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Improvement of Power Quality in Electrical Distribution System using Shunt Active Power Filter Controlled by Fuzzy Logic Controller

تحسين جودة القدرة في نظم التوزيع الكهربائية باستخدام المرشح الفعال المتحكم بواسطة المنطق المبهم

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الملخص: إن كثرة استخدام الأحمال الغير خطية في حياتنا العامة مثل دوائر توحيد التيار و دوائر التحكم في سرعة المحركات الكهربائية... الخ قد أدى إلى ارتفاع نسبة التوافقيات في التيار المسحوب و بناء عليه أصبح من الضروري استخدام المرشح الفعال بدلا من المرشحات التقليدية غير الفعالة. حيث أن المرشح الفعال هو واحد من أنجح الحلول المقترحة للتغلب على التوافقيات المصاحبة لكل من موجتى الجهد و التيار وكذلك تعويض القدرة غير الفعالة لتحسين معامل القدرة. لقد تم استخدام المنطق المبهم FUZZY LOGIC للتحكم في المرشح بهدف الحصول على نتائج أفضل و خصوصا في حالة تغير الحمل. في هذا البحث تم استخدام برنامج MATLAB/SIMULINK لمحاكاة تشغيل المرشح الفعال و حساب التشويه الكلى للموجة (THD) بسبب التوافقيات و ذلك قبل و بعد توصيل المرشح بالشبكة الكهربائية حيث أوضحت النتائج أن استخدام المنطق المبهم للتحكم في المرشح الفعال يعطى نتائج أفضل من استخدام طرق التحكم التقليدية و خصوصا في حالة تغير الحمل.

Abstract

In the recent years the growing use of nonlinear loads, such as power converter, Uninterruptible Power Supply (UPS), and Adjustable Speed Drives (ASD) had been increased rapidly. All of these loads inject harmonic current into the power system. This paper presents a study and simulation of a three-phase Active Power Filter (APF) controlled by Fuzzy Logic Controller (FLC) to improve the Power Quality (PQ) of the distribution system by reducing the Total Harmonic Distortion (THD) and compensating the reactive power. The Synchronous Reference D-Q Frame (SRF) theory is used to generate the reference compensating currents for APF. In this paper APF controlled by FLC is developed to regulate the voltage of the DC capacitor. The main purpose of the proposed FLC is to provide good static and dynamic performances compared to conventional PI controller. The proposed APF was tested using the MATLAB/SIMULINK toolbox and the results satisfy the harmonic limit specified by IEEE harmonic standard 519. The obtained simulation results are presented and compared with the conventional PI controller. The simulation results show that the proposed FLC has better performance over the PI controller especially when the load is varied.

Keywords: Power Quality, Active Power Filter, Fuzzy Logic Control, Synchronous reference D-Q Frame (SRF) theory.

I. Introduction

Harmonic distortion is one of the main PQ disturbances which caused by the nonlinear loads. These harmonics have a harmful effect on power system components. Hence, it is necessary to reduce the dominant harmonics to met IEEE 519-1992 harmonic standard [1]. APF is one of the most effective way of providing harmonic elimination and reactive power compensation. APF are essentially three-phase voltage source PWM inverter with a control circuit. The basic concept of APF is to produce current and voltage components to cancel the harmonics produced by the nonlinear loads. The cancelation can be done by a series injection of voltage or a shunt injection of harmonic current. There are several topologies for the APF which are, shunt APF, series APF, hybrid APF, and universal APF. Shunt APF topology is based on the principle of injection of load harmonic currents into

the system [2]. The APF must provide all the reactive power and only the harmonic active power as shown in Fig. (1), but the fundamental active power of the load is obtained from the source.

An important task in designing APF is to maintain the voltage of the capacitor connected to the DC side of the inverter constant to ensure that the fundamental active power supplied by the source will be equal to the fundamental active power of the load, and no fundamental active power passes through the inverter into the dc capacitor [3]. Generally, conventional PI controller is used to regulate the DC bus voltage. The PI controller fails to perform satisfactorily under load variation [4]. In this paper a FLC is used to regulate the DC bus voltage. FLC has better dynamic behavior than conventional PI controller especially under load variation.

