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Shunt Active Power Filter for Harmonic Mitigation by using Fuzzy Logic Controller

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Abstract— **Active filters are widely used in power system for reactive power compensation and voltage / current harmonic elimination. Harmonic contents of the source current has been calculated and compared for the different cases to demonstrate the influence of harmonic extraction circuit on the harmonic compensation characteristic of the shunt active power filter. In this paper, a fuzzy logic controlled, three-phase shunt active filter is used to improve power quality by compensating current harmonics which is required by a nonlinear load. The merit of fuzzy control is that it is based on defined linguistic rules and does not require any mathematical model of the system unlike the other traditional controller. Hence, this paper proposed a control approach and analyzed by simulations.**

Index Terms— **Active power filter, Fuzzy logic controller (FLC), Harmonic distortion.**

I. Introduction

Now a day's power electronic based equipments are used in industrial and domestic purpose which have significant impacts on the quality of supplied voltage and have increased the harmonic current distortion on distribution systems. They have many negative effects on power system equipment and point of common coupling, such as additional losses in underground cables, transformers and electric machines, operation of the protection systems, over voltage and shunt capacitor, error of measuring instruments, unbalanced supply voltages, excessive neutral current, poor power factor, increased losses and reduced overall efficiency [6] and efficiency of customer sensitive loads.

To reduce power quality problems the active line conditioning systems is an important key, which suppress the power system disturbances. Series active filters are used to solve voltage distortions and related issues. Shunt active filters are able to compensate voltage distortions and compensating for current issues. However, due to complexity of series active compensators comparing with commercially available shunt active filters [1].

Harmonic distortion (HD) is one of the main power quality problems which are caused by the non-linear based loads. The presences of harmonics increase the transformer heating, electromagnetic disturbances and solid state device malfunction. Hence, it is necessary to reduce the dominant harmonics below 5% as Specified in IEEE 519-1992 harmonic standard [2].

Recently, Active Power Filters (APF) or Active

Power-Line Conditioners (APLC) is developed for compensating harmonics and reactive power simultaneously. The active power filter topology can be connected in series for voltage harmonic compensation and in parallel for current harmonic compensation. Mostly need current harmonic compensation, so the shunt active filter is used than series active filter. The shunt active power filter has the ability to keep the mains current balanced and sinusoidal after Compensation regardless of whether the load is non-linear and balanced or unbalanced [4].

Recently, FLCs have generated a good deal of interest in certain applications. The advantages or FLCs over conventional controllers are that they do not need an accurate mathematical model, they can work with linguistics inputs; can handle lion-linearity, and they are more robust than conventional nonlinear controllers [8].

FLC schemes that is suitable for extracting the fundamental component of the load current(s) and simultaneously controlling dc capacitor voltage of the shunt APLC [3].

II. BASIC COMPENSATION PRINCIPLE

Fig 1 shows the proposed SAPF with nonlinear load and controller. The system consists of active filter in shunt [7]. The SAPF consist of six power transistors six power diodes, a dc capacitor and three filters resistor-inductor. The power converter is a voltage source PWM inverter consists with equal series resistances Rc and inductances Lc for each phase. The capacitor C is use as an energy storage capacity. Reduction of current harmonics is achieved by injecting equal but opposite current harmonic components at the point of common coupling (PCC), this facilitates improving the power quality on the connected power system.

A. Current supplied by source

The instantaneous current,

$$Is(t) = i_L(t) - i_c(t) \quad (1)$$

Source voltage,

$$Vs = V_m \sin \omega t \quad (2)$$

Current harmonic components, can be represented as

$$I_L(t) = \sum_{n=1}^{x} I_n \sin(n\omega t + \varphi_n)$$

$$= I_1 \sin(\omega t + \varphi_1) + [\sum_{n=2}^{\infty} I_n \sin(n\omega t + \varphi_n) \quad (3)$$

Instantaneous load power,

$$P_L(t) = i_s(t) * V_s(t)$$

$= Vm \sin^2 \omega t * \cos \varphi_1 + V_m I_1 \sin \omega t * \cos \omega t * \sin \varphi_1 + V_m \sin \omega t * [\sum_{n=2}^{\infty} I_n \sin (n\omega t + \varphi_n)]$

$= P_f (t) + P_r (t) + P_h (t)$ (4)

