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Intelligent control of shunt active filter for power quality improvement using fuzzy logic

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Now a days, power quality issues are very important for the sensitive equipments to increase the efficiency of the syatem. In the power system, disturbances are due to non linear characteristics and fast switching of the power electronics apparatus. Because of the use of the power electronic devices many distortions are introduced. Due to these harmonics the devies connected to the system suffer and their life is reduced. Our main aim is to use a shunt active filter that improves these harmonics and gives a sinusoidal current at the load side. For improving power quality fuzzy controllers are used and found to be better than traditional controllers.

Keywords: *Fuzzy, controller, PWM, filter, control rules, fuzzy inference system, mamdani-type*

1.0 INTRODUCTION

Power quality is a problem caused by the modern use of power electronic devices. These devices use the diodes, thyristors, IGBTs and other devices. Because of the rapid turning on and off i.e. switching many distortions are introduced. These distortions cause changes in the line currents and voltages and hence the currents at the source side also varries and changes. The abrupt change of the source side current causes abrupt movements in the generator shaft which reduces its life. These current and voltage distortions need to be rectified. Earlier passive filters were used. But they couldn't control the reactive power. These devies were banks of capacitors that were switched on/off manually and had many limitations including their large size. The active power filters use a control that is based on the harmonic sensing. [1] In paper we are using active power filter and an intelligent control using fuzzy logic is done. In active power filters generally non liner systems are considered. It is not so difficult to design a linear control system but its difficult to design a non-linear control system. In intelligent control fuzzy logic, neural networs, fuzzy-neural network are the basic tools. Intelligent control is a challenging. In linear system we express the system model either using state space or using transfer function. For example we have a plant that we want to control i.e. we regulate some of the variables like speed of motor, the ph value of a reactor or the volatge level of power system busbar. Mathematical models are dervied using bassic laws that we have in physics, chemistry and science. Systems are generally non-linear. Uncertanities in the model should be taken care by the intelligent control. The model should be adaptive to the changes in the variables of the enviornment. The intelligent control should be distributed in nature.

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In real world we don't deal with zeros and ones but rather our language have words that are in between. The real world doesn't have crisp boundaries for example small, big, very big, huge etc. These vague concepts are called Fuzzy. The computers use machine language but the human brain uses fuzzy concepts. The real world has lots of uncertainity. A mathematical tool called as Fuzzy Logic tool is used in soft computing to deal with uncertainity. As nowadays the power system is becoming more complex the capability of the traditional controllers decreases and hence we have to use fuzzy logic. A Mat Lab toolbox, SIMULINK provides with simulations tools for linear/nonlinear systems and continuous/discrete systems.

Reactive power and harmonics of the nonlinear load is generally sensed by the active power filter. In this paper, we are sensing line currents only which will be the compensational current. [10] An instantaneous VAR compensator and a system to supress harmonics is proposed. Traditional controllers (P,PI,PID) dont work properly under load disturbances and system variable changes. The popularity of fuzzy logic controllers has increased during the past few years because of the increase in the power electronic devices. [2,3,4] The main advatage of using fuzzy controllers is that they don't need an accurate mathematical model and the input to the system can be imprecise data which gets processed in the controller. The fuzzy controllers are robust than conventional controllers. The active power filters are installed at the PCC. The active power filter generates the compensationg current that is in opposition to the sensed distored waveform. The Mamdani type FLC is used because it gives better result as compared with other types but it uses large number of fuzzy sets and rules.

2.0 CONTROL STRATEGIES

Active power filters sense harmonic current reactive power of the non-linear load. The average value of the voltage is set to the reference value by the dc capacitor. The reactive power component of the load current is not sensed and hence the calculations are simplified. A better switching pattern is produced by producing constant switching frequency. The filter thus acts as a harmonic and current compensator. Simple sinusoidal generation technique in which the load current is sensed for the generation of compensating current. [6] This techniques is further modified to sense line current of the load side only. [7, 8] A current reference generator generates a stepped sinusoidal wave. The three phase volatge and currents are calculated by measuring only two three phase voltage and currents. Hence, only two sensing devices are used.[5]

3.0 COMPENSATION PRINCIPLE

Active power filters inject current that is in phase opposition to the sensed load current harmonics thus cancelling it out.