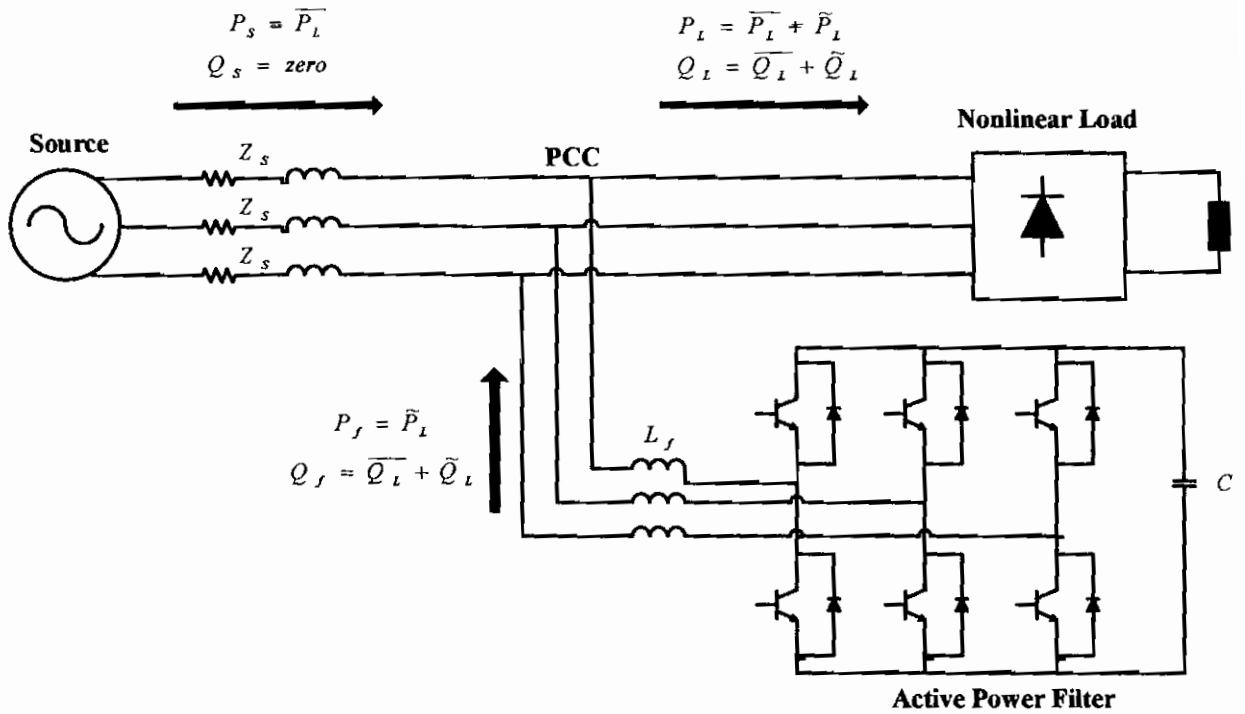


Fig. (1) Power Exchange among the Network, APF, and the Load

The paper is organized into five sections. The control strategy for shunt APF is given in section II. In section III, the design of DC bus fuzzy logic controller is detailed and discussed. Simulation results are given and studied in section IV. Finally, conclusions are drawn and given in section V.

II Control Strategy for Shunt APF

Figure (2) shows the schematic diagram of the proposed control scheme. In Fig. (2) the three-phase load current is sensed and transformed into two-phase components in SRF by equations (1) and (2) [5]. When the three phase currents are transformed into SRF, there will be a dc component with a superimposed ac component. If the angular frequency of rotation of synchronous reference frame is at fundamental ω_0 , then the dc component corresponds to fundamental current, and the ac component corresponds to all the harmonics in the current waveform.

From the SRF transformation, the q-axis represents reactive component of current and the d-axis represents active component of current so, a high pass filter (HPF) is applied only for the d-axis component

of load current to extract only the harmonic active current, and all the reactive current.