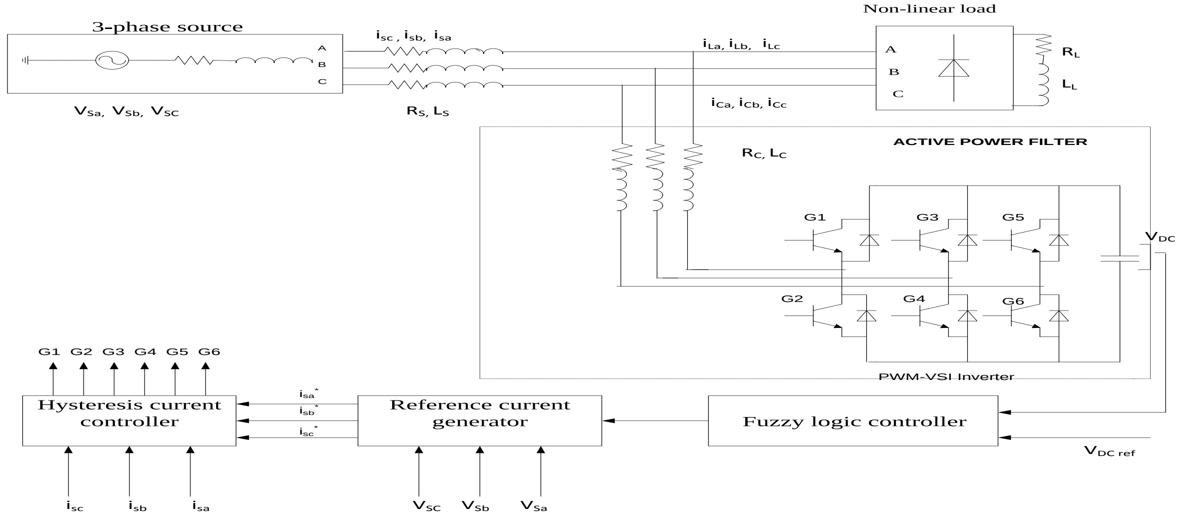

Fig1. Block diagram of Shunt Active Power Filter with proposed FLC

From the equation the fundamental power drawn by the load is

$$P_f (t) = V_m I_1 \sin^2 \omega t * \cos\varphi_1 = v_s (t) * i_s (t) \quad (5)$$

From this equation the source current this supplied,

$$I_s (t) = p_f (t)/v_s (t) = I_1 \mathrm{COS}\varphi_1 \sin \omega t = I_{sm} \sin \omega t \quad (6)$$

Where,

$$I_{sm} = I_1 \mathrm{COS}\varphi_1 \quad (7)$$

The total peak current is

$$I_{sp} = I_{sm} + I_{sl} \quad (8)$$

If the active filter provides harmonic power, then is(t) will be in phase with the voltage and purely sinusoidal. At this time, the filter must provide the following compensation current:

$$I_c (t) = i_L (t) - i_s (t) \quad (9)$$

A. *Estimation of reference source current*

The desired source currents, after compensation is,

$$I_{sa}* = I_{sp} \sin \omega t \quad (10)$$

$$I_{sb}* = I_{sp} \sin (\omega t+120^0) \quad (11)$$

$$I_{sc}* = I_{sp} \sin (\omega t-120^0) \quad (12)$$

Where $I_{sp} = I_{sm} + I_{sl}$ *is* the amplitude of the source current.

B. *Role of DC side capacitor*

The active filter produces a fundamental voltage which is in-phase with fundamental leading current of the passive filter. A small amount of APF is consisting due to the leading current and fundamental voltage of the passive filter and it delivers to the dc capacitor. Therefore, the electrical quantity adjusted by the dc-voltage controller is consequently. To maintain Vdc equal to its reference value, the losses through filter's resistive-inductive branches will be compensated by acting on the supply current.

C. *Design of DC side capacitor* (C_{dc})

Mainly, selection of active power filter inductor (LC), DC link capacitor (C_{dc}) and it is reference value ($V_{dc,ref}$) are the main parameters while designing the power circuit. The output of the bridge is a PWM voltage that has to be filtered by an inductance to limit the level of ripple current. The APF filtering inductor is used to reduce the ripple of VSI fed converter caused by the switching of the power devices. Hence, the design of filtering inductor is based on principle of harmonic current reduction technique. On the dc side of the Shunt APF, capacitor supplies the dc voltage V_{dc}. The quality of distortion compensation is affected by the choice of the energy storage element parameters, a high dc voltage V_{dc}, ameliorate the dynamics of the filter and minimize the voltage ripple in the capacitor. As per the specification of peak of dc ripple voltage and rated filter current $I_{c,\ rated,}$ the following relation can obtain for (C_{dc}):

$$C_{dc} = \frac{\pi . I_{c,rated}}{\sqrt{3}.\omega . V_{dcr,p-p}} \quad (13)$$

The value of C_{dc} depends on the maximum possible variation in load and not on the steady state value of load current. Hence, proper forecasting in the load variation reduces the value of C_{dc}. Further, filter inductor can be calculated as:

$$L_{c,min} = \frac{m_a V_{dc,ref}}{(2\sqrt{2}) . \Delta I_{SW,P-P} . K_L . f_{sw,max}} \quad (14)$$

