

# Fuzzy Controller for Reactive Power Compensation with Statcom to Improve Power Factor

Bade Varsha L. and R. M. Nagarale

**Abstract:** This paper deals with modelling of STATCOM along with the design of linear current and voltage controllers. The fuzzy logic control method is used to design linear current and voltage controllers to improve the power factor with the help of reactive power compensation. STATCOM is nothing but the static synchronous compensator which regulates the voltage and corrects the power factor at the point of common coupling by injecting reactive power. The principle of operation is same as that of synchronous condenser. The use of proposed method removes the fluctuations and improves the magnitude of the current and voltage also phase angle which goes to nearly zero value. The performance of the method is obtained through MATLAB SIMULINK tool box.

**Index Terms:** Reactive Power Compensation, STATCOM, Fuzzy controller.

## I. INTRODUCTION

The STATCOM i.e. static compensator is very commonly used for the reactive power control. The STATCOM is also known as static VAR generator (SVG) is a voltage converter device which uses in order to generate the active and reactive power needed by the system. The STATCOM has several advantages such as fast response, continuous and quick control of reactive power. The power system becomes very complex because there is interconnection of long distance transmission lines [1-3]. The grids become unstable in nature as the loads are vary in their phase angle and magnitude that affects on power factor [4-6]. Commissioning new transmission systems was extremely expensive and also takes more amount of time to set up. Therefore, in order to meet increasing power demands, utilities must rely on power export or import arrangements through the existing transmission systems. To improve power factor the capacitor banks are used but it is having number of disadvantages [7].

To avoid these disadvantages the Power electronic devices are used in the field of power transmission and

distribution systems. The reactive power (VAR) compensation and control have been recognized which is efficient and increases the power system transmission capability and stability [8-11]. The FACTS (Flexible AC Transmission Systems) devices, such as STATCOM has been introduced recently which employs a VSI with a fixed DC link capacitor as a static replacement of the synchronous condenser. It does not require no. of capacitor or inductor banks. Only a fixed set of capacitor provides the required VAR control, with a rapid control of bus voltage and improvement of utility power factor. It has some advantages over conventional thyristorised converters in terms of speed of response [12]. The penalty paid for this improvement is in terms of some harmonics which requires the separate filtration techniques. The SPWM i.e. Sinusoidal Pulse Width Modulation technique is used to reduce the harmonic distortion [13] the modulation index is also increases so that this modulation index minimises the size of link reactor. The modelling, analysis of STATCOM steady state and dynamic performance have been studied using non-linear controller [14]. The dynamic and steady state nature of STATCOM using SVPWM method (Space Vector Pulse Width Modulation) is

more better than SPWM because SVPWM inverter has higher modulation index [15].

The linear controller method is more convenient for STATCOM application as compared to nonlinear controller [16-18]. In order to mitigate this, in [19] design of a linear current controller and voltage controller on the basis of gain and time constant adjustment along with the parameter of the coupling inductor and storage capacitor.

These controllers are used in STATCOM and control the reactive power for improvement of power factor on the variation of DC link voltage. But in this paper some fluctuations are there so that in order to avoid these fluctuations and to improves the reactive power we are introduced fuzzy controller for the improvement of power factor with reactive power compensation. In addition, this research work demonstrates fast, dynamic performance of the STATCOM in various operating conditions.

This paper is organized as follows. Section II illustrates the modelling of the STATCOM & analysis. Section III presents the design of fuzzy controller for the STATCOM. Section IV presents the simulation results. Finally, Section V concludes this paper.

## II. STATCOM MODELLING AND ANALYSIS

### A. Operating principle:

As is well known, the STATCOM is, in principle, a static replacement of the age-old synchronous condenser. Fig.1 shows the schematic diagram of the STATCOM at PCC through coupling inductors. The fundamental phasor diagram of the STATCOM terminal voltage with the voltage at PCC for an inductive load in operation, neglecting the harmonic content in the STATCOM terminal voltage, is shown in Fig.2. Ideally, increasing the amplitude of the STATCOM terminal voltage  $V_{oa}$  above the amplitude of the utility voltage  $V_{sa}$  causes leading current  $I_{ca}$  to be injected into the system at PCC as shown in Fig.2.

### B. Modeling:

The modelling of the STATCOM, through well known, is viewed in the lines below, for the sake of convenience. The modelling is carried out with the following assumptions:

- 1) All switches are ideal.
- 2) The source voltages are balanced.
- 3)  $R_s$  represents the converter losses of the coupling inductor.
- 4) The harmonic contents caused by switching action are negligible.