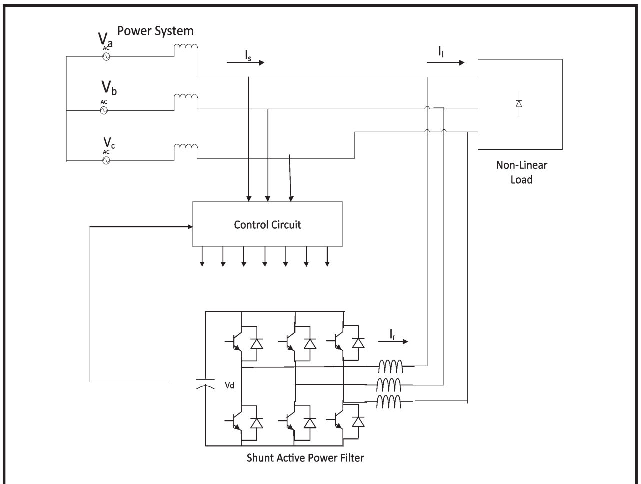

FIG. 1 (2.1)TOPOLOGY OF SHUNT ACTIVE FILTER

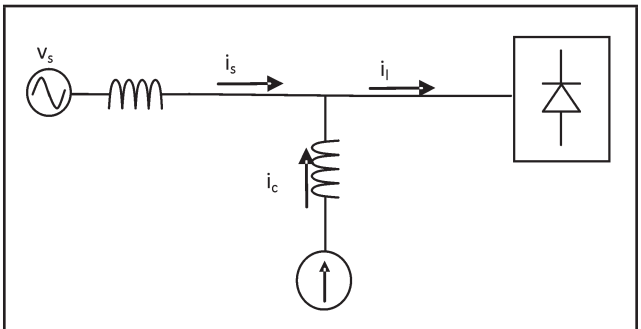

FIG. 2 I_C IS GENERATED TO COMPENSATE LOAD CURRENTS

Figure 2 shows the basic principle to control the shunt active power filter. i_c is the compensation current which is produced by the active power filter and used to cancel out the harmonics at the souce side. Ideally the source current should be in phase with souce voltage.

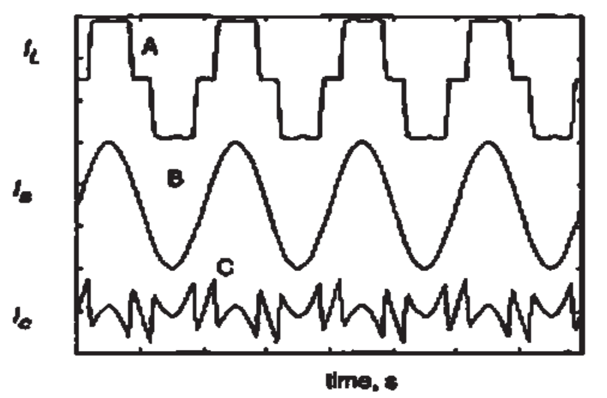

FIG. 3 CURRENT WAVEFORMS OF LOAD, SOUCE AND COMPENSATOR

Figure 3 shows the current waveforms. The load current waveform is shown by Curve A. Pure sinusoidal waveform is shown by Curve B and curve C shows the compensation current.

3.1 Reference Source Current Estimation

At most care is taken to ensure that mounting. from the Figure 2, the inst. currents can be written as

$i_s(t)= i_l(t)- i_c(t)$ …(1)

Voltage of the souce can be calculated as,

$v_s(t)= v_m\sin\omega t$ ….(2)

The fundamental component and harmonic components of the load can be calculated as

$i_L(t)= \sum_n^{\infty}= I_n\sin(n\omega t+\varphi_n)$

$= I_1 \sin(n\omega t+\varphi_1) + \sum^{\infty}_{n=2} \sin(n\omega t+\varphi_n)$ ...(3)

Instantaneous power at the load side can be calculated as

$P_L(t)= v_s(t)*i_l(t)$ ...(4)

$=V_mI_1 \sin^2\omega t *\cos\varphi_1+v_mI_1 \sin\omega t *\cos\omega t *\sin\varphi_1+V_m \sin\omega t * \sum I_n \sin(n\omega t+\varphi_n)$

$= P_f(t)+P_r(t)+P_h(t)$ ...(5)

The real power drawn by the load is

$P_f(t)= V_m I_1\sin^2\omega t * \cos\varphi_1= v_s(t) *i_s(t)$ ...(6)

Source current after compensation,

$i_s(t)= P_f(t) / v_s(t)= I_1\cos\varphi_1\sin\omega t$

$=I_m\sin\omega t$ ...(7)

where $I_{sm}=I_1\cos\Phi_1$.