D. *Hysteresis current controller (HCC)*

HCC is utilized independently for each phase and directly generates the switching signals for three-phase voltage source inverter. An error signal *e*(t) is the difference between the desired current i_{ref} (t) and the actual current i_{actual}(t). If the error current exceeds the upper limit of the hysteresis controller, the upper switch of the inverter arm is turned OFF and the lower switch is turned ON [4]. If the error current flow through the lower limit of the hysteresis controller, the lower switch of the inverter arm is turned OFF and the upper switch is turned ON. Than result, the current gets back into the hysteresis controller. The switching performance as follows

$$S= \begin{cases} 0 & if\ i_{actual}(t) > i_{ref}(t) + h \\ 1 & if\ i_{actual}(t) < i_{ref}(t) - h \end{cases}$$

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III. FUZZY LOGIC CONTROLLER

Fuzzy logic control is deduced from fuzzy set theory in 1965; where transition is between membership and non membership function. Hence, limitation of fuzzy sets can be undefined and ambiguous; FLC's are an excellent choice when precise mathematical formula calculations are impossible. Fig2 shows block diagram of the fuzzy logic control technique. For implementing the control algorithm of a shunt active power filter in a closed loop and sensed the dc capacitor voltage, then compared with the desired reference value $V_{DC,ref}$. The error signal $e = V_{DC,ref} - V_{DC}$ is passed through Butterworth design based LPF with a cut off frequency of 50 Hz; that pass only the fundamental component. The error signal $e(n)$ and integration of error signal is termed as ce(n) are used as inputs for fuzzy processing [4]. The output of the FLC limits the magnitude of peak reference current I_{max}. This current takes care of the active power demand of the non-linear load and losses in the distribution system. The switching signals for the PWM inverter are generated by comparing the actual source currents (i_{sa}, i_{sb}, i_{sc}) with the reference current $(i_{sa}^*, i_{sb}^*, i_{sc}^*)$ using the HCC method.

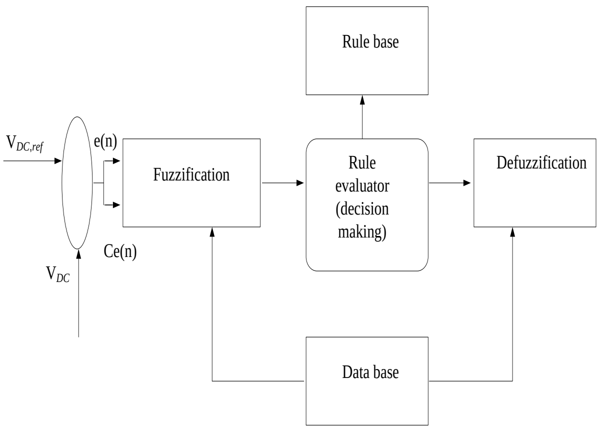

Fig2. Fuzzy Logic Controller

A. *Fuzzification:*

Fuzzy logic uses linguistic variables instead of numerical variables. In a control system, error between reference signal and output signal can be assigned as Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (ZE), Positive small (PS), Positive Medium (PM), Positive Big (PB) [5]. The triangular membership function is used for fuzzifications. The process of fuzzification converts numerical variable (real number) to a linguistic variable (fuzzy number).

B. *Rule Elevator:*

FLC uses linguistic variables instead of the numerical values. The basic FLC operation uses the following fuzzy set rules to control the system

AND -Intersection: $\mu_{A \cap B} = \min[\mu_A(X), \mu_B(x)]$

OR -Union: $\mu_{A \cup B} = \max[\mu_A(X), \mu_B(x)]$

NOT -Complement: $\mu_{\bar{A}} = 1 - \mu_A(x)$

C. *Defuzzification:*

The rules of FLC generate required output in a linguistic variable, according requirements; linguistic variables have to be transformed to crisp output. This selection of strategy is a compromise between accuracy and computational intensity.

D. *Database:*

The Database keeps the definition of the triangular membership function which required by fuzzifier and defuzzifier.

