM	Z	Z	PS	PM	PM	Z	Z
PB	Z	Z	NS	PM	PB	Z	Z

The inference method employs the MAX-MIN method. The fuzzy control action produced from the inference is imprecise and for real applications it must be converted into a precise control action form.

Since the inferred output is a linguistic result, a defuzzification operation is carried out next. This gives a crisp result. The centre of gravity method is preferred for defuzzification of the fuzzy variable into physical domain.

$$K_P = K_P^{*} + \frac{\sum_{j=1}^{n} \mu_{j\,(e,e_C)}\,\Delta K_{Pj}}{\sum_{j=1}^{n} \mu_{j(e,e_C)}} \qquad (3)$$

$$K_I = K_I^{*} + \frac{\sum_{j=1}^{n} \mu_{j(e,e_C)}\,\Delta K_{Ij}}{\sum_{j=1}^{n} \mu_{j\,(e,e_C)}} \qquad (4)$$

IV. SIMULATION RESULTS AND DISCUSSIONS

The AFLC based simulation and the hysteresis controller based simulation for verifying the performance of the PEHS is obtained using MATLAB/SIMULINK. The SIMULINK model contains three phase supply, RITHAPF sub-block, TCR sub-block and non-linear load sub-block. The RITHAPF contains the hysteresis controller or AFLC block in Fig.4. The asymmetrical nonlinear load is represented by three phase diode bridge rectifier with a resistive load. The unbalanced load is represented by a three-phase asymmetrical linear impedance.

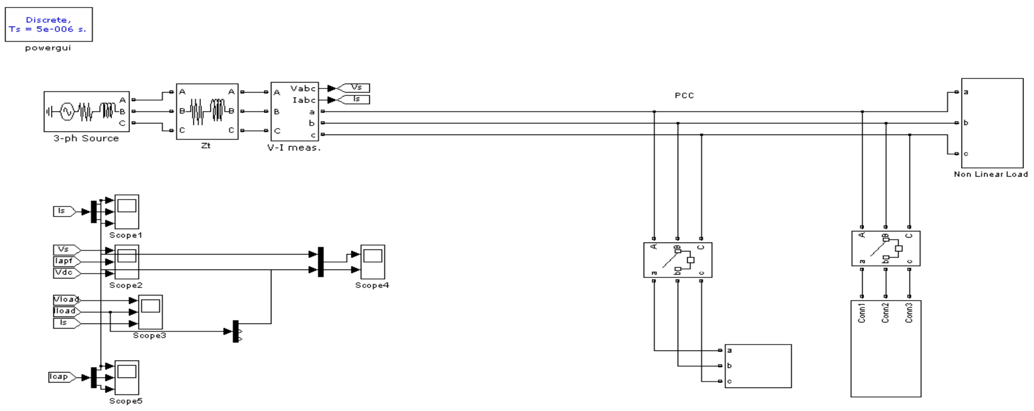

Fig.4 Simulation model of Power Electronic Hybrid System.

Table.3 SIMULATION PARAMETERS

Parameters	**Value**
Grid line voltage	400V
Grid angular frequency	2π * 50 Rad/s
Grid line impedance	0.01+1e-6Ω
Loads RL	1000 Ω
TCR	5 H
Dc link Capacitor	20 μF
Grid line impedance	0.01+1e-6 Ω
Filter inductor	2 Mh

The simulation result of PEHS with hysteresis controller and AFLC for three phase input current is shown in Fig.5 and Fig.6 respectively. The three phase input source current is named as I_{as}, I_{bs}, I_{cs} respectivel

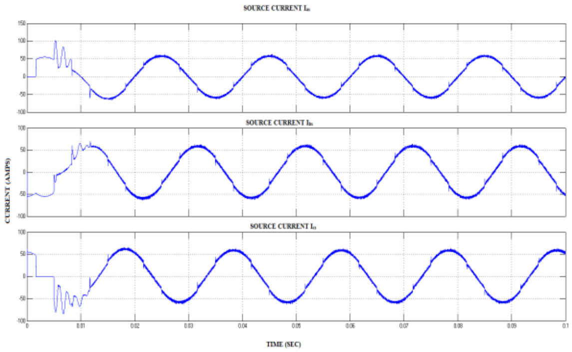

Fig.5 Waveform of input source current with hysteresis controller.

