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MATLAB-Simulink Model Based Shunt Active Power Filter Using Fuzzy Logic Controller to Minimize the Harmonics

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Abstract- The problem of quality electrical energy provided to the users has arisen. This is due to the increasing presence in network of nonlinear loads.They constitute a harmonic pollution source of the network, which generate many disturbances, and disturb the optimal operation of electrical equipments. This work, proposed a solution to eliminate the harmonics introduced by the nonlinear loads. It presents the analysis and simulation using Matlab Simulink of a active power filter (APF) compensating the harmonics and reactive power created by nonlinear loads in steady and in transients. The usefulness of the simulation approach to APF is demonstrated , have a better power quality insight using Matlab Simulink in order to develop new fuzzy logic controller based active power filter.

Index Terms- Active Power Filters, Harmonics, Fuzzy Logic Controller, MATLAB

I. Introduction

Modern electrical systems, due to wide spread of power conversion units and power electronics equipments, causes an increasing harmonics disturbance in the ac mains currents[1].Power Quality (PQ) is an important measure of an electrical power system. The term PQ means to maintain purely sinusoidal current wave form in phase with a purely sinusoidal voltage wave form[2].

The power generated at the generating station is purely sinusoidal in nature. The deteriorating quality of electric power is mainly because of current and voltage harmonics created by the power electronics based equipments such as adjustable-speed drives, electronic power supplies, battery chargers, electronic ballasts etc[3]. These nonlinear loads absorb non-sinusoidal currents and consume reactive power. Harmonic currents produced by non linear loads are injected back into power distribution systems through the point of common coupling[4]. The controller is the main part of the active power filter operation and has been a subject of many researches in recent years[5][6]. Conventional PI voltage and current controllers have been used to control the harmonic current and dc voltage by the shunt APF[7]. However, the conventional PI controller requires precise linear mathematical model of the system, which is difficult to obtain under parameter variations, nonlinearity, and load disturbances . Recently fuzzy logic controllers have generated a great interest in many applications. The advantages of fuzzy logic controllers are: robustness, no need to accurate mathematical model, can work with imprecise inputs, and can handle non-linearity[8].

This paper presents fuzzy logic control schemes for harmonic current and inverter dc voltage control to improve the performance of the shunt APF. The performance of fuzzy controller is evaluated through computer simulations under steady-state conditions. The obtained results showed that, the proposed active power filter controller have provided a sinusoidal supply current with low harmonic distortion and in phase with the line voltage.The fuzzy logic controller algorithm developed and implemented.

II. Fuzzy Logic Controller

Over the past few decades, the use of fuzzy set theory, or fuzzy logic, in control systems has gained widespread popularity, especially in Japan. In 1970s, Japanese scientists have been instrumental in transforming the theory of fuzzy logic into a technological realization[9]. Today, fuzzy logic-based control systems, or simply fuzzy logic controllers (FLCs), can be found in a growing number of products, from washing machines ,speedboats, air conditioner, handheld auto focus cameras etc. The inference engine is the heart of a fuzzy controller and fuzzy rules operation[10]. Its actual operation divided in three steps as shown in fig 1.

i) Fuzzification – actual inputs are fuzzified and fuzzy inputs are obtained.
ii) Fuzzy processing – processing fuzzy inputs according to the rules set and producing fuzzy outputs.
iii) Defuzzification – producing a crisp real value for a fuzzy output.

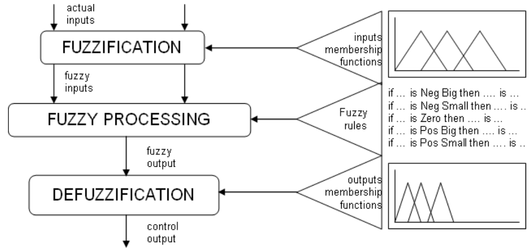

Fig.1 Operation of a Fuzzy Controller

III. Active Power Filter

The block diagram of shunt active power filter shown in fig 2. It is controlled to draw or supply a compensating current i_c from or to the utility, so that it cancels current harmonics on the ac side. In this manner a shunt active power filter can be used to eliminate current harmonics and reactive power compensation[11].