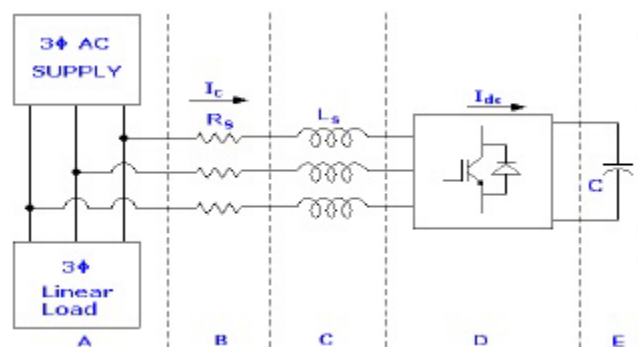


Fig. 1: Schematic diagram of STATCOM [19]

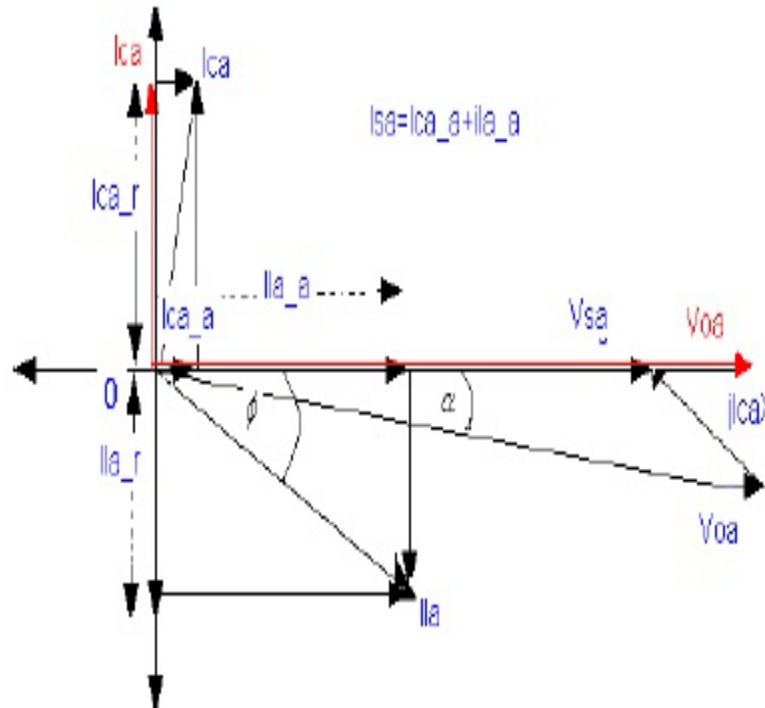


Fig. 2: Phasor diagram for inductive load operation [19]

The 3-phase stationary abc coordinate vectors with 120 apart from each other are converted into  $\alpha\beta$  two-phase stationary coordinates. The  $\alpha$  axis is aligned with a axis and leading  $\beta$  axis and both converted into dq two-phase rotating co-ordinates. The Park's abc to dq transformation matrix is used here. The

actual proposed circuit is too complex to analyze as a whole, so that it is partitioned into several basic sub-circuits, as shown in Fig.1. The 3-phase system voltage  $V_{s,abc}$  lagging with the phase angle  $\alpha$  to the STATCOM output voltage  $V_{o,abc}$  and differential form of the STATCOM currents are defined in (1) and (2).

$$v_{s,abc} = \begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix} = \sqrt{\frac{2}{3}} v_s \begin{bmatrix} \sin(\omega t - \alpha) \\ \sin(\omega t - \alpha - \frac{2\pi}{3}) \\ \sin(\omega t - \alpha + \frac{2\pi}{3}) \end{bmatrix} \quad (1)$$

$$L_s \frac{d}{dt} (i_{c,abc}) = -R_s i_{c,abc} + v_{s,abc} - v_{o,abc} \quad (2)$$

Where,  $v_s, \bar{\omega}, R_s$  and  $L_s$  have their usual connotations. The above voltages and currents are transformed into dq frame.

$$L_s \frac{d}{dt} (i_{cq}) = -R_s i_{cq} - \omega L_s i_{cd} + v_{sq} - v_{oq} \quad (3)$$

$$L_s \frac{d}{dt} (i_{cd}) = \omega L_s i_{cq} - R_s i_{cd} + v_{sd} - v_{od} \quad (4)$$

