Fuzzy Logic Controller based STATCOM for Voltage Profile Improvement in a Micro-Grid

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Abstract—**Microgrids constitute a very essential part in today's power system for fulfilling the increasing power demand but when working under isolated conditions microgrids become very vulnerable due to the fact that normally microgrids have small generation capacities and most of the generation sources are renewable/constant power sources, which reduces the transient as well as voltage stability limits of a microgrid when working under isolated conditions. In this work a single synchronous generator based isolated microgrid system is studied. The microgrid system feeds power to a concentrated time varying load. Fluctuation in load causes variation in the load bus voltage which reduces the stability of the system. A Static Synchronous Compensator (STATCOM) is used to improve the voltage profile of the load bus. Two different controllers: PI and fuzzy logic are used for the control purpose of the STATCOM. The performance of the STATCOM with both the controllers is evaluated with different load conditions: R-L load, nonlinear load and dynamic load. The results are analyzed and compared. The simulation is done in Matlab/Simulink.**

Keywords- STATCOM, Decoupled Control, Fuzzy Logic Controller, PI controller, Micro-grid, Reactive power compensation

I. INTRODUCTION

Over the last two decades demand of electricity has increased a lot along with the increased population. To meet this increased electricity demand the ultimate solution is formation of micro-grid. Micro-grid consists of small generating stations combined with some local load. For generation of electricity renewable energy sources are also used, whose power is variable in nature. Along with this the micro-grid has one demerit that voltage profile is highly distorted due to small generating capacities along with fluctuating loads [1]. These fluctuations in load affect the quality of power as well as the voltage profile. So maintaining a flat voltage profile with fluctuating power demand is a big challenge for power engineers. Implementation of Flexible AC Transmission Systems (FACTS) devices is the most feasible solution for the above mentioned problem. Among all the FACTS devices such as Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), Static Synchronous Series Compensator (SSSC) etc. [2], STATCOM is often used to improve the voltage profile in micro grids. During reactive power compensation normally STATCOM gives faster response than SVC [3]. STATCOM supplies additional leading/lagging Var to the system to make the voltage constant at a given bus.

A lot of research has been already done in this area. Performance of STATCOM depends on accuracy and robustness of the controller [4], [5]. Various types of controllers are used for the power control process in STATCOM. Basically conventional PI controllers are used. But now in recent days Fuzzy Logic Controller (FLC) [6], Sliding Mode Controller (SMC) [7] are also used for this purpose. Stability margin of DFIG based wind farm is improved in [8] using a PID damping controller and a hybrid PID plus fuzzy logic controller of the STATCOM. Both frequency domain approach and time domain approach are used for modeling the system. Fuzzy logic approach is also used in [9] to determine optimal placement of the DSTATCOM and photo-voltaic array in a distribution system. Fuzzy logic is also used in [10] for modeling the uncertainty of loads, distributed generations, and purchased power from the grid. By considering an uncertain environment, the effect on decreasing the risk of technical issues like active loss and voltage profile in distribution network is evaluated.

In this work a single alternator based isolated micro-grid system is considered. The generator feeds power to a concentrated time varying load. A STATCOM is utilized to improve the voltage profile at the load bus. The performance of the STATCOM is evaluated with PI and Fuzzy logic controllers and the performance comparison of the both the controllers is done with different load conditions. Three different loads have been considered in this work: R-L load, nonlinear load and dynamic load. The micro-grid and loads are modeled and simulated using Matlab/Simulink. The results are presented in this paper.

II. SYSTEM DESCRIPTION

Fig. 1 shows the schematic diagram of the micro-grid system. A single generator connected to a linear RL load through a transmission line. This system is verified under several load condition and load changes. Due to these load changes system's voltage profile is also affected, when load

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increases a voltage dip appears, when load decreases a voltage swell appears. But as the load changes, maintaining the profile is a difficult challenge. For that reason a STATCOM is connected at the load bus, which improves the voltage profile at the load bus.

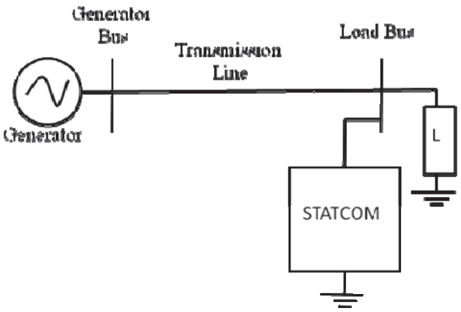


Fig. 1 Block diagram of micro grid system

III. SYSTEM MODELLING

The generating station considered in this paper consists of three major parts.