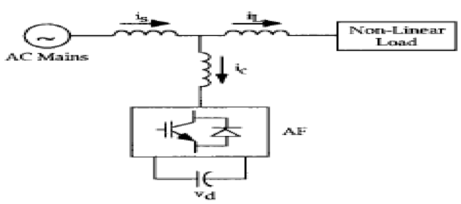

Figure 2 Block diagram of Basic Active Power Filter

From figure 2 the instantaneous currents can be written as ;

$$i_s(t) = i_L(t) - i_c(t) \quad ……………………..(1)$$

The source voltage is given by

$$v_s(t) = V_m \sin \omega t \quad ……………………..(2)$$

if a nonlinear load is applied, then the load current will have a fundamental component, and the harmonic components can be represented as;

$$i_L(t) = \sum_{n=1}^{\infty} I_n \sin(n\omega t + \phi_n) \quad ……………(3)$$

$$i_L(t) = I_1 \sin(\omega t + \phi_1) + \sum_{n=2}^{\infty} I_n \sin(n\omega t + \phi_n) \quad …(4)$$

Instantaneous load power can be given as

$$p_L(t) = v_s(t) * i_L(t) \quad …………..(5)$$

$$p_L(t) = V_m I_1 \sin^2 \omega t * \cos \phi_1 + V_m I_1 \sin \omega t * \cos \omega t * \sin \phi_1 + V_m \sin \omega t * \sum_{n=2}^{\infty} I_n \sin(n\omega t + \phi_n)$$

$$p_L(t) = p_f(t) + p_r(t) + p_h(t) \quad ………………….(6)$$

From equation (4) real (Fundamental) power is drawn by the load

$$p_f(t) = V_m I_1 \sin^2 \omega t * \cos \phi_1 = v_s(t) * i_s(t) \quad ……(7)$$

From equation (7) the source current supplied by the source, after compensation

$$i_s(t) = \frac{p_f(t)}{v_s(t)} = I_1 \cos \phi_1 \sin \omega t = I_{sm} \sin \omega t \quad …..(8)$$

Also there are some switching losses in the PWM converter. Hence, the utility must supply a small overhead for the capacitor leaking and converter switching losses in addition to the real power of the load.

Hence, total peak current supplied by the source

$$I_{sp} = I_{sm} + I_{sL} \quad ………..(9)$$

If the active filter provides the total reactive and harmonic power then i_s (t) will be in phase with the utility voltage and pure sinusoidal. The active filter must provide the following compensation current as shown in equation(10).

$$i_c(t) = i_L(t) - i_s(t) \quad ……….(10)$$

It is necessary to calculate $i_s(t)$, the fundamental component of load current, as the reference current for the accurate and instantaneous compensation of reactive and harmonic power.

A. Estimation of Reference Source Current

The peak value of the reference current I_{sp} can be estimated by controlling the dc side capacitor voltage. The ideal compensation requires the main current to be sinusoidal and in phase with the source voltage irrespective of the load current nature. The reference source currents after compensation can be given as

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

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

$$i_{cb}^* = I_{sp} \sin(\omega t + 120^o),$$

Where $I_{sp} = I_1 \cos \phi_1 + I_{sL}$ is the amplitude of the reference source current, while the phase angles can be obtained from the source voltages. Hence, the waveform and phases of the source currents are known only the magnitude of the source currents needs to be determined.

The peak value of the reference current has been estimated by regulating the dc side capacitor voltage of the PWM converter. This capacitor voltage is compared by a reference value and the error is processed in a PI controller. The output of the PI controller has been considered as amplitude of the reference source current, and this is estimated by multiplying peak value with the unit sine vectors in phase with the source voltage.

B. Role of Dc Filter

The dc side capacitor serves two main purposes (1) it maintains a steady state ripple free dc voltage and (2) it serves as an energy storage element to supply the real power difference between load and source during the transient period. In the steady state the real power supplied by the source should be equal to the real power demand of the load add a small power to compensate for the losses in the active filter. Thus dc capacitor voltage can be maintained at a reference value.

However, when the load condition changes, the real power balance between the source and the load will be disturbed. This real power difference is to be compensated for by the dc capacitor. This changes the dc capacitor voltage away from the reference voltage. In order to keep the satisfactory operation of the active filter, the peak value of the reference current must be match with the real power drawn from the source. The charging or discharging of the capacitor compensates the real power consumed by the load. If the dc capacitor voltage is recovered and attains the reference voltage, the real power supplied by the source is equal to the load power.