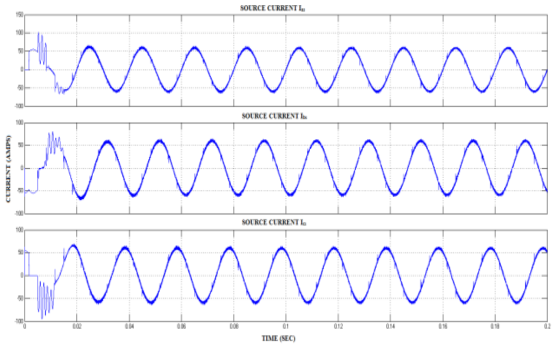

Fig.6 Waveform of input source current with AFLC.

Fig.7 and Fig.8 shows the waveform of source voltage V_s, active power filters current I_{apf} and dc voltage V_{dc} with hysteresis controller and AFLC respectively. The harmonics in the three phase active power filter current are compensated. The distortions in dc voltage are gradually reduced and the voltage is maintained constant.

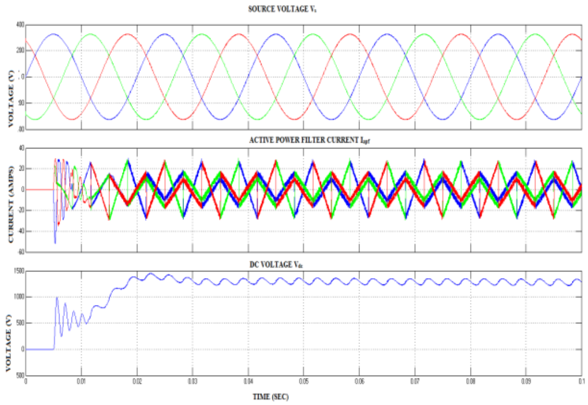

Fig.7 Waveform of source voltage, active power filter current and dc voltage with hysteresis controller

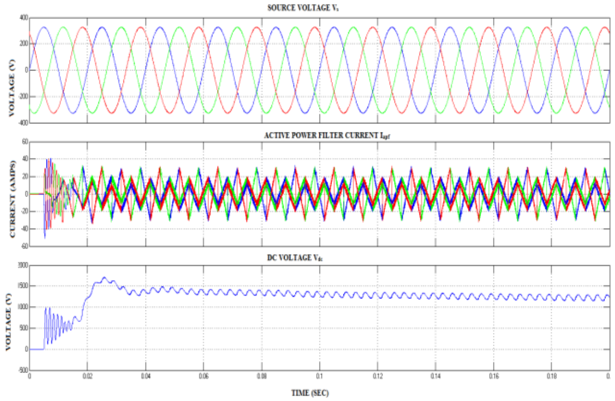

Fig.8 Waveform of source voltage, active power filter current and dc voltage with AFLC.

Fig.9 and Fig.10 shows the waveform of load current and compensating current with hysteresis controller and AFLC respectively. The compensated source current is also shown.

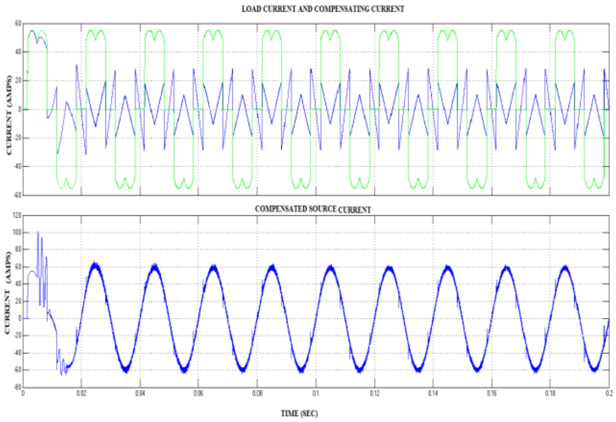

Fig.9 Waveform of load current and compensating current with hysteresis controller.