The peak current that is used for the compensation of lossed in the PWM converter is given by,

$I_{sp} = I_{sm}+ I_{sl}$ …(8)

The compensation current should be provided by the APF which is given by,

$i_c(t)= i_L(t)-i_s(t)$ ...(9)

After compensation the source currents can be calculated as

$$i_{sa}^* = I_{sp}\sin\omega t$$

$$i_{sb}^* = I_{sp}\sin(\omega t -120^0)$$

$$i_{sc}^* = I_{sp}\sin(\omega t +120^0)$$

The amplitude of the source current is given as Where I_{sp} $(=I_1\cos\Phi_1+I_{sl})$

An error signal is generated by comparing the capacitor voltage with a reference value. The fuzzy controller processes this error. [9]

4.0 DESIGN OF POWER CIRCUIT

The role of the capacitor is to maintain a ripple free source current and it also stores energy which can be used during transient periods. The capacitor is used to supply the difference between the supply and the load plus some losses and is maintained at a constant reference value. When the DC capacitor compensates the difference, its voltage change away from the reference value. The peak value of the reference current is to be proportional to the difference of the real power between the source and the load.

The DC capacitor is regulated and is used to calculate the reference source current. When the DC voltage is lesser than the reference value it means that the real power of the source side is lesser than the load demand and vice versa. This change in capacitor voltage has been verified from the simulation results.

The model design requires the design of the following components:

- Design of filter inductor, L_c.
- Design of DC side capacitor, C_{dc}.

Selection of reference capacitor voltage, $V_{dc,ref}$.

4.1 Design of L_c and $V_{dc,ref}$

The following assumptions are made:

1. The source voltage is sinusoidal.
2. The AC side line current distortion is assumed to be lesser than 5%.
3. Active power filter has a fixed capability to produce reactive power.
4. The amplitude modulation factor (ma) of the PWM converter is between 0 and 1.

The active power filter controls i_{c1} to compensate the reactive power of the load.

Ideally i_{s1} should be in phase and i_{c1} should be orthogonal to V_s which is shown in figure 4.

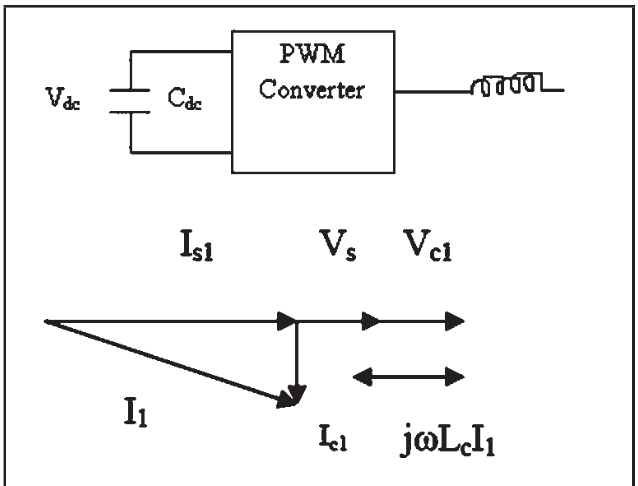

FIG. 4 PHASOR DIAGRAM OF ACTIVE POWER FILTER

The active power filter can compensate the reactive power from the utility only when $V_{c1} > V_s$ and can be shown by the equation for the three phase reactive power of the active power filter.

$$Q_{c1}=3V_s\,I_{c1}=3V_sV_{c1}/\omega L_c(1-(V_s/V_{c1})) \quad ...(10)$$

Amplitude modulation factor, m_a is $v_m/(V_{dc}/2)$.

And $v_m=\sqrt{2}\,V_c$, and $V_{dc} = 2\sqrt{2}\,V_{c1}$ for $m_a=1$.

The ripples in the filter are also filterd by L_c and hence its used for harmonic current reduction. The ripple current is given by:

$$I_{ch(mf\omega)}= V_{ch(mf\omega)} / m_f\,\omega L_c \quad ...(11)$$

4.2 Design of C_{dc}

The principle of instantaneous current flow is used to design the DC side capacitor. The ripple voltage has to be reduced which is a governing factor in its desing. The DC side capacitor value can be found from the following equation.[29]

$$C_{dc}=(\pi x I_{c1,rated})/\sqrt{(3\omega V_{dc,p\text{-}p(max)})} \quad ...(12)$$

The value of L_c and V_{dc} can be calculated by solving equations (10) and (11).