To regulate the DC bus voltage, the capacitor voltage is sensed and compared with the reference value. The error and the change of error are the inputs to the fuzzy controller. The output of the fuzzy controller is added to the output of the HPF, the summation and q-axis component of load current are inversely transformed to three-phase component in stationary reference frame and compared with the actual inverter current to drive the switching signals of the inverter power switches.

$$\begin{bmatrix} i_{Lq}^s \\ i_{Ld}^s \\ i_{L0}^s \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} i_{Lq}^e \\ i_{Ld}^e \end{bmatrix} = \begin{bmatrix} \cos \theta_e & -\sin \theta_e \\ \sin \theta_e & \cos \theta_e \end{bmatrix} \begin{bmatrix} i_{Lq}^s \\ i_{Ld}^s \end{bmatrix} \quad (2)$$

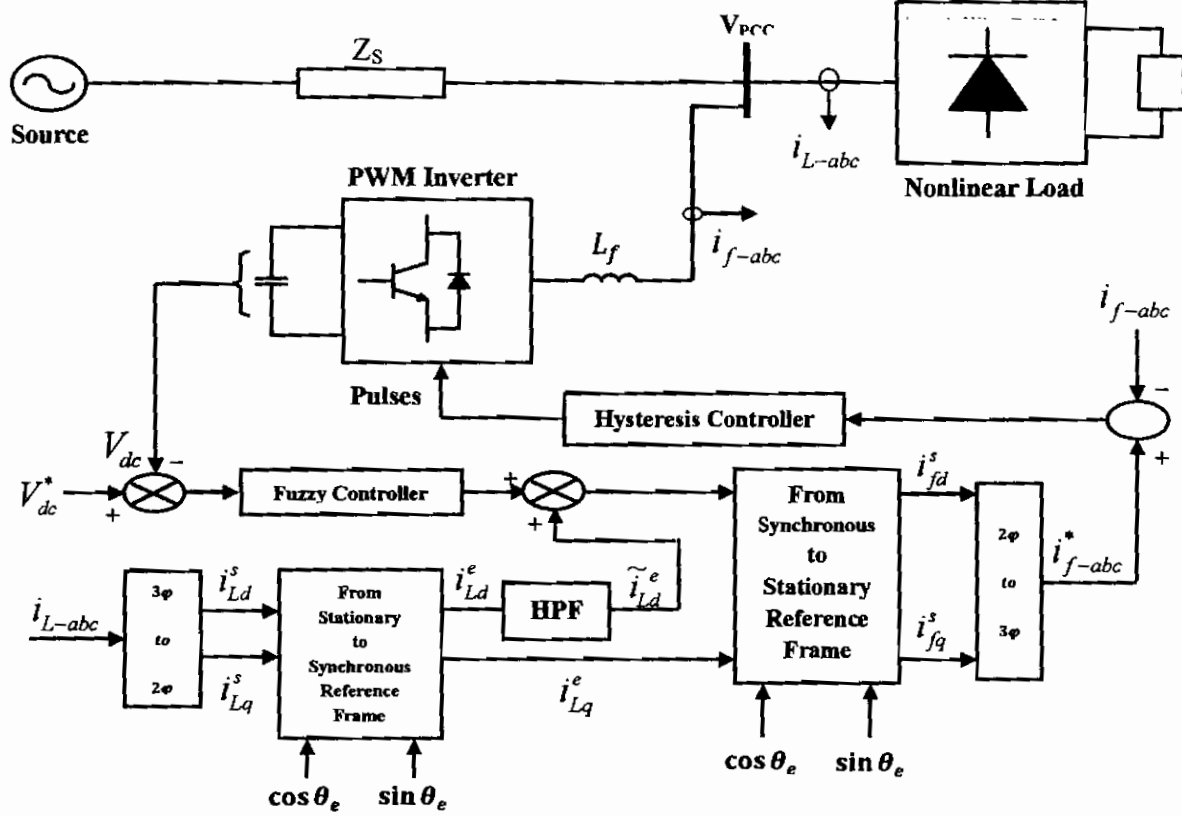


Fig. (2) Schematic Diagram for Controlling APF

To derive the switching signals of the inverter power switches, a hysteresis current controller method is used. In this method, inverter output current is forced to follow the current reference in each phase. Deviation between these two quantities is limited by upper and lower band in a hysteresis loop. If actual current reach upper limit of hysteresis band, the inverter leg is switched off, so that the current decreases till it reaches lower band of hysteresis loop where the inverter leg is switched on again and actual current increases to upper band as shown in Fig. (3) [6, 7, 8].

