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Design of a Fuzzy Logic Controller Based STATCOM for IEEE9 Bus System

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ABSTRACT

In this paper, a fuzzy logic controller is designed for static synchronous compensator (STATCOM) to enhance interconnected power system stability. The power frequency model for STATCOM with conventional PI (Proportional Integral) controller is presented first. Fuzzy logic controller in then designed for main controller of the STATCOM. The main controller is used for regulating the AC bus voltage. The Static Synchronous Compensator (STATCOM) is performing a significant role in reactive power compensation and transient stability enhancement in modern power systems. This paper investigates the application of a rule based fuzzy logic control technique for controlling a STATCOM at steady and transient condition. This study demonstrates that fuzzy logic based STATCOM considerably improves the transient stability of power system during occurrence of fault. The control strategy is evaluated by simulation programs and the comparison indicates the fuzzy logic based STATCOM gives improved performance compared with PI STATCOM controller based technique.

Key words: STATCOM, Proportional Integral, Fuzzy Logic, IEEE 9 Bus System, Power System Stability

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INTRODUCTION

In recent years, various types of FACTS devices (UPFC, STATCOM, TCSC, SVC, etc.) have been studied for their use in the existing power systems with a view to improve the flexibility, controllability and to enhance system stability. Reactive power compensation is an important issue in electrical power systems and STATCOM plays an important role in controlling the reactive power flow to the power network and hence the system voltage fluctuations and angle stability. One of the most important advantages of the STATCOM is its behavior during the voltage collapse at the bus where it is located as it supplies almost a constant reactive power without being affected by voltage variation across it [1]. Normally the STATCOM comprises a voltage source shunt converter connected through a transformer and filter across a load bus where the voltage is to be regulated [1]. The control of active and reactive components of STATCOM current is normally achieved through a PI controller. However, these controllers suffer from inadequacies of providing a robust control and transient stability enhancement over a wide range of power system operating conditions [2].

In recent years fuzzy logic control is beginning to receive more attention. The advantages of applying fuzzy logic control in power systems are apparent. Modern power systems are large, complex, geographically widely distributed and highly nonlinear systems. Moreover, power system operation conditions and topologies are time varying and the disturbances are unforeseeable. These uncertainties make it very difficult to effectively deal with power system stability problems through conventional controller that is based on linearized system model. Therefore the fuzzy logic control approach, as one area of artificial intelligence, has been emerging in recent years as a complement to the conventional approach. The fuzzy logic controller is an intelligent controller and this is its most added advantage of. The human knowledge can be coupled with easily through control rules. Also the fuzzy logic controller is a nonlinear controller and is not sensitive to system topology, parameters and operation condition changes. These features make it very attractive for power systems applications [2].

In this paper, the fuzzy controller is designed for STATCOM to improve the transient stability of AC power system.

STATCOM

One of the many devices under the FACTS family, a STATCOM is a regulating device which can be used to regulate the flow of reactive power in the system independent of other system parameters. STATCOM has no long term energy support on the dc side and it cannot exchange real power with the ac system. In the transmission systems, STATCOMs primarily handle only fundamental reactive power exchange and provide voltage support to buses by modulating bus voltages during dynamic disturbances in order to provide better transient characteristics, improve the transient stability margins and to damp out the system oscillations due to these disturbances. [3]

A STATCOM consists of a three phase inverter (generally a PWM inverter) using SCRs, MOSFETs or IGBTs, a D.C capacitor which provides the D.C voltage for the inverter, a link reactor which links the inverter output to the a.c supply side, filter components to filter out the high frequency components due to the PWM inverter. From the d.c. side capacitor, a three phase voltage is generated by the inverter. This is synchronized with the a.c supply. The link inductor links this voltage to the a.c supply side. This is the basic principle of operation of STATCOM. [4]

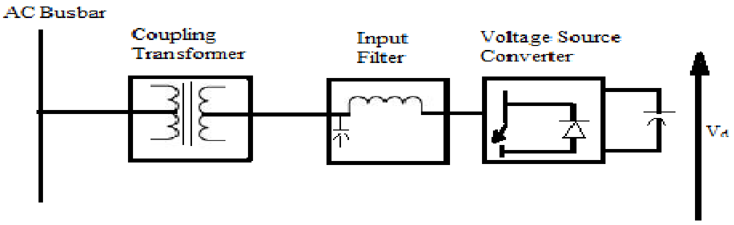

Fig. 1 Block diagram of STATCOM as shunt compensation

For two AC sources which have the same frequency and are connected through a series inductance, the active power flows from the leading source to the lagging source and the reactive power flows from the higher voltage magnitude source to the lower voltage magnitude source. The phase angle difference between the sources determines the active power flow and the voltage magnitude difference between the sources determines the reactive power flow. Thus, a STATCOM can be used to regulate the reactive power flow by changing the magnitude of the VSC voltage with respect to source bus voltage.