The switching function S of the STATCOM can be defined as follows:

$$S = \begin{bmatrix} S_a \\ S_b \\ S_c \end{bmatrix} = \sqrt{\frac{2}{3}} m \begin{bmatrix} \sin(\omega t) \\ \sin\left(\omega t - \frac{2\pi}{3}\right) \\ \sin\left(\omega t + \frac{2\pi}{3}\right) \end{bmatrix} \quad (5)$$

The modulation index, being constant for a programmed PWM, is given by,

$$MI = \frac{v_{o,peak}}{v_{dc}} = \sqrt{\frac{2}{3}} m \quad (6)$$

The STATCOM output voltages in dq transformation are

$$v_{o,qdo} = m [0 \quad 1 \quad 0]^T v_{dc} \quad (7)$$

The dc side current in the capacitor in dq transformation

$$i_{dc} = m [0 \quad 1 \quad 0] [i_{cq} \quad i_{cd} \quad i_{co}]^T \quad (8)$$

The voltage and current related in the dc side is given by,

$$\frac{dv_{dc}}{dt} = \frac{m}{C} i_{cd} \quad (9)$$

The complete mathematical model of the STATCOM in dq frame is obtained as,

$$\frac{d}{dt} \begin{bmatrix} i_{cq} \\ i_{cd} \\ v_{dc} \end{bmatrix} = \begin{bmatrix} \frac{-R_s}{L_s} & -\omega & 0 \\ \omega & \frac{-R_s}{L_s} & -\frac{m}{L_s} \\ 0 & \frac{m}{C} & 0 \end{bmatrix} \begin{bmatrix} i_{cq} \\ i_{cd} \\ v_{dc} \end{bmatrix} + \frac{V_s}{L_s} \begin{bmatrix} -\sin \alpha \\ \cos \alpha \\ 0 \end{bmatrix} \quad (10)$$

### III. DESIGN OF FUZZY CONTROLLER FOR STATCOM

#### A. Basics of Fuzzy controller

The determination of the output control signal, is done with an inference engine with a rule base having if-then rules in the form of "IF  $\varepsilon$  is.....AND  $\Delta\varepsilon$  is....., THEN output is....." With the rule base, the value of the output is changed

according to the value of the error signal  $\varepsilon$ , and the rate-of-error  $\Delta\varepsilon$ . The structure and determination of the rule is are using trial-and-error methods and is also done through experimentation. All the variable fuzzy subsets for the inputs  $\varepsilon$  and  $\Delta\varepsilon$  are defined as (NB, NM, NS, Z, PS, PM, PB). The fuzzy control rules is illustrated in table I. The basic diagram of fuzzy controller is shown in Fig.3.

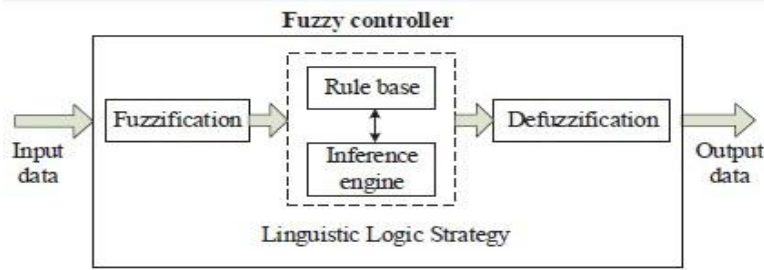


Fig. 3: Basic representation of fuzzy controller

**Table I. FLC Rule Base**

$\epsilon/\Delta\epsilon$	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

The membership functions for error, change in error and output is shown in Fig.4, 5 and 6 respectively.