4.3 Control Scheme

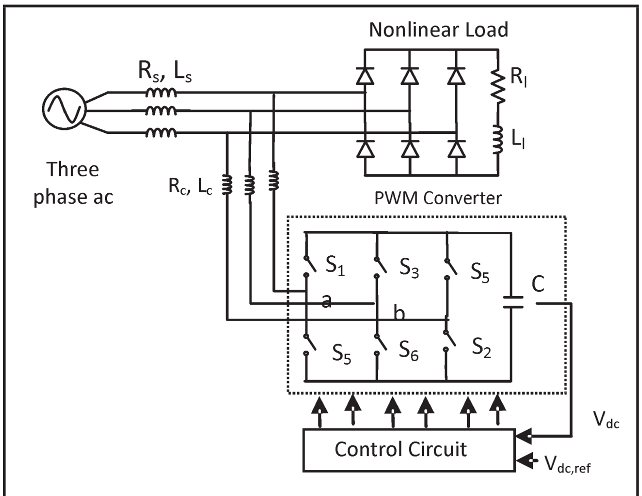

FIG. 5 SCHEMATIC DIAGRAM OF THE FUZZY CONTROLLER.

Actual curents are compared with the reference currents to obtain the switching signals and these are then given to the PWM converter [6].

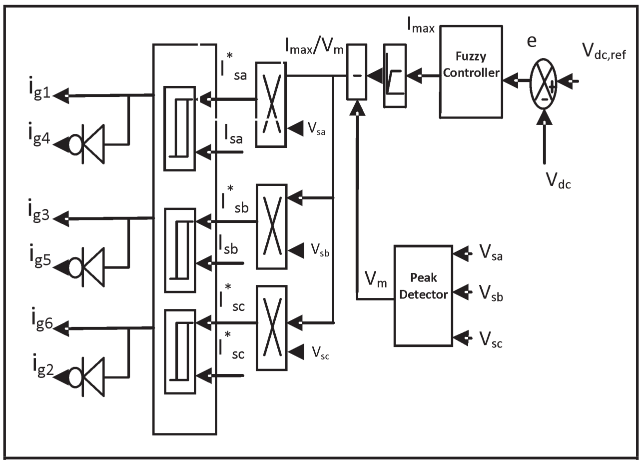

FIG.6 4 FUZZY CONTROL SCHEME

A set of simple linguistic rules are evaluated. A mathematical model is not required. Fuzzy logic is used for the mapping of input to output. From this inference is dervired which is the conclusion. The various steps in an FIS system is as under:

1. Fuzzification
2. Decision making using the operators (AND, NOT, OR).
3. Assembling the consequents.
4. Defuzzification.

A membership function is based on a membership curve which is used for fuzzification of the linguistic variables. A triangular membership function is used. Mamdani and TS are the most common methods for the consequent part (THEN part) of the rule. In this paper Mamdani method is used. In Mamdani, based on the degree of membership the output gets trunucated. In defuzzification the fuzzy output is converted into crisp form. The input to the fuzzy system are the error and the change in error signals which are obtained from the real system. The Fuzzy levels are: NB, NM, NS, ZE, PS, PM,and PB. P means Positive, N means Negative, B stands for Big, M for Medium and S for Small [6]. The fuzzy controller uses continuous universe of discourse, Mamdani's 'min operator' and the defuzzification by the 'height method'.