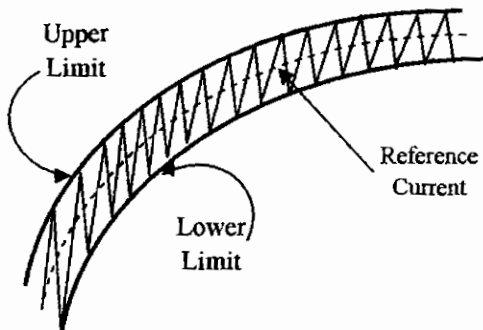


Fig. (3) Hysteresis Current Control Operation Waveform

A hysteresis band current control technique has proven to be most suitable for all the applications of current controlled voltage source inverters in active power filters. A hysteresis band current control is characterized by unconditioned stability, very fast response and good accuracy.

III. Design of DC Bus Fuzzy Logic Controller

The error and the change of error are the inputs to the fuzzy controller as shown in Fig. (4) and [9, 10]. Both quantities (error and the change of error) are normalized. Thus, each range is between -1 and 1 .

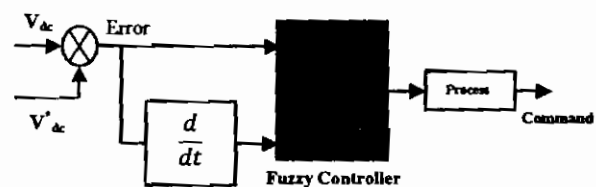


Fig. (4) Structure of Fuzzy Logic Controller

In this case, seven fuzzy sets, NL (Negative Large), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium), PL (Positive Large) have been chosen for each input and output. Membership functions used for the input and the output is triangular. Figure(5) shows the normalized triangular membership function for both error and change in error used in fuzzification

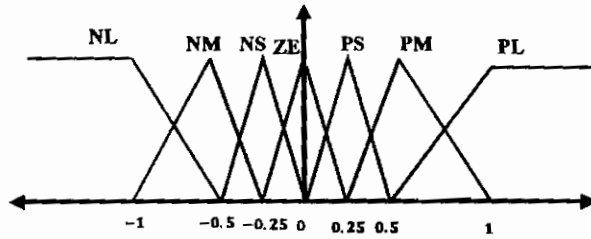


Fig. (5) Normalized Triangular Membership Functions used in Fuzzification

The fuzzy control rule design involves defining rules that relate the input variables to the output model properties. For better control performance, a fuzzy rule base is formulated in Table I

Table I Fuzzy Control Rules

Error $\frac{dE}{dt}$	NL	NM	NS	ZE	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	ZE
NM	NL	NL	NL	NM	NS	ZE	PS
NS	NL	NL	NM	NS	ZE	PS	PM
ZE	NL	NM	NS	ZE	PS	PM	PL
PS	NM	NS	ZE	PS	PM	PL	PL
PM	NS	ZE	PS	PM	PL	PL	PL
PL	NL	NM	NS	ZE	PS	PM	PL

The elements of table I are determined based on the theory that in the transient state, large error need coarse control, however small errors need fine control. Based on this theory, the elements of the rule Table I are obtained from an understanding of filter behavior [11].

IV. Simulation Results

The system consists of three loads connected to the network through three switches S_2, S_3, S_4 , which are normally closed, the first load is considered to be 150 KW, ASD which consists of a diode rectifier with a DC side inductor, the second load is considered to be 135 KW, 30 KVAR, ASD which consists of a diode

rectifier with a DC side capacitor and an AC side inductor, and the third load is a 8 KW lighting load which is represented by a resistor. The filter is connected to the switch S_1 which is normally opened as shown in Fig. (6). The waveforms of the load voltage V_{PCC} , and the supply current I_s are shown in Fig. (7) and Fig. (8) respectively.