E. *Rule Base:*

The Rule base stores the linguistic control rules required by rule evaluator (decision making logic). The rules used in this proposed controller are shown in table 1.

Table1. Fuzzy control rule

e(n)/ ce(n)	**NB**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	MN	NS	ZE	PS	PM
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

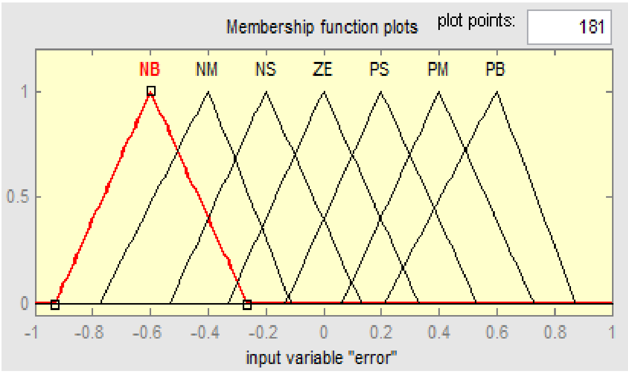

Fig3. Triangular membership function for input variable 'error'

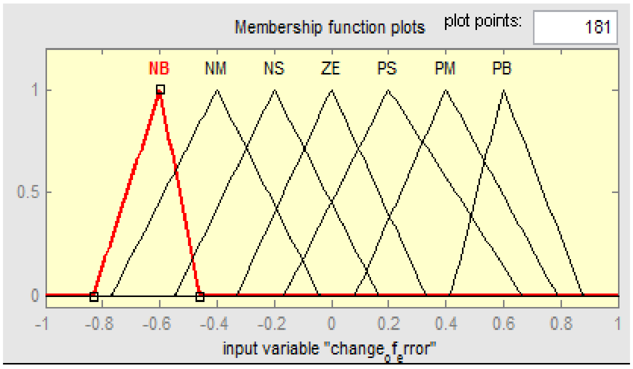

Fig4. Triangular membership function for input variable 'change of error'

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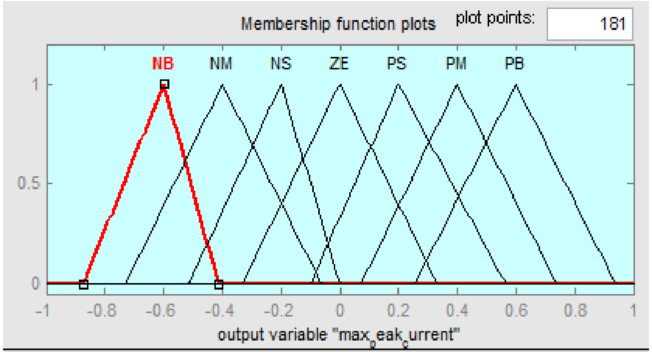

Fig5. Triangular membership function for output variable 'maximum current'

IV. SIMULATION AND RESULTS

The performance of the proposed fuzzy logic control strategy is evaluated through simulation using Matlab/Simulink power tools. Power devices used are IGBTs with diodes.

System parameters	**Values**
Source voltage, frequency	120V, 50 Hz
Source impedance (R_s, L_s)	0.1Ω, 0.15mH
Filter impedance (R_c, L_c)	0.3Ω, 3.3mH
Load impedance (R_l, L_l)	6.5Ω, 18mH
Reference DC link voltage ($V_{dc,ref}$)	200V
DC link capacitance (C_{dc})	1900μF
Switching frequency (f_s)	10-12 KHz

FLC based APF system simulation results are verified and presented; the source voltage before compensation is presented in Fig7 which shows the voltage is sinusoidal. The source current before compensation is shown in Fig8.