Using control strategy suggested in the charging dynamics of VSI (voltage source inverter) capacitor can be derived based on energy conservation, i.e. the input real power Pac from ac system to STATCOM should be equal to the real power Pd absorbed by the capacitor of VSI. So we have (in SI units)

$$P_{ac} = \frac{3V_{\phi}V_{s\phi}}{X_c}\sin\psi = P_d = V_d I_d = V_{dc}\frac{dv_d}{dt} \tag{1}$$

Where the subscript ϕ means a phase variable of rms value. Vd and Id are the average capacitor voltage and charging current, respectively, with harmonics neglected. Angle ψ is the leading phase angle of STATCOM terminal bus voltage V with respect to its terminal voltage Vs behind Xs [5-10].

PI STATCOM CONTROLLER

The reference reactive power (Q_{ref}) is compared with the measured reactive power (Q). The reactive power error is sent as the input to the PI controller and the output of the PI controller determines the phase angle of the STATCOM fundamental voltage with respect to the source voltage.

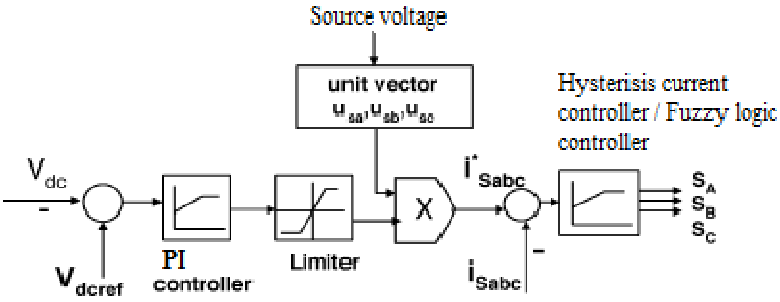

Fig. 2 PI STATCOM Controller

The control diagram of grid-interfacing inverter for a 3-phase 4-wire system is shown in Fig-2 . The fourth leg of inverter is used to compensate the neutral current of load. The main aim of proposed approach is to regulate the power.

Design a Fuzzy Logic Controller Based STATCOM of IEEE-9 Bus System

The Static Synchronous Compensator (STATCOM) is one of the key FACTS devices. Based on a voltage-sourced converter, the STATCOM regulates system voltage by absorbing or generating reactive power. STATCOM output current (inductive or capacitive) can be controlled independent of the AC system voltage.

In our case study the power grid consists of three 500-kV equivalent generators of 3000 MVA, 2500 MVA and 2000 MVA respectively connected by a 600-km transmission line. The STATCOM controller is located at the midpoint of the line (bus B2) and has a rating of ± 100MVA. In the block diagram G1, G2 and G3 denote the three generators. B1, B2, B3,…, B9 indicates the bus bars. T.L shows the transmission line. A, B and C are the three loads on bus bars B1, B2 and B3 respectively. This is shown in block diagram representation in fig-3.