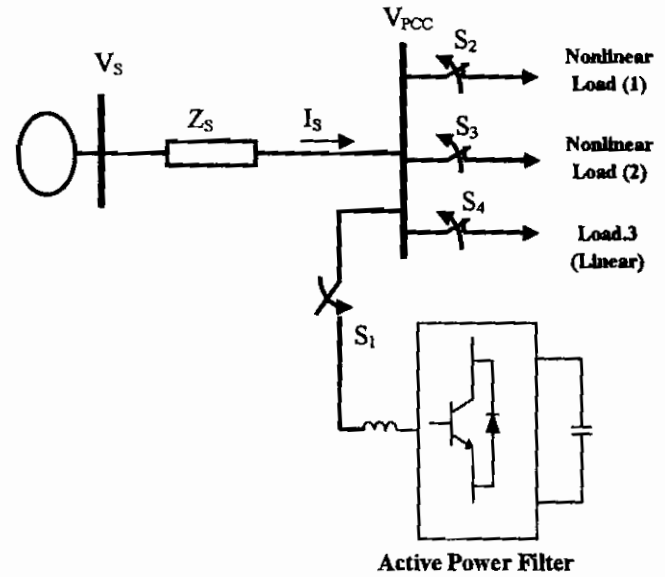


Fig. (6) Case Study to Simulate the Operation of the APF

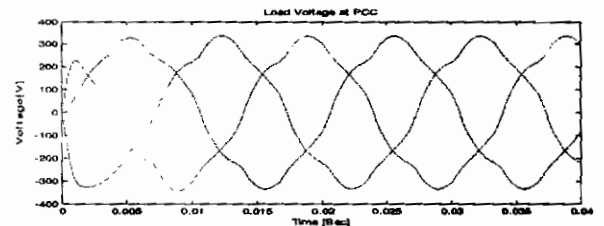


Fig. (7) Load Voltage at PCC V_{PCC} Without Filter

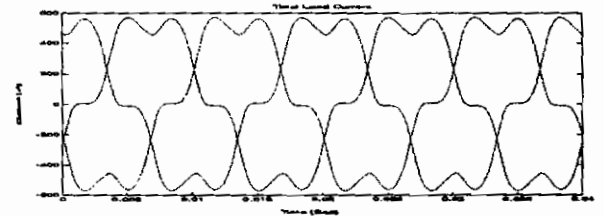


Fig. (8) Total Supply Current I_s Without Filter

The THD in the load current is 20.66%, and in load voltage is 8.15% which is unacceptable according to IEEE harmonic standard limits.

The SIMULINK model for the studied system can be shown in Fig. (9).