1. Alternator
2. Automatic voltage regulator (AVR)
3. Speed governor & Diesel engine

A. Modelling of Alternator

In this work a salient pole type synchronous machine is considered. The modelling of the alternator [11] is done in synchronously rotating d^e - q^e reference frame. The modelling is done according to the following equations

$$V_{fr} = R_{fr}I_{fr} - L_{md}\frac{dI_{ds}}{dt} + \left(L_{lfr} + L_{md}\right)\frac{dI_{fr}}{dt} + L_{md}\frac{dI_{fr}}{dt} \tag{1}$$

$$0 = R_{dr}I_{dr} - L_{md}\frac{dI_{ds}}{dt} + L_{md}\frac{dI_{fr}}{dt} + L_{dr}\frac{dI_{dr}}{dt} \tag{2}$$

$$0 = R_{qr}I_{qr} - L_{mq}\frac{dI_{qs}}{dt} + L_{qr}\frac{di_{qr}}{dt} \tag{3}$$

$$V_d = -R_s I_d - \omega\psi_q + \frac{d\psi_d}{dt} \tag{4}$$

$$V_q = -R_s I_q + \omega\psi_d + \frac{d\psi_q}{dt} \tag{5}$$

Flux linkage expressions in (4) and (5) are as follows.

$$\psi_d = -L_{ds}I_{ds} + L_{md}\left(I_{fr} + I_{dr}\right) \tag{6}$$

$$\psi_q = -L_{qs}I_{qs} + L_{mq}I_{qr} \tag{7}$$

Expression for electro-magnetic torque developed is given below.

$$T_e = \frac{3}{2}\frac{P}{2}\left(\psi_{ds}I_{qs} - \psi_{qs}I_{ds}\right) \tag{8}$$

B. Modeling of AVR

Due to continuous fluctuation of load, voltage profile at the load bus as well as the generator bus are distorted. To maintain a constant voltage at the generator bus automatic voltage regulator (AVR) is used [12]. The model of the AVR is given in Fig.2.

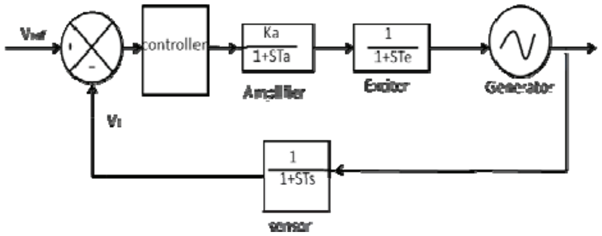


Fig. 2 AVR block diagram

C. Modelling of speed governor and diesel engine

In regulating the speed, Speed governor plays a very crucial role and by this the frequency is also kept constant at the reference value. According to the load and speed, frequency also varies. So, by using the speed governor, the speed and hence the frequency of the micro grid can be made constant [13]. The block diagram is given below in Fig.3.

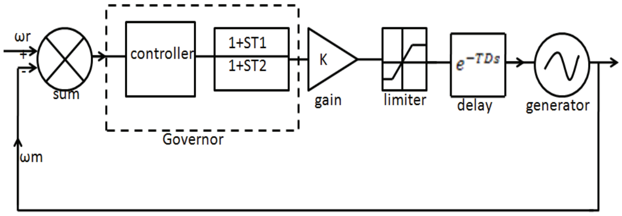


Fig. 3 Block diagram of speed governor

IV. CONTROL OF STATCOM

To maintain a flat voltage profile at the load bus STATCOM is used. Control structure of the STATCOM is shown in Fig. 4. Here STATCOM is used at the load bus. A hysteresis current controller based control strategy is used for the decoupled control of active and reactive power of STATCOM. In this control strategy two control loops are used for control of active and reactive power independently.

First the voltage at the load bus and current are sensed and the peak of load bus voltage is calculated. Then the in phase component are calculated by dividing the three phase voltages by the peak value. Then by the transformation given in (9)-(11), the quadrature voltages are calculated.