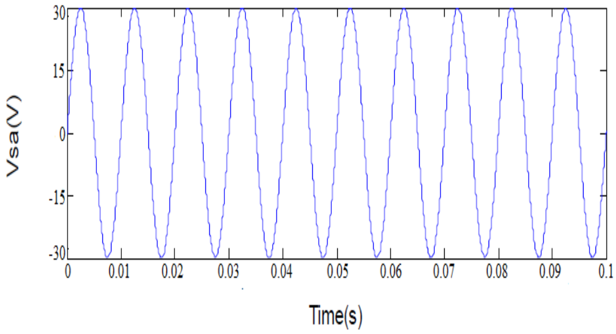

Fig6. Source voltage before compensation

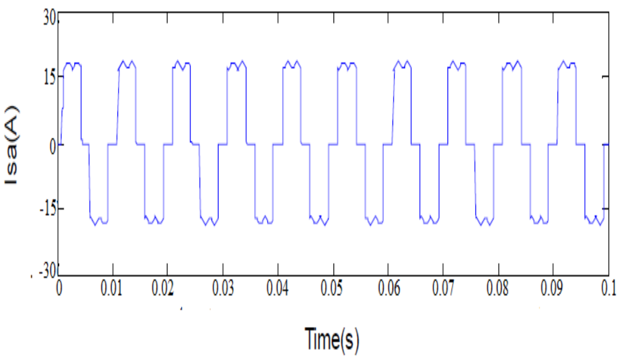

Fig7. Source current before compensation

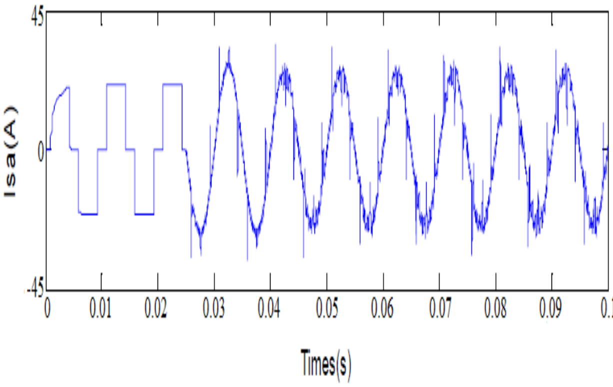

Fig8. Source current after compensation

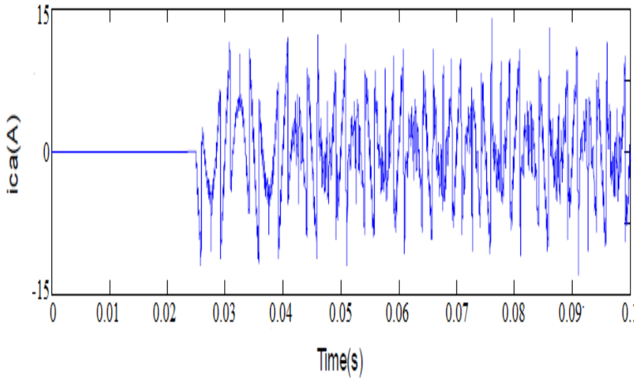

Fig9. Filtering current of FLC

By using fuzzy logic controller, total harmonic distortion (THD) reduces from 28.61% to 3.85%. Which are shows in fig10 and fig11.

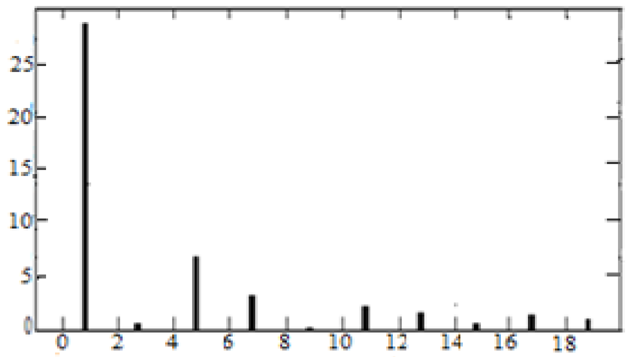

Fig10. FLC based APF; Order of harmonics,
The source current without active filter (THD=28.61%),

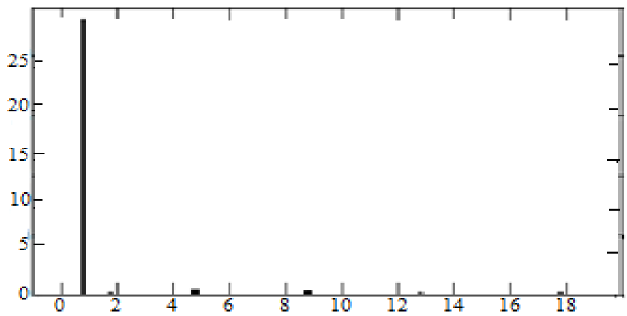

Fig11. FLC based APF; Order of harmonics,
The source current with active power filter (THD=3.85%)

V. CONCLUSION

The shunt APF is implemented with three-phase supply controlled with voltage source inverter and is connected at the point of common coupling for filtering the current harmonics. The VSI switching signals are derived from hysteresis band current controller. The hysteresis controller changes the bandwidth based on instantaneous compensation current variation. The proposed controller based shunt active power filter performs perfectly for mitigate the harmonics and FLC is better than other controllers.

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