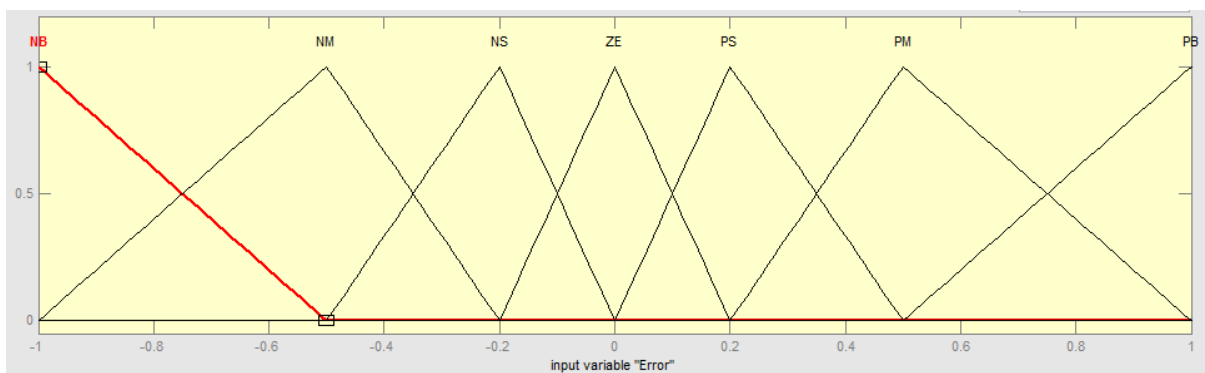


Fig. 4: Membership function of error( $\epsilon$ )

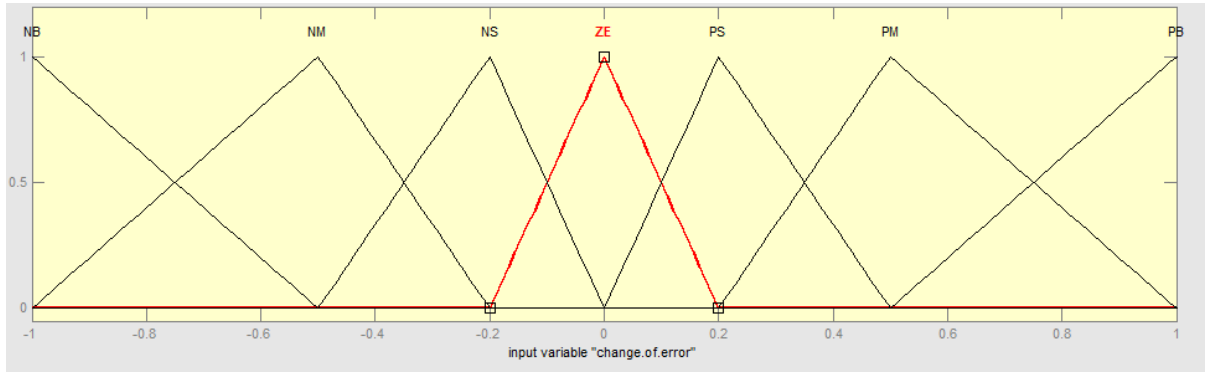


Fig.5: Membership function of change in error( $\Delta\epsilon$ )