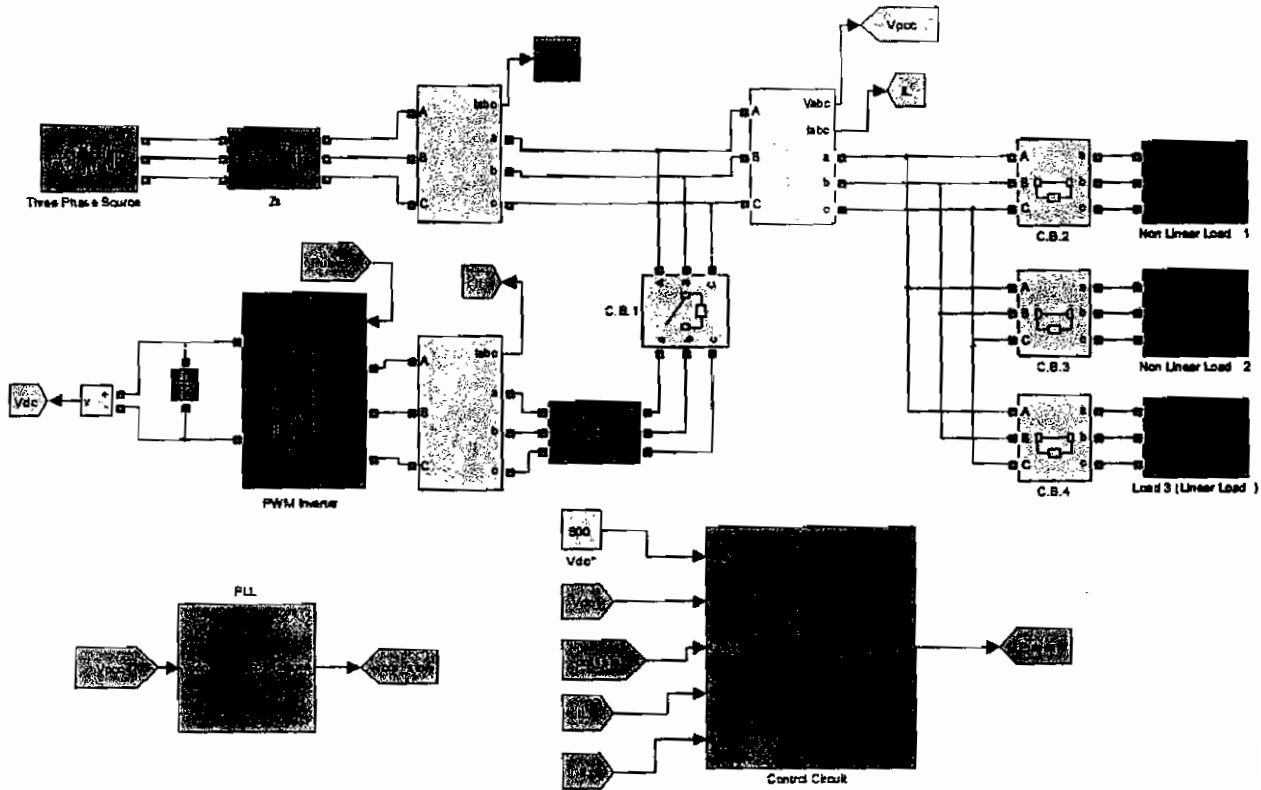


Fig. (9) SIMULINK model for the Studied System

At $t = 0.04$ sec, the switch S_1 is closed to connect the filter to the network. The waveforms of the load voltage and supply current in this case when the filter is controlled by PI controller can be shown in Fig. (10) and when the filter is controlled by FLC can be shown in Fig. (11). It is observed that when the filter is

controlled by PI controller the THD in current is improved from 20.66% to 2.05%, and in voltage is improved from 8.15% to 0.9%. And when the APF is controlled by FLC the THD in current is improved to 0.58% and in voltage is improved to 0.28%.

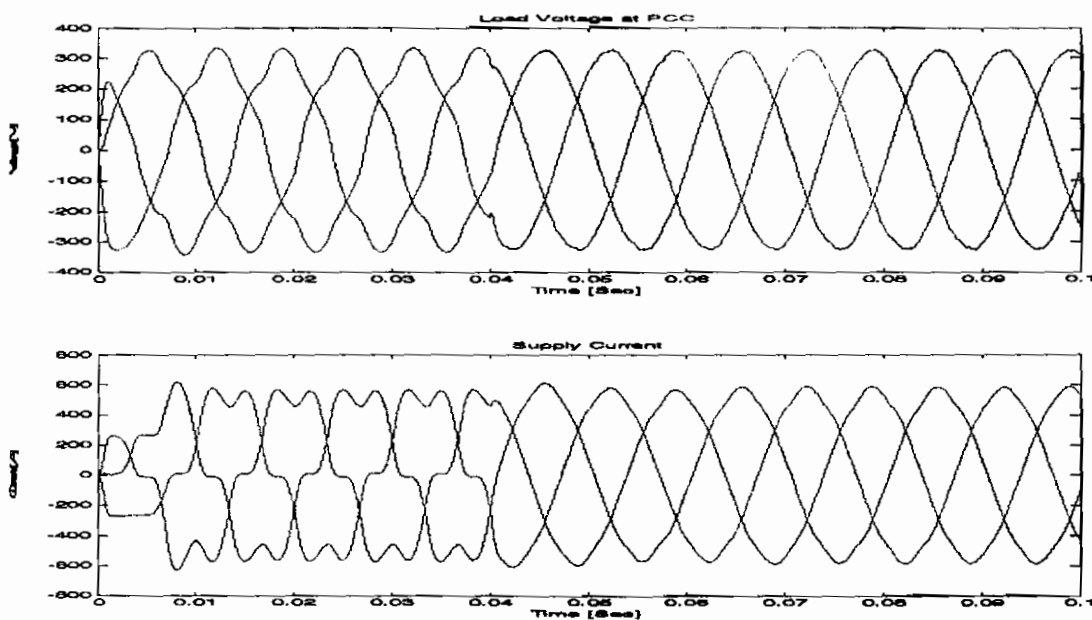


Fig. (10) Waveforms of Load Voltage and Supply Current when the Filter Controlled by PI Controller is Connected to the Network