$$w_a = -u_b/\sqrt{3} + u_c/\sqrt{3} \tag{9}$$

$$w_b = \sqrt{3}u_a/2 + \left(u_b - u_c\right)/2\sqrt{3} \tag{10}$$

$$w_c = -\sqrt{3}u_a/2 + \left(u_b - u_c\right)/2\sqrt{3} \tag{11}$$

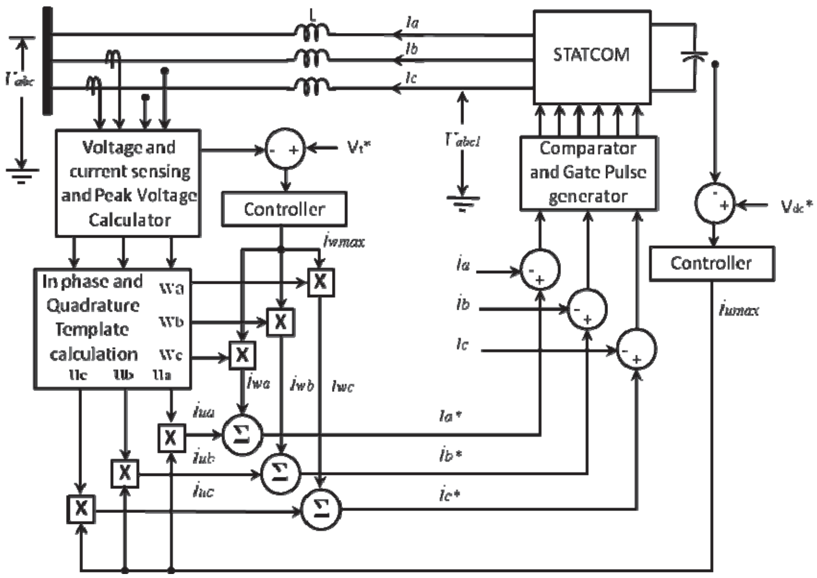


Fig. 4. Control structure of STATCOM

The in phase components of the STATCOM currents are given in (12).

$$\begin{aligned} i_{ua} &= i_{u\,max} u_a \\ i_{ub} &= i_{u\,max} u_b \\ i_{uc} &= i_{u\,max} u_c \end{aligned} \tag{12}$$

The quadrature components of the STATCOM currents are given in (13).

$$\begin{aligned} i_{wa} &= i_{wmax} w_a \\ i_{wb} &= i_{wmax} w_b \\ i_{wc} &= i_{wmax} w_c \end{aligned} \tag{13}$$

Then the reference values of the STATCOM currents are calculated as given in (14).

$$\begin{aligned} i_a^* &= i_{ua} + i_{wa} \\ i_b^* &= i_{ub} + i_{wb} \\ i_c^* &= i_{uc} + i_{wc} \end{aligned} \tag{14}$$

The control strategy is given below.

A. *Structure of PI controller*

The PI controllers used in this work has the following structure.

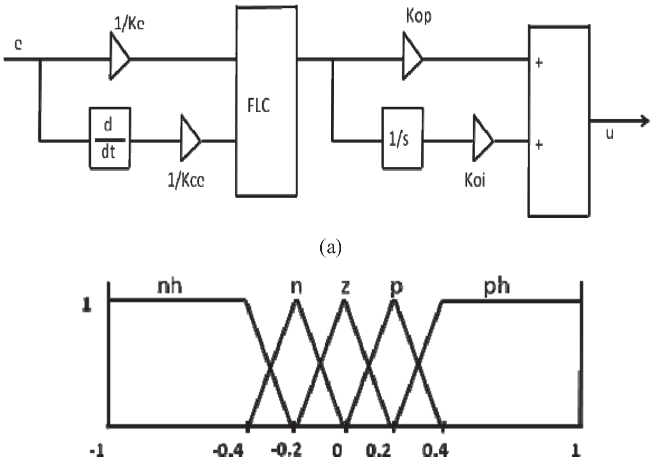
$$u = k_p e + k_i \int edt \tag{15}$$

Where 'k_p' and 'k_i' are the proportional and integral gain, 'u' is the control output and 'e' is the error input to the controller.

B. *Structure of Fuzzy logic Controller*

The Fuzzy logic controller is used in the reactive power control loop of STATCOM to control the peak voltage. The error and rate of change of error, 'e_{Vt}' and 'ce_{Vt}' respectively are calculated and are normalized. The normalized value of 'e_{Vt}' and 'ce_{Vt}' are given to the FLC as inputs. The control output u' is again multiplied with output gain factor 'K_{op}' to get proportional –derivative action and integral of the output u' is multiplied with another gain K_{oi} to get proportional-integral action. Both the values are then added up to get a combined proportional-integral-derivative action from FLC.

The structure of the fuzzy logic controller is shown in Fig. 5(a). The input and output membership functions are shown in Fig. 5(b). The input and output fuzzy sets use both triangular and trapezoidal membership function, which are found to be near optimum. The rule base for the FLC is shown in Table-I.