The real reactive power injection may result in the ripple voltage of the dc capacitor. A low pass filter is generally used to filter these ripples which introduce a finite delay[11]. To avoid the use of this low pass filter the capacitor voltage is sampled at the zero crossing of the source voltage. A continuously changing reference current makes the compensation non instantaneous during transient. Hence this voltage is sampled at the zero crossing of any phase voltage. This makes the compensation instantaneous. Sampling only twice in a cycle as compared to six times in a cycle[12] give a little higher dc capacitor voltage rise or drip during transients, but the settling time is less.

In order to form the equation set, fundamental component is given reference output value and all other harmonics are equated to zero. In present simulation model, switching angles are evaluating for the 5^{th}, 7^{th} and 11^{th} harmonics[13].

The equation (11) derived for total harmonic distortation of the output voltage and current of an inverter is used in order to reduce the harmonics.

$$\%THD = \left[\frac{1}{a^2_1} \sum_{n=5}^{\infty} (a^2{}_n \right] \times 100 \quad \text{.........(11)}$$

Where n = 6i ± 1(i = 1, 2, 3….)

IV. MATLAB SIMULINK MODEL

The proposed algorithm has been simulated using MATLAB and its tools Sim Power System and Simulink. Simulation model for obtaining the three phase source voltage are to be balanced and sinusoidal. A load with highly nonlinear characteristics is considered for the load compensation.

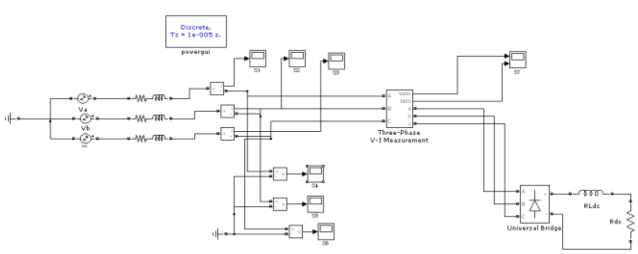

Fig.3 Three phase supply with nonlinear loads

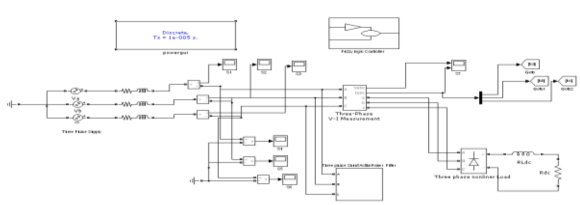

fig.4 Model of nonlinear loads and shunt active power filter Using fuzzy logic controller

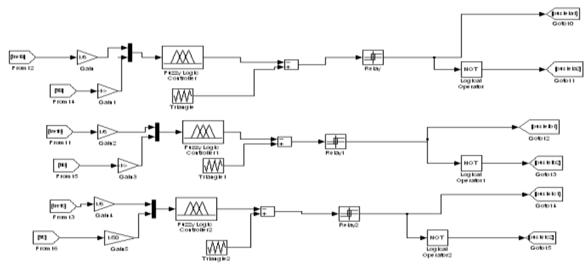

Fig.5 MATLAB Simulink model of fuzzy logic controller

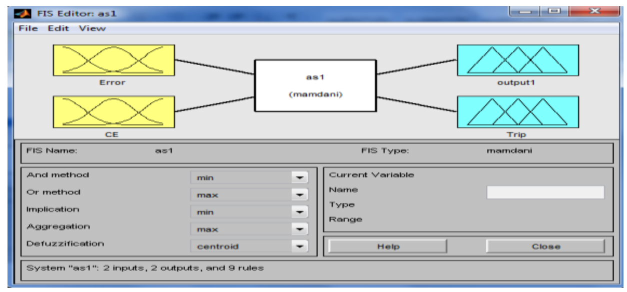

fig. 6 the membership function of input and output

V. SIMULATION RESULTS

The whole system is simulated in MATLAB. The system parameters selected for the simulation studies are given in TABLE 1. The three-phase source voltages are assumed to be balanced and sinusoidal. A load with highly nonlinear characteristics is considered for the load compensation[14].

At the first stage, all IGBT devices are turned off so the DC-link is charged by the parallel diode, which is equivalent to three-phase bridge rectifier and then the second transient stage, the fuzzy controller is plunged into to control the DC link voltage to a rated value gradually without overshoot[15]. Case 1: with nonlinear load and Case 2: with fuzzy logic controller

Table1. System Parameter

System parameter	values
Supply voltage	230v
Frequency	50Hz
Source impedance	0.05Ω, 0.5mH
Filter inductance	1.25mH
Filter capacitance	21e-5F
DC Voltage	400v

Fig 7,9. shows the source voltage and current curves before and after the APF is plunged into.