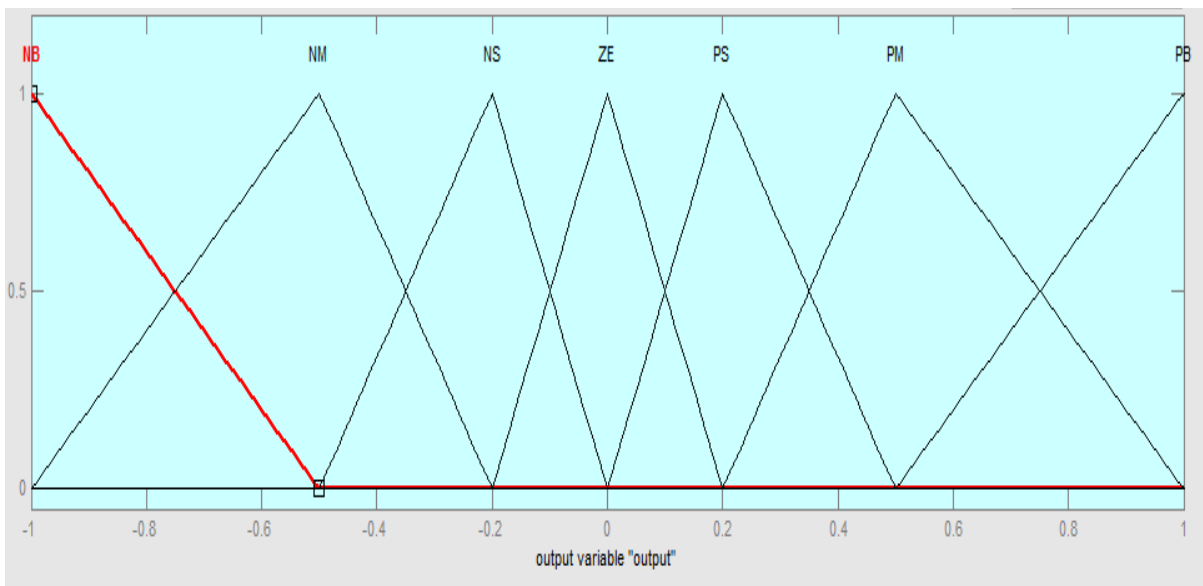


Fig.6: Membership function of output

#### IV. SIMULATION RESULTS

##### A. Simulation using FLC

In the simulation diagram is divided in to two parts for the convience i.e. Fig.7 and 8 shows proposed circuit configuration and proposed circuit control using FLC respectively. In proposed circuit configuration, the source is connected to load so that it produces impact on gate pulsating signal because controller output gives to  $V_{sc}$  and  $V_{dc}$  gets improved. When

$V_{dc}$  improved, the reactive power injected to the system is improve and power factor improves. The control circuit using FLC is shown in detailed in Fig.8. In control circuit the Clark's and Park's transformation is performed to give signals to the discrete SVPWM (Space Vector Pulse Width Modulation) generator. With SVPWM pulses are generated.