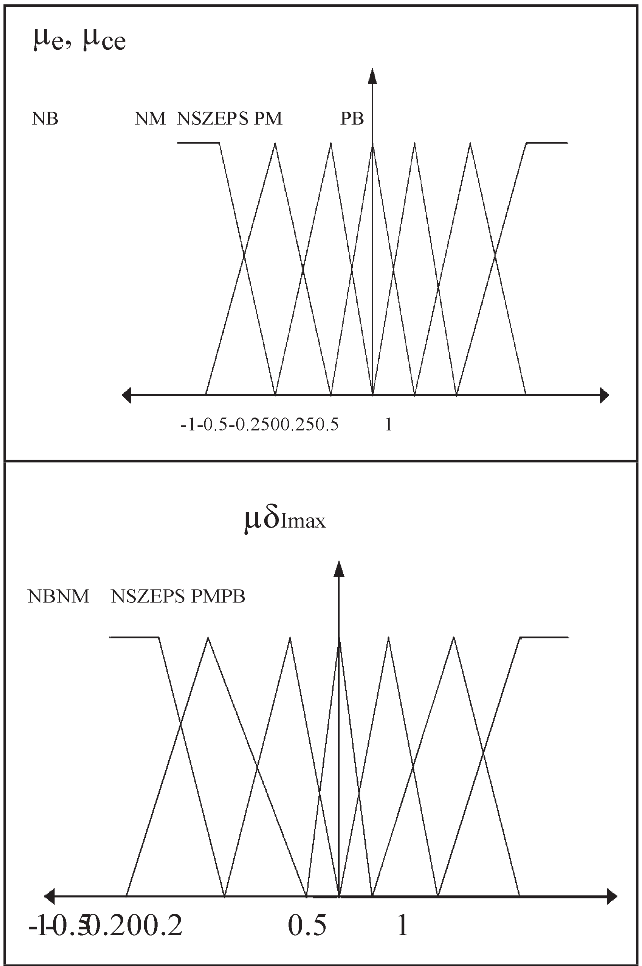

FIG.7 NORMALIZED TRIANGULAR FUNCTIONS USED INFUZZIFICATION.

A new modified rule base system is introduced which is shown by Table 1. The output of the controller is a crisp vairalbe δI_{max} which is the change of the reference current.

TABLE 1

CONTROL RULE TABLE

(e)	→	**NB**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
	NB	NB	NB	NB	NM	NS	NS	ZE
	NM	NB	NB	NB	NM	NS	ZE	PS
change in	**NB**	NB	NB	NM	NS	ZE	PS	PM
error (ce)→	**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

The rules are formulated based on the time step response of the system. There is better control in transient, if error is large it needs a harsh control and input/outputs are given in Table 2. The filter behaviour has to be understood based on which the rule table has been designed. The modifications are done to the table based on the simulations on the Matlab program. The rule table is entered into the FIS block.

5.0 SIMULATION RESULTS

PWM converter is modelled seperately and then integrated into the main program in MATLAB™. A non-linear load which is three-phase rectifier is used. The system parameters that are used in the program are as under:

TABLE 2

SYSTEM PARAMETERS FOR SIMULATION STUDY

Parameters	Values
Source voltage (V_s)	100 V (peak)
System frequency (f)	50 Hz
Source impedance (R_s,L_s)	0.1 Ω;0.15 mH
Filter impedance (R_c,L_c)	0.4 Ω;3.35 mH
Load impedance (R_l,L_l)	6.7 Ω;20 mH
DC link capacitance	2000 μF
Reference DC link voltage (V_{dcref})	580 V

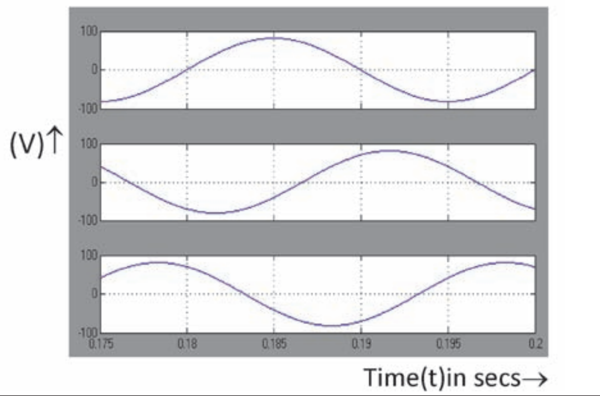

FIG. 8 SOURCE VOLTAGES OF PHASE A, B AND C WITH NO CONTROLLER.

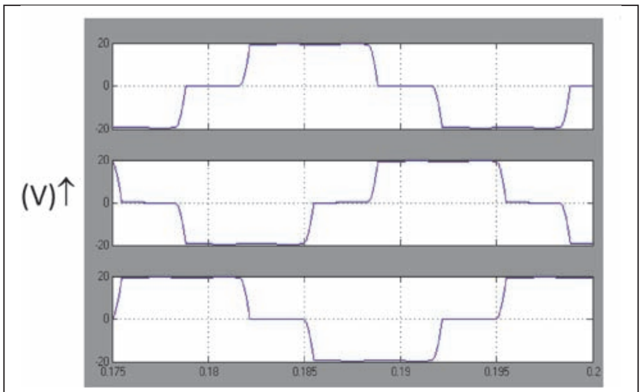

FIG. 9. SOURCE CURRENTS WHEN THE COMPENSATOR IS NOT CONNECTED.