Fig 8,10. shows the THD of the nonlinear load before and after the APF is plunged into. It can be seen that APF with fuzzy logic controller can compensate the harmonics, which makes the source current sinusoidal.

In table 2 the rules of fuzzy logic controller are described which is used in fuzzy opration.

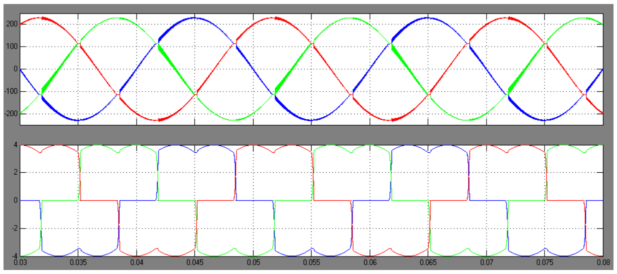

Fig. 7 Three phase voltage and current waveform with non linear load

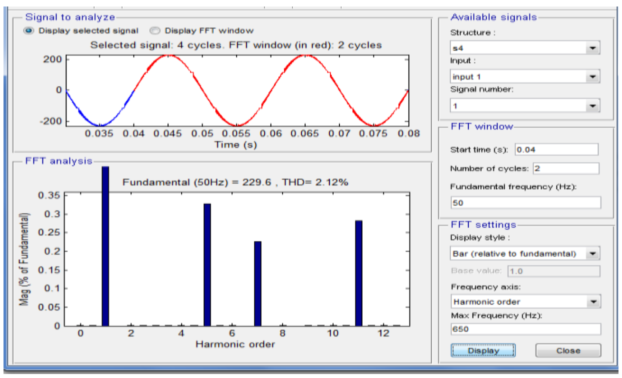

Fig.8 THD analysis of three phase voltage waveform with nonlinear load

Table2.Rules of fuzzy logic controller

Rule no.	INPUT	OUTPUT
1	(Error==NB) &(CE==NB)	(output1=NB)(Trip=Right)(1)
2	(Error==NB) &(CE==CZ)	(output1=NB)(Trip=Right)(1)
3	(Error==NB) &(CE==PB)	(output1=CZ)(Trip=Wrong)(1)
4	(Error==CZ) &(CE==NB)	(output1=NB)(Trip=Right)(1)
5	(Error==CZ) &(CE==CZ)	(output1=CZ)(Trip=Wrong)(1)
6	(Error==CZ) &(CE==PB)	(output1=PB)(Trip=Right)(1)
7	(Error==PB) &(CE==NB)	(output1=CZ)(Trip=Wrong)(1)
8	(Error==PB) &(CE==CZ)	(output1=PB)(Trip=Right)(1)
10	(Error==PB) &(CE==PB)	(output1=PB)(Trip=Right)(1)

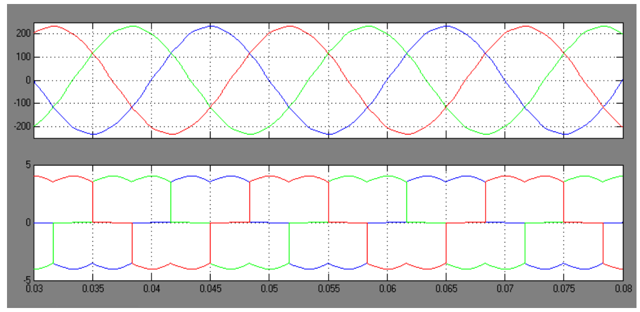

Fig.9 Three phase voltages and current waveform with shunt active power filter with connected fuzzy logic controller

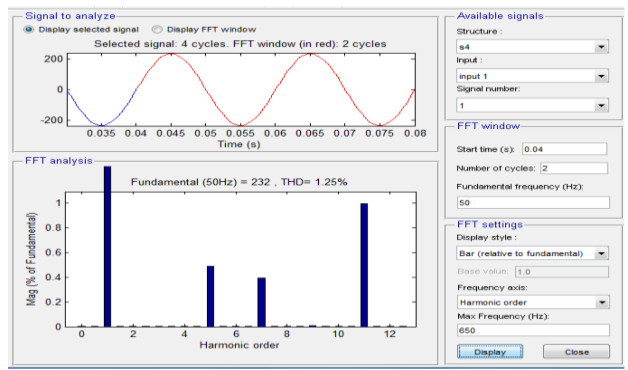

Fig.10 THD analysis of voltages with shunt active power filter using fuzzy logic controller

In Table 3 ,The Total Harmonics Distortion of non linear load before using Shunt APF is about to 2.12 but after using shunt APF with fuzzy logic is about to 1.25.