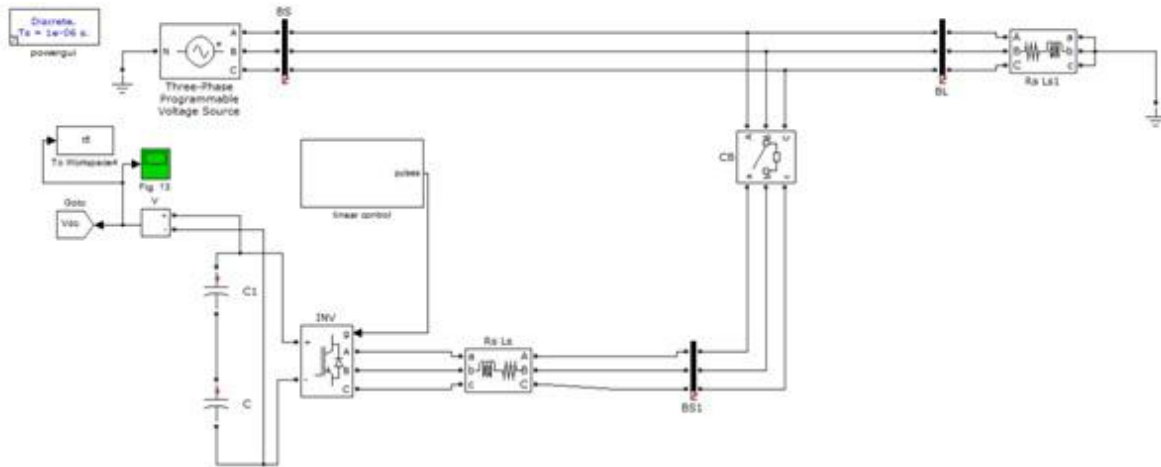


Fig. 7: Proposed circuit configuration

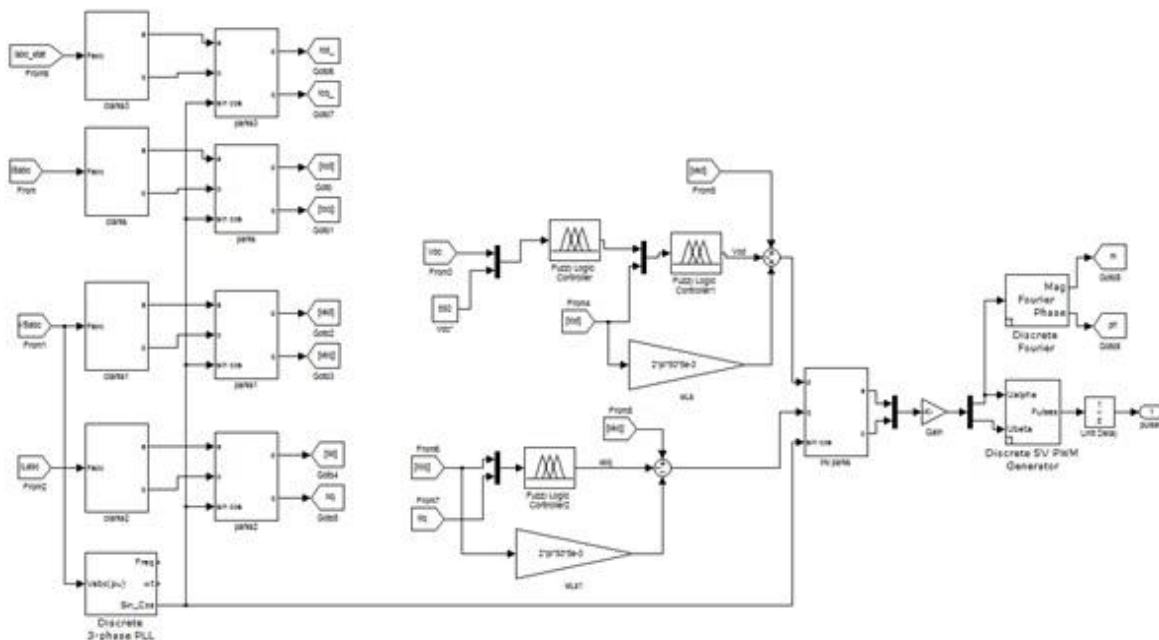


Fig. 8: Proposed control circuit using FLC

### B. Responses using FLC Model

The dc link capacitor is charged to 550V at that time STATCOM operates well which is shown in Fig.9. In this paper fuzzy controller is used so that, it improves the magnitude of the voltages is shown in Fig.10,11, and 13. The controller output is connected to the voltage source converter, voltage gets increases that affects on the

reactive and active power shown in Fig.12. The Fig.14 and 15 depicts modulation index of STATCOM which is unity and phase angle of the STATCOM is nearly zero respectively. The grid phase A and STATCOM output A voltage is shown in Fig.16. The Fig. 17 shows the change of STATCOM phase A current due to change of load current by an arrow.