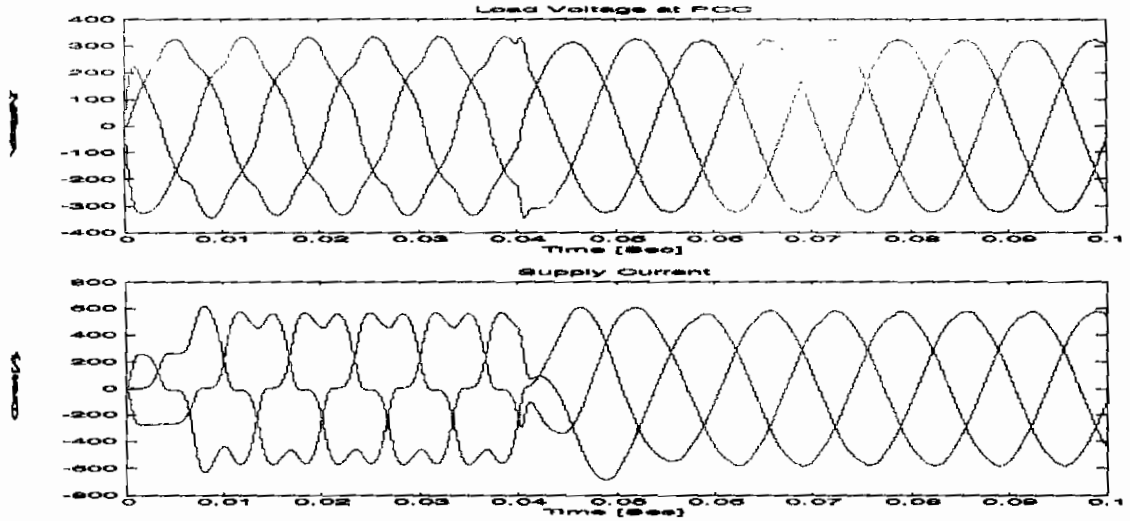


Fig. (11) Waveforms of Load Voltage and Supply Current when the Filter Controlled by FLC is Connected to the Network

And at $t = 0.14$ sec, the switch S_2 is opened to disconnect the first load from the network. The waveform of the load current can be shown in Fig. (12)

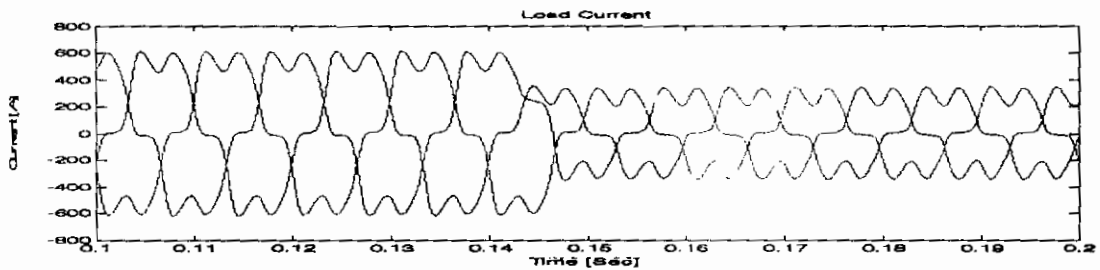


Fig. (12) Waveform of Load Current when the switch S_2 is Opened at $t = 0.14$ Sec

In this case, when the load is changed and the filter is still connected to the network, while the filter is controlled by PI controller, the waveforms of the load voltage and supply current can be shown in Fig. (13), and when the filter is controlled by FLC can be shown

in Fig. (14). It is observed that when the filter is controlled by PI controller the THD in current is 4.77%, and in voltage is 1.07%. And when the APF is controlled by FLC the THD in current is 1.05% and in voltage is 0.26%.