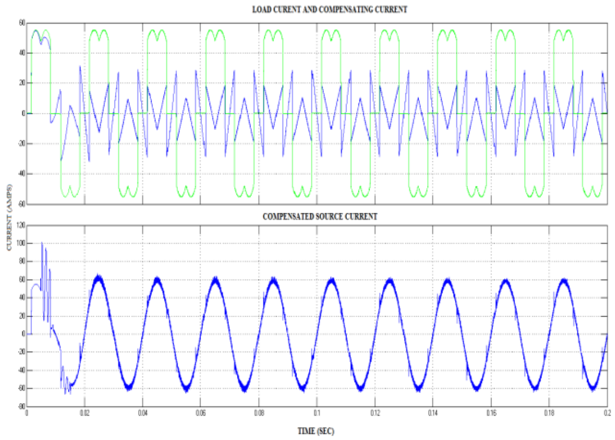

Fig.10 Waveform of load current and compensating current with AFLC.

The FFT analysis of the power electronic hybrid system with Hysteresis controller and AFLC is shown in Fig.11 and Fig.12 respectively. The THD value of power electronic hybrid system between the use of hysteresis controller and AFLC is compared. It is seen that the THD value of the PEHS is reduced with AFLC when compared with hysteresis controller.

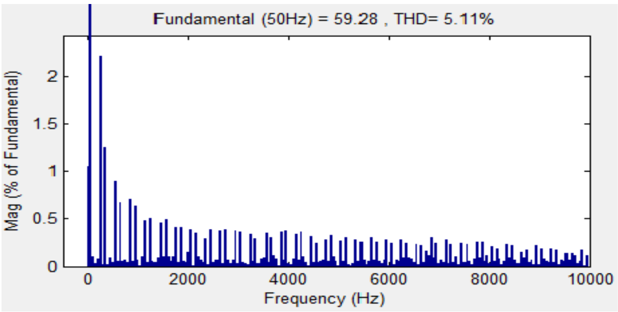

Fig.11 FFT Analysis of PEHS with hysteresis Controller.

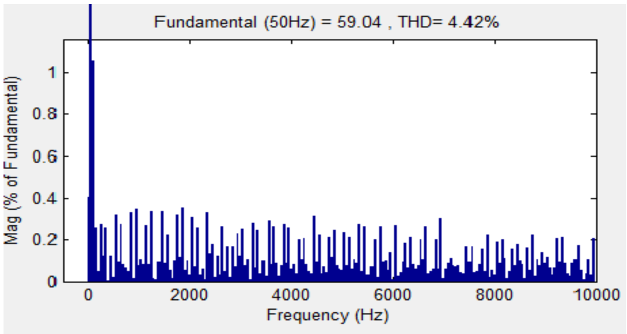

Fig.12 FFT Analysis of PEHS with AFLC.

The THD results of each parameter values from the simulation are listed in the Table.4 below.

Table.4 SIMULATION RESULTS WITH THD VALUES

Parameters	THD with hysteresis controller	THD with adaptive fuzzy logic controller
Source Current	5.11%	4.42%

Source Voltage	0.22%	0.23%
Active Power Filter	30.32%	30.30%
Compensating Current	4.84%	4.06%

V. CONCLUSION

This paper proposes an Adaptive Fuzzy Logic Controller in PEHS to suppress the reactive power and the harmonic current in industries where there are asymmetrical and non-linear loads. This overcomes the phase shift variation with the harmonic current frequency in the system. When compared with the hysteresis controller, the AFLC is advantageous and it also helps in reducing the tracking error and increasing the dynamic response. Thus the power quality is improved and the imbalance and current harmonics are suppressed. Furthermore, power factor is also enhanced. The above results demonstrate that this application has better performance and is effective.

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