Table3. Simulation Result

	%THD
Before compensation	2.12
After compensation	1.25

VI. CONCLUSION

The paper presents the application of the fuzzy logic controller to control the compensating voltage. The Mamdani max-min approach is used for the fuzzy inference and the defuzzification method, respectively. The design of input and output membership for the fuzzy logic controller is very important for the system performance. The simulation results show that the fuzzy logic controller provides a good performance to control the compensating voltage of shunt active power filter. The %THD of the voltages at PCC point can be followed the IEEE Std. 519-1992.

REFERENCES

[1] I. J. Pitel, S. N. Talukdar, and P. Wood, "*Characterization of Programmed-Waveform Pulse-Width Modulation*," IEEE Transactions on Industry Applications, Vol. IA-16, Sept./Oct. 1980, pp. 707–715.

[2] Wilson E. Kazibwe and Mucoke H. Senduala : "*Electric Power Quality Control Techniques".* New York: Van Nostrand Reinhold, 1993

[3] N. Mohan, "A Novel Approach to Minimize Line- Current Harmonics in Interfacing Power Electronics Equipment with 3-Phase Utility Systems", IEEE Trans on Power Delivery, Vol. 8, July. 1993, pp 1395-1401.

[4] Elias M. Stein, Timonthy S. Murphy : "*Harmonic Analysis: Real-Variable Methods, Orthogonality and Oscillatory Integrals*.", Princeton, N.J.: Princeton University Press, 1993

[5] J.S. Lai and T.S. Key, "*Effectiveness of harmonic mitigation equipment for commercial office buildings,*" IEEE Transactions on Industry Applications, vol.33, no.4, sep 1997, pp. 1065-1110

[6] S. Hansen, P. Nielsen and F. Blaabjerg, "*Harmonic cancellation by mixing nonlinear single-phase and three-phase loads*,"IEETransactions on Industry Applications, vol. 36, no.1, 2000, pp. 152-159,

[7] B. Acarkan, S. Zorlu and o. Kilis, "*Nonlinear resistance modeling using matlab and simulink in estimation of city street lighting harmonic activity,"* IEEE EUROCON ,The International Conference on Computer as a Tool, vol. 2, Nov. 2005, pp. 1251-1254,

[8] A. Dell'Aquila, G. Delvino, M. Liserre, P. Zanchetta, "*A new fuzzy logic strategy for active power filter*," in: Proc. Eighth Int. Conf. on Power Electronics and Variable Speed Drives, September 2000, pp. 392–397 (IEEConf. Publ. No. 475).

[9] S. Fan, Y.Wang, "*Fuzzy model predictive control for active power filter,"* in:Proc. IEEE Int. Conf. on Electric Utility Deregulation, Restructuring and Power Technologies (DRPT 2004), vol. 1, April 2004, pp. 295–300.

[10] S.K. Jain, P. Agrawal, H.O. Gupta, "*Fuzzy logic controlled shunt active power filter for power quality improvement,"* IEE Proc. Electr. Power Appl.149 (September (5)) (2002) , pp317–328.

[11] S.-J. Huang, J.-C. Wu, "A control algorithm for three-phase three wired active power filter under non-ideal mains voltages", IEEE Trans. Power Electr. Vol.14 no.4, JULY 1999 ,PP 753–760.

[12] B.N.Singh,A.Chandra,A1-Haddad, "*Performance comparision of two control techniques applied to an active filter*,"8TH international conference on Harmonics and Power Quality,October 1998.pp.133-138

[13] D. Chen, S. Xie, "*Review of the control strategies applied to active power filters"*, in: Proc. IEEE Int. Conf. on Electric Utility Deregulation, Restructuring and Power Technologies (DRPT-2004), Hong Kong, April, 2004, pp. 666–670.

[14] A.M. Massoud, S.J. Finney, B.W.Williams, "*Practical issues of three-phase, three-wire, voltage source inverter-based shunt active power filters,"* in: Proc.11th Int. Conf. on Harmonics and Quality of Power, 2004, pp. 436–441.

[15] B. Singh, A. Chandra, K. Al-Haddad, "*Computer aided modeling and simulationof active power filters*," Electr. Mach. Power Syst. 27 (11)1999 pp. 1227–1241.

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