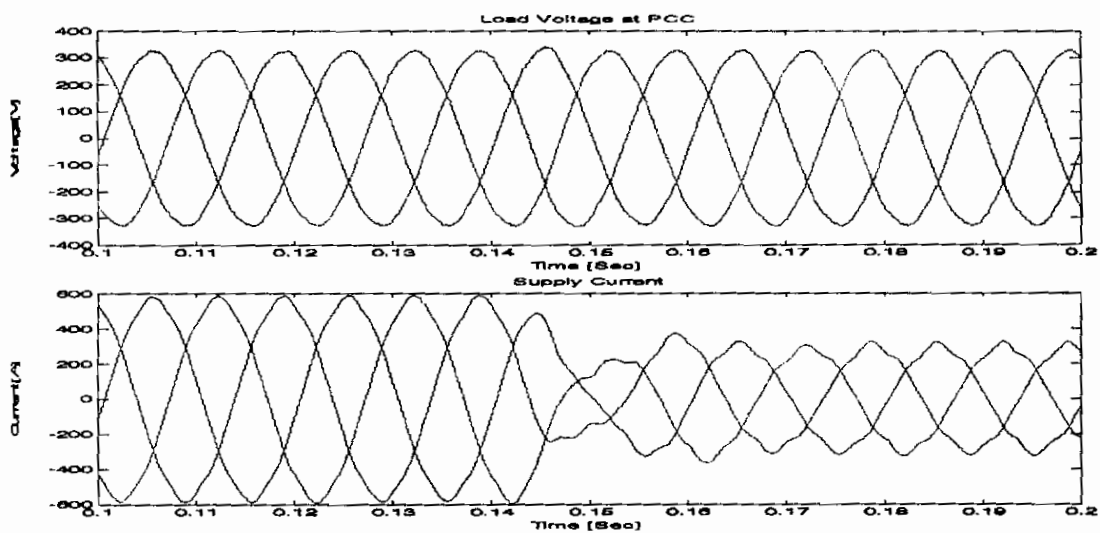


Fig. (13) Waveforms of Load Voltage and Supply Current when the Filter Controlled by PI Controller is Connected to the Network

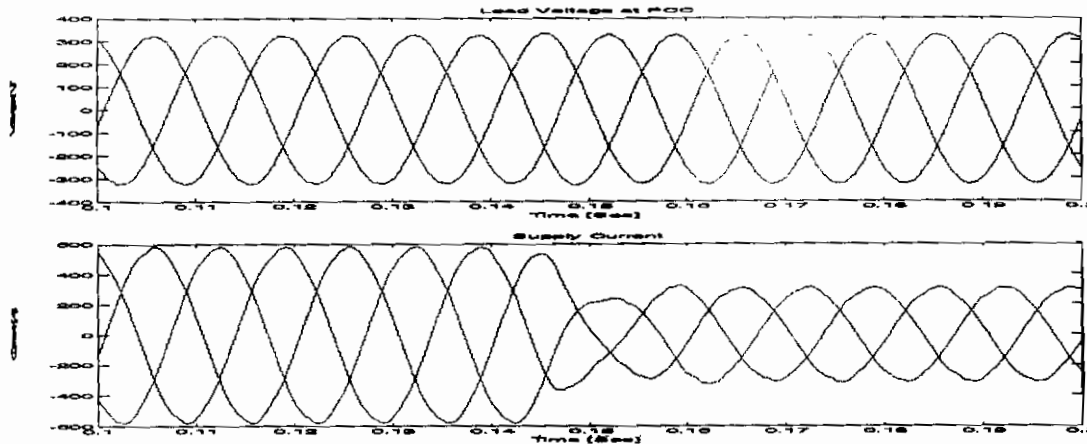


Fig. (14) Waveforms of Load Voltage and Supply Current when the Filter Controlled by FLC is Connected to the Network

The THD in load voltage and supply current for all cases can be shown in Tables II and III respectively.

Table (II) THD in Load Voltage

	Before Changing The Load	After Changing The Load
Without APF	8.15%	5.09%
With APF Controlled by PI Controller	0.9%	1.07%
With APF Controlled by FL Controller	0.28%	0.26%

Table (III) THD in Supply Current

	Before Changing The Load	After Changing The Load
Without APF	20.66%	27.17%
With APF Controlled by PI Controller	2.05%	4.77%
With APF Controlled by FL Controller	0.58%	1.05%

V. Conclusions

This paper has presented a fuzzy logic control technique for APF for PQ improvement under load variations. The APF was simulated using MATLAB/SIMULINK and the performance was analyzed in a sample power system with a source and nonlinear loads connected to the PCC. The proposed APF using both FLC and PI controller had been tested for varying load and the THD in supply current is measured for both controllers. The THD of the power supply current before installing the filter was 20.66%, while after connecting the APF the THD has been reduced to 2.05% with PI controller while it was 0.58% with FL controller. When the load is varied and the APF is still connected the THD was 4.77% with PI controller while it was 1.05% with FL controller. The simulation results show that, the FLC demonstrates better dynamic behavior than conventional PI controller, and the THD percentage of source current is under limits of IEEE-519 standard.

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