Application of Fuzzy Logic Controller in Shunt Active Power Filter

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Abstract

This paper presents application of fuzzy logic controller for shunt active power filter to improve power quality in the distribution systems. The main feature of fuzzy logic controller does not require any complex mathematical model of the systems to regulate dc bus capacitor voltage. The reference compensating current has been estimated by unit vector template generation technique. The actual compensating current of the active power filter tracks the reference current by conventional hysteresis band current control scheme. The performance of fuzzy logic controller has been compared with conventional PI controller. The transient response of proposed fuzzy controller is found to be better than conventional PI controller. The simulation study has been performed on MATLAB simulink.

Keywords: Active power filter (APF), Power quality, point of common coupling (PCC), Total Harmonics distortion (THD)

I. INTRODUCTION

Extensive use of power electronics equipment like rectifiers, variable speed drives have caused an increase of harmonic disturbances in power systems. Harmonic causes many problems like low power factor, excessive neutral current, transformer overheating, capacitor blowing, motor vibration etc. To enhance power quality, harmonics need to be eliminated. The active power filter can solve problem of harmonic elimination and satisfies the reactive power demand of nonlinear load.

For low voltage level most compensator for APF use a standard two level voltage source inverter. It can improve power quality by harmonic elimination and raising load power factor. The shunt active power filter injects compensating current in the grid and source current becomes sinusoidal. Literature suggests various compensating current calculation techniques. The most popular techniques are instantaneous P-Q theory [1], unit vector template generation technique (UVTG) [2] and d-q reference frame theory [3]. All the techniques are effective for harmonics elimination and reactive power compensation. The UVTG technique does not require complex Clarke or Park’s transformation to estimate compensating current of the filter.

As the load harmonics may be complex, change rapidly and randomly, APF has to respond quickly with high control accuracy in current tracking. The inverter tracks the reference compensating current by hysteresis current control method. The hysteresis current control technique offers several advantages like, appropriate stability, fast transient response, simple implementation and operation, high accuracy, inherent current peak limitation, overload rejection, compensation of effects due to load parameters changes and semiconductor voltage drops of the inverters [4], [5].

Literature suggests the dc bus capacitor voltage regulation by conventional PI controller. For optimum performance of the APF, selection of proportional and integral gain of the controller is very important, which further requires complex mathematical model of the system [6]. The performance of the conventional PI controller is influenced by load variation, losses in the static switches etc. The fuzzy logic controller does not require accurate mathematical model of the system. They are more robust and easy to implement using low cost microcontroller.

II. SYSTEM CONFIGURATION AND CONTROL SCHEME

A three phase ac supply is feeding power to a three phase diode bridge rectifier connected to a resistive- inductive load. Due to nonlinear load, it draws harmonics and reactive power from the source. Hence source current becomes non sinusoidal and power factor becomes poor. The shunt APF is a device, which fulfills harmonics and reactive power demand of the load by injecting compensating currents at the point of common coupling (PCC). Thus total current drawn from the AC mains becomes sinusoidal and in phase with supply voltage. The basic structure of shunt APF as shown in Fig. 1 is having a standard three phase IGBT based voltage source inverter, dc bus capacitor and input ac inductor. Hysteresis current control PWM scheme is used to generate gating signal for IGBTs.
III. UNIT VECTOR TEMPLATE GENERATION TECHNIQUE

To get unit vector template signal, the input source voltages are sensed and multiplied by gain equal to $1/V_m$ ($V_m$ is equal to peak amplitude of fundamental voltage).

$$\begin{bmatrix} U_a \\ U_b \\ U_c \end{bmatrix} = \frac{1}{V_m} \begin{bmatrix} V_m \sin \omega t \\ V_m \sin(\omega t - 120) \\ V_m \sin(\omega t - 240) \end{bmatrix}$$  \hspace{1cm} (1)

The peak value of reference current can be calculated by regulating the DC bus capacitor voltage of the inverter. The actual capacitor voltage is compared with reference value and error signal is processed in PI controller (eq.3) or fuzzy logic controller (fig-2).

$$e(t) = V_{ref} - V_{act}$$  \hspace{1cm} (2)

$$I_m^* = K_p e(t) + K_i \int e(t) dt$$  \hspace{1cm} (3)

Ideal compensation requires source current to be sinusoidal and in phase with its phase voltage. The estimated source current after compensation is given by,

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = I_m^* \begin{bmatrix} U_a \\ U_b \\ U_c \end{bmatrix}$$  \hspace{1cm} (4)

Reference compensating current required to be generated by APF is given as,
Fuzzy logic controller does not require complex mathematical model of the system. We need good understanding of the process to be controlled. The control action of the fuzzy controller depends upon the linguistic rules. For the closed loop control of active power filter is done by regulating dc bus capacitor voltage around their reference value. The actual capacitor voltage is measured and compared with reference value. The obtained error signal ‘e’ and change of error signal ‘ce’ are taken as input to the fuzzy logic controller. The output of the fuzzy controller is peak value of the reference source current \( I_{\text{max}} \), which satisfies the active power demand of the load and switching losses in the inverter itself.

The PWM gating signals are generated by comparing actual source currents with their reference value in the hysteresis band controller. The internal structure of the fuzzy controller is shown in the fig. 2. In the proposed scheme the numerical variables \( e \) and \( ce \), are converted into linguistic variables by choosing fuzzy sets: NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium), PB (Positive Big).

The proposed controller has been designed using seven fuzzy sets for inputs and output. Triangular membership function has been taken. Fuzzification is done by universe of discourse and defuzzification is done by centroid method. Fig. 3 shows membership functions for input ‘\( e \)’ and ‘\( ce \)’. Fig. 4 shows membership functions for output \( \delta I_{\text{max}} \). Different rules are formed which relates different conditions of error and change in error with output.
V. Result and Discussion

![Fig. 5: Performance of SAPF based on fuzzy logic controller.](image)

The proposed scheme has been simulated and tested by MATLAB Simulink power system toolbox. The load current is non-sinusoidal and rich in harmonics. The total harmonics distortion of the source current is 30.74 % as shown in fig. 6. The shunt APF supply the harmonics and reactive power demand of the load and supply current becomes almost sinusoidal and in phase with its supply voltage. Fig. 5 and 7 shows the source current after compensation and the harmonics spectrum of the source current. Fig. 7 shows the performance of the shunt APF. Harmonics in the source current is reduced from 30.74 % to 7.35 %.

Fig. 5 also indicates the transient and steady state response of fuzzy logic controller. The DC link voltage becomes stable within 2 cycles of the supply voltage. There is no peak overshoot in the dc link voltage, which is generally observed with conventional PI controller. There are reduced ripple during the steady state.

![Fig. 6: harmonics spectrum of load current](image)
VI. CONCLUSION

This paper compares the performance of fuzzy logic controller with conventional PI controller. Fuzzy logic controlled shunt active power filter is effective for harmonics and reactive power compensation. The transient response of fuzzy logic controller is better than PI controller. The result obtained in steady state, are comparable with PI controller. The effectiveness of APF is found effective to meet IEEE-519 standard recommendations on harmonics level.

REFERENCES