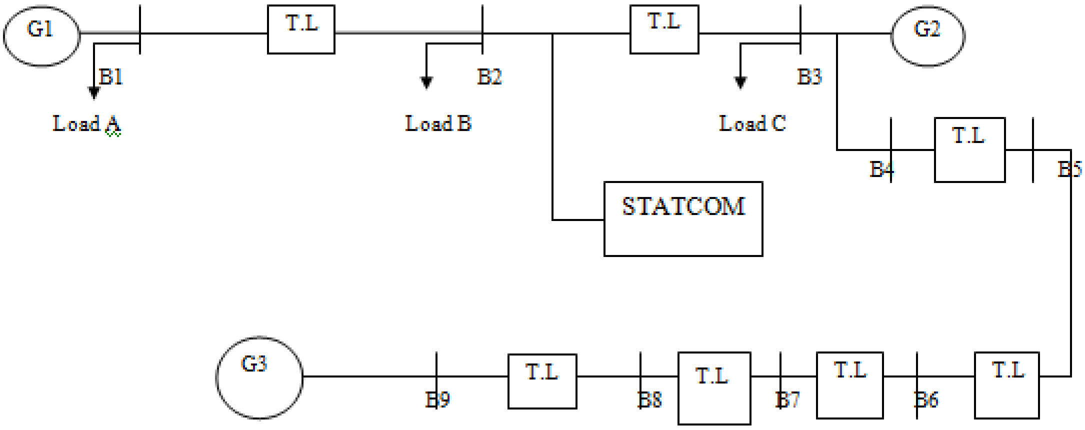

Fig. 3 IEEE-9 Bus system with STATCOM controller

STATCOM CONTROLLERS

Fig. 4 shows the structure of the STATCOM controller. The STATCOM control system has two components: AC voltage regulator and DC voltage regulator. The STATCOM control system uses AC voltage regulator for the generator terminal. AC voltage regulator controls the voltage of the generator terminal and it is regulated by modulating the magnitude of the shunt converter voltage. The AC voltage regulator is connected with current selection and current limiter, and DC voltage regulator is connected with the current regulator.

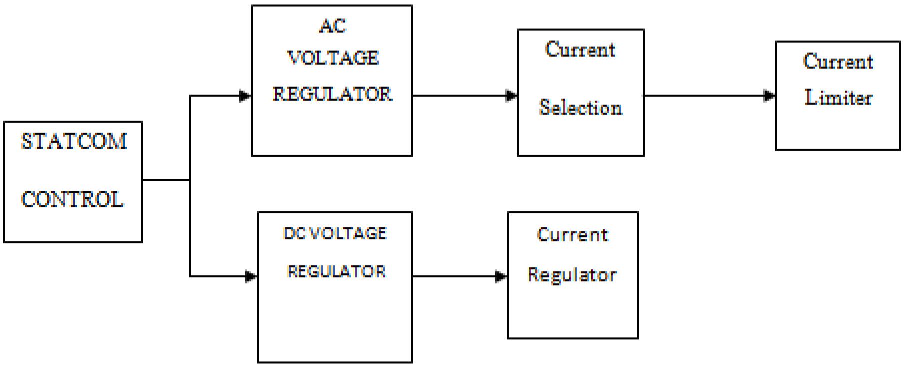

Fig. 4 STATCOM Controller

Design of AC Voltage Regulator with PI Controller

The structure of AC voltage regulator is shown in Fig. 5. The magnitude of voltage is added to the feedback obtained as output of the rate limiter, and the error is corrected. The sum is fed to K_p (proportional gain) and K_i (integral gain). The proportional gain and the integral gain through integrator are then added. The sum obtained is given to saturation which gives the current reference i_q, and is also fed back through droop and filter as another input before the proportional gain and integral gain. Input and constant are given to relational operator and the output is stored in memory. The inputs and memory pass through the switch to rate limiter and then to voltage reference v_{ref}.

Design of AC Voltage Regulator STATCOM with Fuzzy Logic Controller

Structure of control system for AC-voltage regulator STATCOM with fuzzy logic controller is shown in Fig-6. The fuzzy main controller is similar to a nonlinear PI controller. Nine fuzzy sets or linguistic variables are defined for E, ΔE1 & ΔE2, and nine for output signal. Fuzzy logic controller is a better option than conventional PI controller because it provides higher level of automation by incorporating expert knowledge and it also robust nonlinear control. In the Fig. 5, we have used a fuzzy logic controller instead of conventional PI controller. There are three inputs of FLC and one output. This input and output gains of FLC are tuned by trial method in such a way to satisfy the minimum error, and best output response is tuned by changing the gain and other parameters. The parameters are changed in such a way that error signal is minimized. To get the desired result, we must apply a rule-based system. The rule base for FLC is designed by the experience of studying the performance of STATCOM.