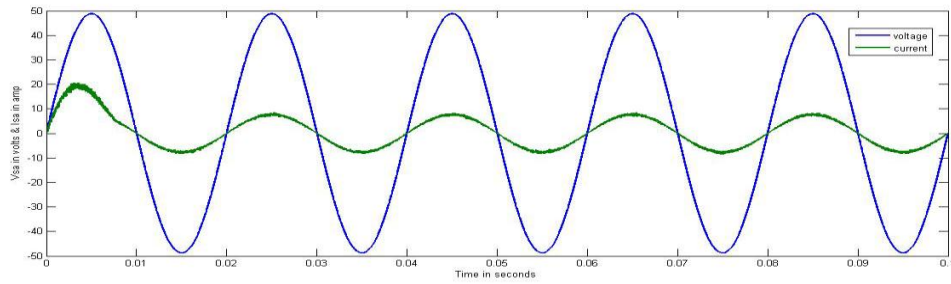


Fig. 9: Grid phase A voltage and phase A current

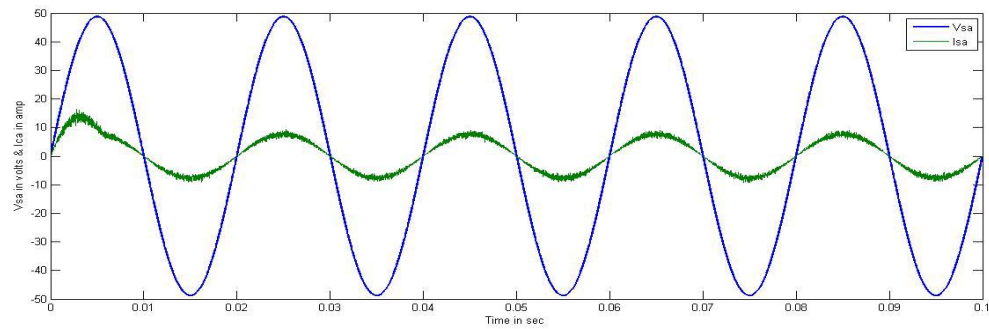


Fig. 10: Grid phase A voltage and STATCOM phase A current

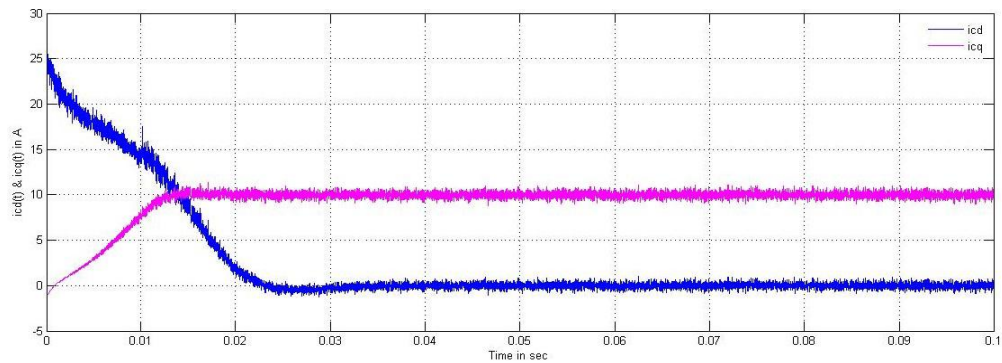


Fig. 11: Active and reactive components of STATCOM current

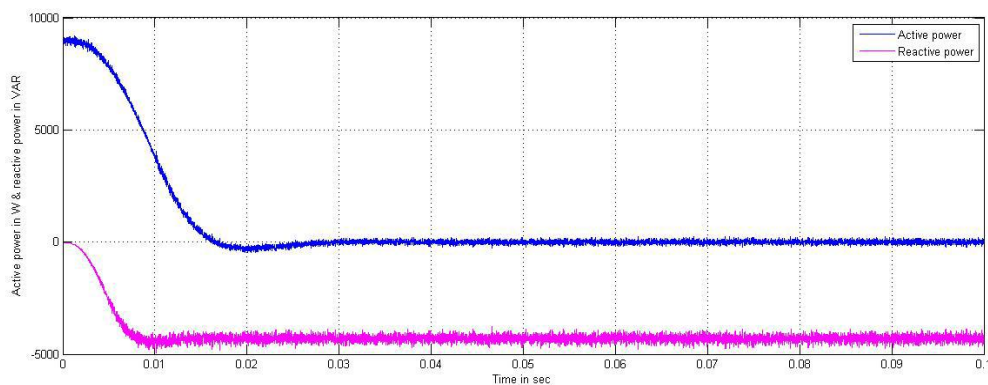




Fig. 12: Active and reactive power of STATCOM

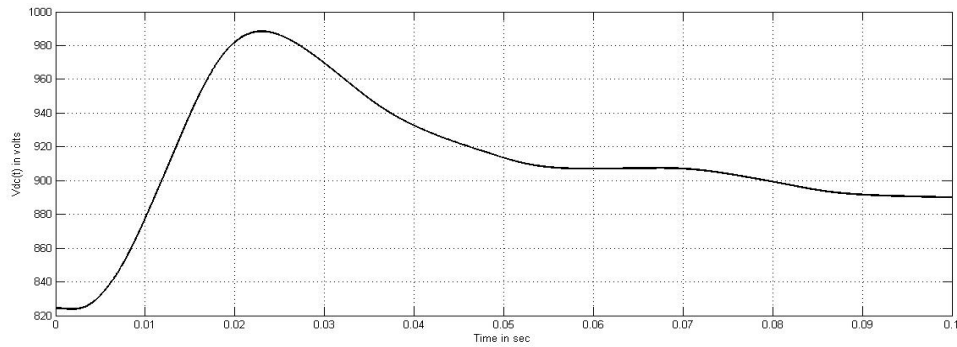


Fig. 13: DC link bus voltage of STATCOM

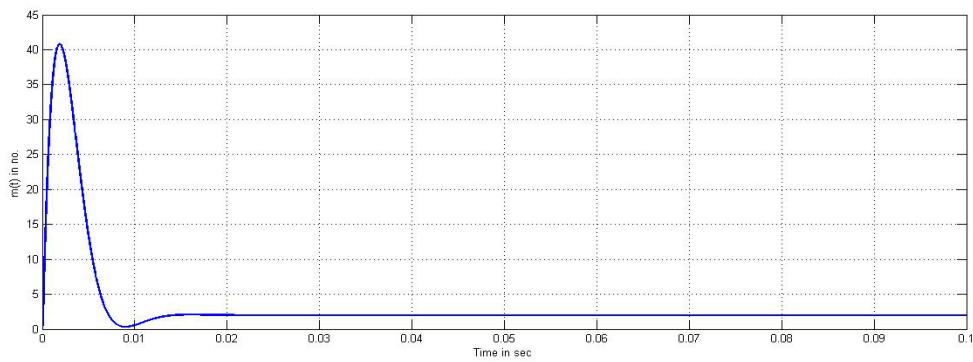


Fig. 14: Modulation Index of STATCOM

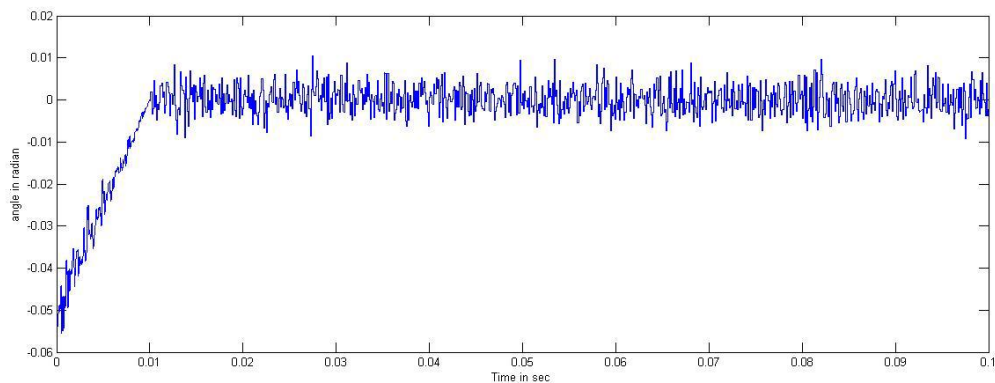


Fig. 15: Phase angle of STATCOM

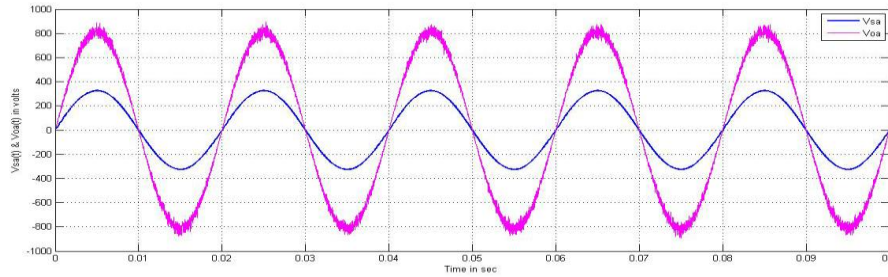


Fig. 16: Grid and STATCOM output phase A voltage

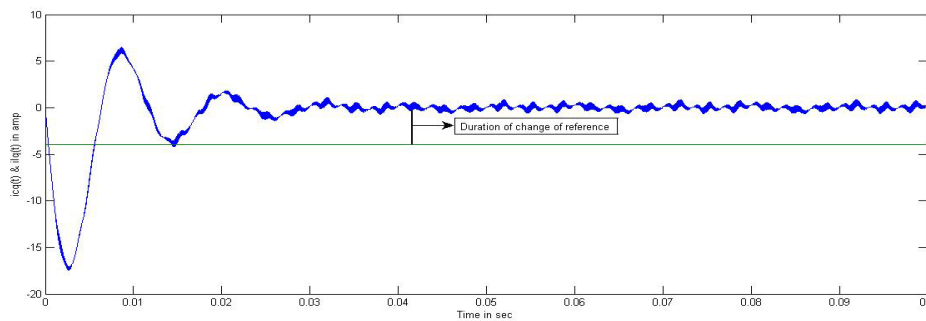


Fig. 17: Change of STATCOM phase A current due to change of reference current

## V. CONCLUSION

In this paper linear current and voltage controllers for STATCOM control are designed based on fuzzy logic control method to remove fluctuations and also it improves the magnitude of the voltages. The FLC improves power factor by making the phase difference between grid and load nearly to the zero value. The motto of using FLC is to improve the power factor using Reactive power compensation. Future work may lie in the investigation of multiple STATCOMs since the interaction among various STATCOMs may affect each other. Also, the extension to other power system control problems can be explored. We can also move towards the adaptive PI controller for the improvement of voltage regulation, reactive power improvement, transient period imitating, indirect control of power factor improvement and various power quality aspects are also proposed.

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## VI. ACKNOWLEDGMENTS

The authors are gratefully acknowledge the Management and Principal, Dr. B.I. Khadakbhavi of M.B.E.Society's, College of Engineering Ambajogai, -431517, (M.S), India. for their support and encouragement.



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