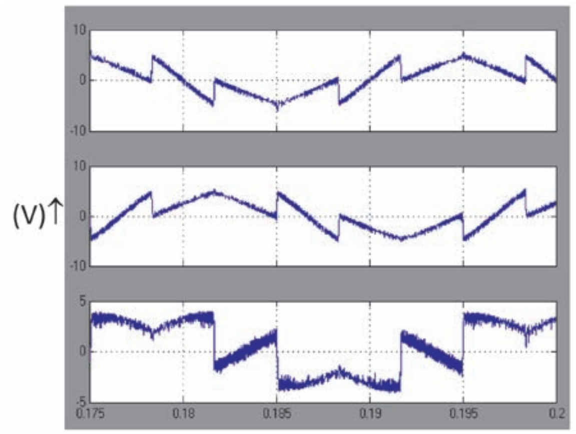

FIG. 10 COMPENSATING CURRENT OF FUZZY CONTROLLER.

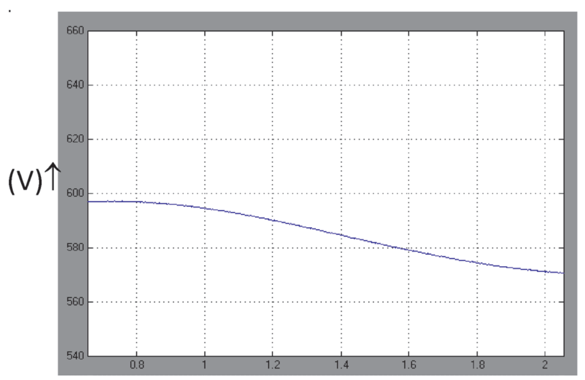

FIG. 11 DC CAPACITOR VOLTAGE DURING SWITCH-ON RESPONSE WITH FUZZY CONTROLLER.

Figure 8 and figure 9 shows the source voltage and source current when the compensator is not connected. The source current is distorted when the compensator is not connected. When the controller is connected a compensationg current is injected into the system which is shown in Figure 10. The DC capacitor voltage remains constant around 580 V. The distortions are removed at the source side which is shown by Figure 12. After compensation the voltage and current are in phase shown in Figure 13.

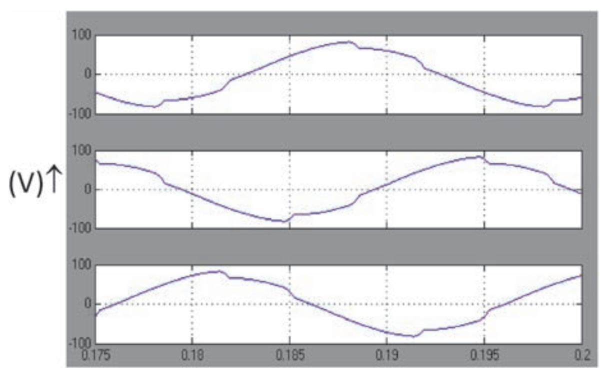

FIG. 12 SOURCE CURRENT FUZZY CONTROLLER.

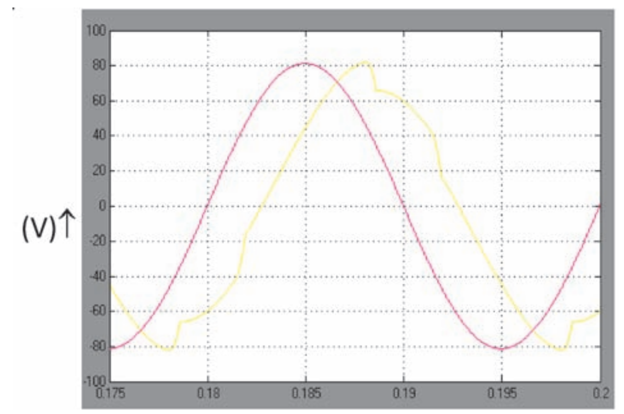

FIG. 13 VOLTAGE AND CURRENT IN PHASE WITH FUZZY CONTROLLER AFTER COMPENSATION.

The Total Harmonic distortion (THD) without compensator is 27.9%. The standard value given by IEEE is under 5%. When the compensator is connected the value of THD is 2.9%. Hence the power quality is seen to improve and the harmonics are eliminated.

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