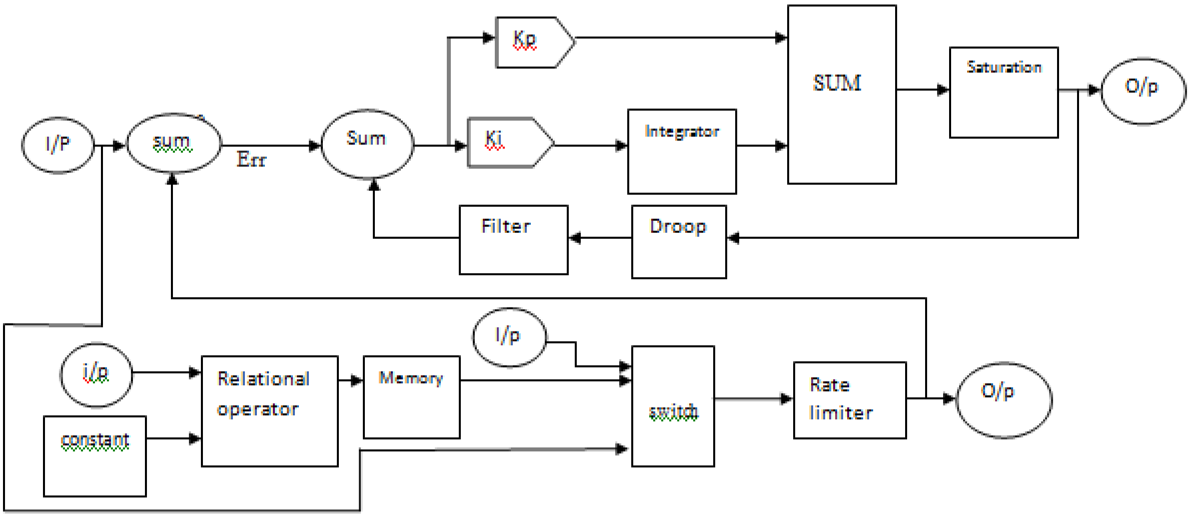

Fig. 5 AC Voltage Regulator with PI Controller

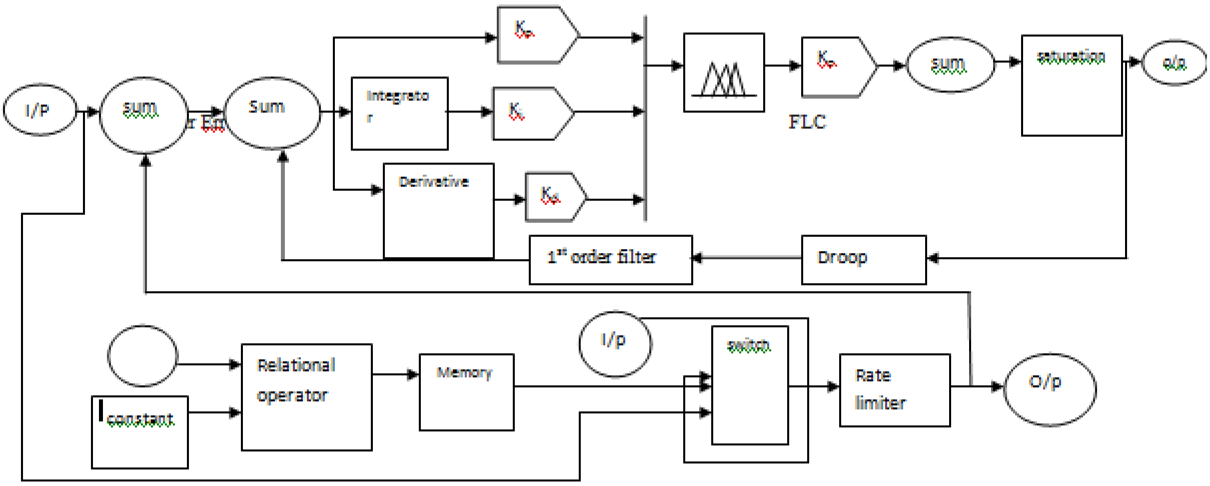

Fig. 6 AC Voltage Regulator with Fuzzy Logic Controller

The rule base table for the proposed Fuzzy Logic Controller design is shown in Table-1. Here the fuzzy variables are having their usual meanings like NB-Negative Big, NM-Negative Medium, NS-Negative Small, Z-Zero Error, PS-Positive Small, PM-Positive Medium and PB-Positive Big.

Table-1 Fuzzy Rule Base for this Model

E ↓	ΔE1/ΔE2 ↓	→						
		NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NM	NS	Z
NM	NM	NB	NB	NM	NM	NS	Z	PS
NS	NS	NB	NM	NS	NS	Z	PS	PM
Z	Z	NB	NM	NS	Z	PS	PM	PB
PS	PS	NM	NS	Z	PS	PS	PM	PB
PM	PM	NS	Z	PS	PM	PM	PB	PB
PB	PB	Z	PS	PM	PB	PB	PB	PB

4. Result & Discussion

The whole model is simulated in MATLAB/Simulink environment. Four results have been studied for comparison purpose. The graph in Fig. 7 shows the active power for PI controller and for fuzzy logic controller based control systems as a function of time. The FLC response becomes stable immediately during the occurrence of fault whereas the PI controller took about 0.6 second to stabilize. The PI controller is taking more time to come back to original stability position whereas Fuzzy logic controller stabilizes immediately. There are no transient oscillations in FLC compared to high magnitude oscillations in PI response, and the comparison indicates that the fuzzy logic based STATCOM gives improved performance compared to the PI STATCOM controller based technique.

The graph in Fig. 8 shows the reactive power for PI controller and for fuzzy logic controller based control systems as a function of time. The FLC response becomes stable immediately during the occurrence of fault whereas the PI controller took about 0.6 second to stabilize. The PI controller is taking more time to come back to original stability position whereas Fuzzy logic controller stabilizes immediately. There are no transient oscillations in FLC compared to high magnitude oscillations in PI response, and the comparison indicates that the fuzzy logic based STATCOM gives improved performance compared to the PI STATCOM controller based technique.

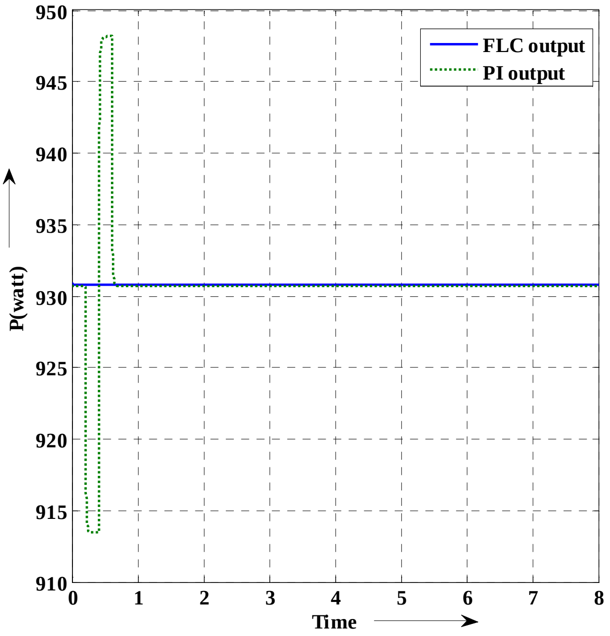

Fig. 7 Active Power for PI Controller and Fuzzy Logic Controller Based Control Systems

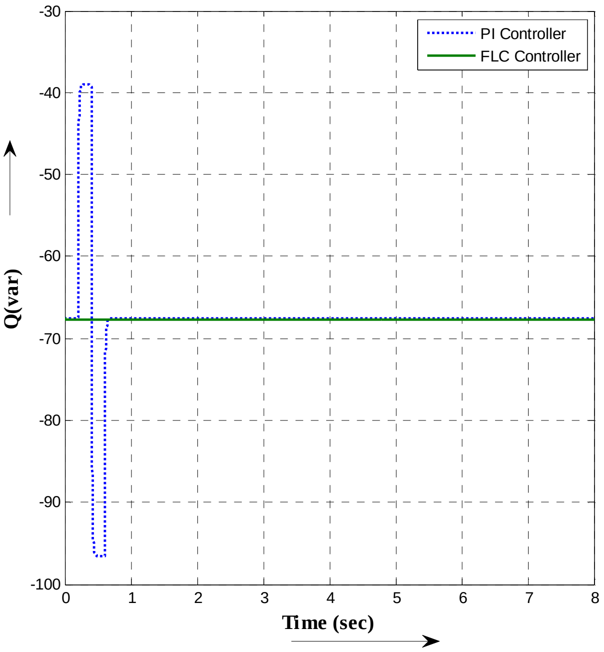

Fig. 8 Reactive Power for PI Controller and Fuzzy Logic Controller Based Control System

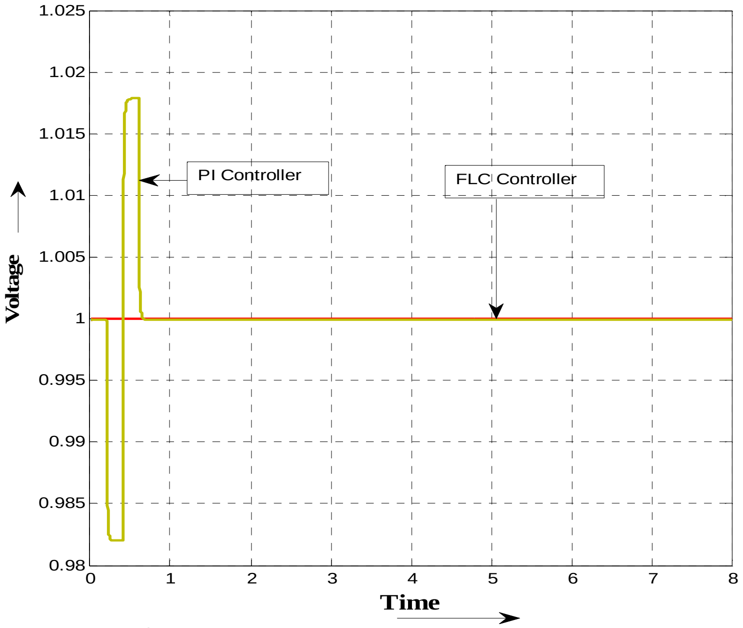

Fig. 9 Voltage for PI Controller and Fuzzy Logic Controller Based Control System

The graph as shown in fig.9 is the voltage for PI controller and for fuzzy logic controller based STATCOM. The voltage is 0.999 pu for PI controller whereas it is 1 pu for fuzzy logic based control system. The FLC response becomes stable immediately during the occurrence of fault whereas the PI controller took about 0.6 second to stabilize. The PI controller is taking more time to come back to original stability position whereas Fuzzy logic controller stabilizes immediately. There are no transient oscillations in FLC compared to high magnitude oscillations in PI response, and the comparison indicates that the fuzzy logic based STATCOM gives improved performance compared to the PI STATCOM controller based technique.

The graph as shown in fig.10 is the current for PI controller and for fuzzy logic controller based STATCOM The current is 0.03 for PI controller whereas it is 0.04 for fuzzy logic based control system. The FLC response becomes stable immediately during the occurrence of fault whereas the PI controller took about 0.6 second to stabilize. The PI controller is taking more time to come back to original stability position whereas Fuzzy logic controller stabilizes immediately. There are no transient oscillations in FLC compared to high magnitude oscillations in PI response, and the comparison indicates that the fuzzy logic based STATCOM gives improved performance compared to the PI STATCOM controller based technique.

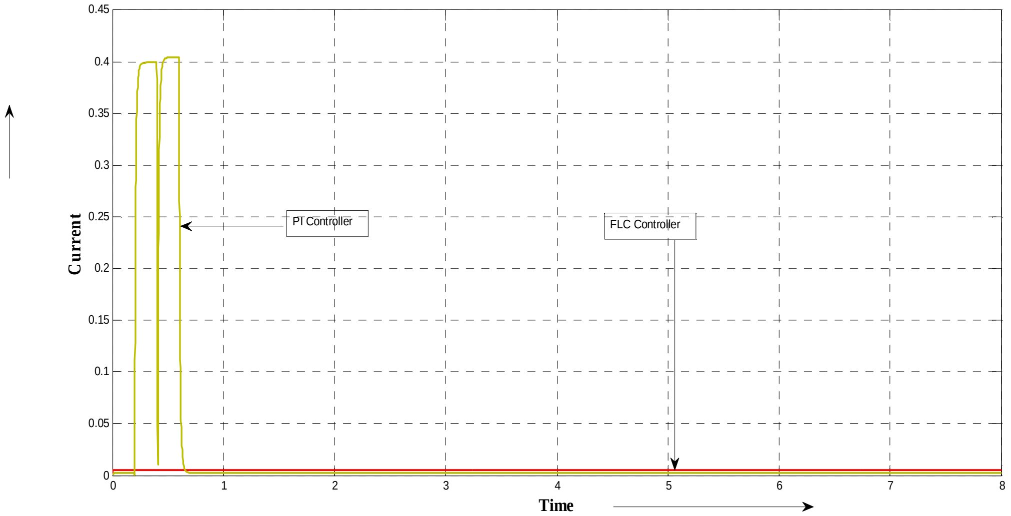

Fig. 10 Current for PI Controller and Fuzzy Logic Controller Based Control System

CONCLUSION

This paper gives an application of fuzzy logic controller for the design of STATCOM for an IEEE 9 bus system. The results clearly shows that in all the cases there is improved performance by the FLC based STATCOM compared to PI controller based STATCOM. This is possible due to its capacity to deal with power system uncertain environment more efficiently.

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