(a)

(b)

Fig.5 Structure and membership functions of Fuzzy logic Controller (a) Structure of FLC (b) Input and output membership functions of FLC

TABLE I. RULE BASE FOR FLC

ce e	nh	n	z	p	ph
nh	nh	nh	nh	n	z
n	nh	nh	n	z	p
z	nh	n	z	p	ph
p	n	z	p	ph	ph
ph	z	p	ph	ph	ph

V. SIMULATION RESULTS AND DISCUSSION

In this work the performance of the STATCOM is analyzed under different load conditions. First the micro-grid is subjected to a linear RL load where the load is varied in steps and performance of the STATCOM is evaluated, using both PI and Fuzzy logic controller and the results are compared. A step increase in load is done at 10 s and at 15 s the load regains its previous value as shown in Fig. 6 and Fig. 7. Both the active and reactive power of the load increases. Due to the load change the variation in the load bus voltage is shown in Fig. 8. It can be clearly noted from the Fig. 8 that the deviation due to load change is more with PI controller where as there is no such deviation present with fuzzy logic controller. Other than that there is some steady state error present with PI controller which is zero in case of fuzzy logic controller. Fig. 9 shows the dc link voltage which is perfectly maintained at 1000 V. The flickering in the dc link voltage increases with the increase in load as seen from the Fig. 9. The reactive power compensated by the STATCOM is shown in Fig. 10.The reactive power compensated with PI controller is more than that with fuzzy logic controller due to the fact that the voltage maintained by the STATCOM with PI controller is more than that with fuzzy logic controller.

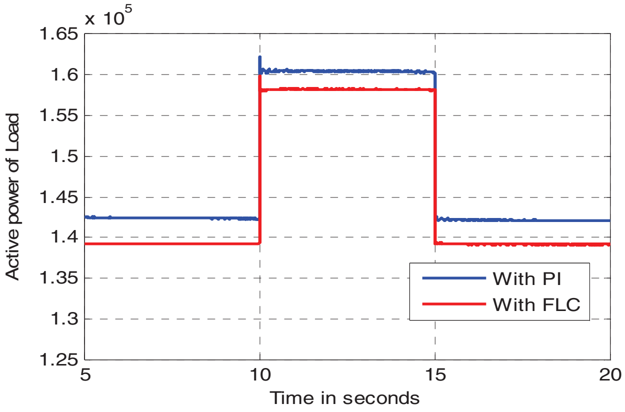


Fig. 6. Active power of linear load

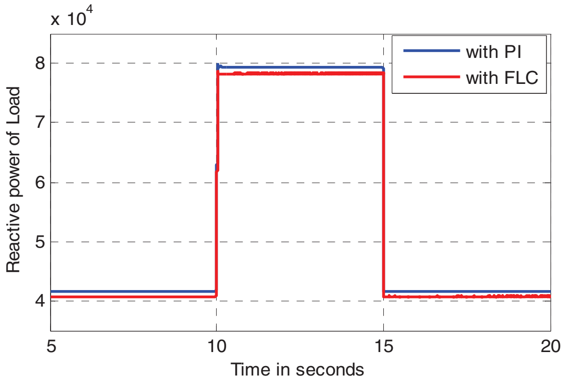


Fig. 7. Reactive power of linear load

The performance of the STATCOM is evaluated with non linear load. Fig. 11 shows the load bus voltage when the system is subjected to nonlinear load variations. Fig. 12 shows the reactive power compensated by the STATCOM. As the load bus voltage with PI controller is less than that with fuzzy logic controller, the reactive power compensated with fuzzy logic controller is more than that with PI controller.

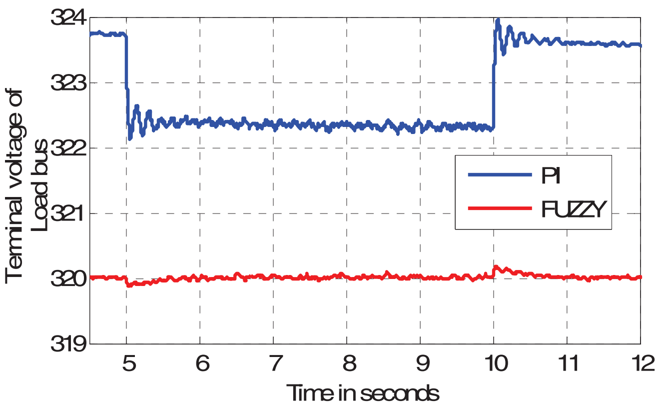


Fig. 8. Terminal voltage of Load bus with linear load

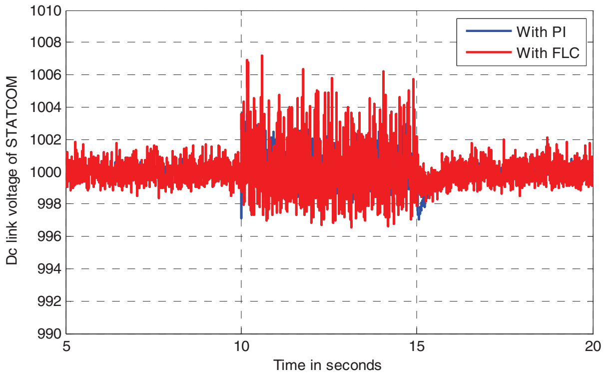


Fig. 9. DC link voltage of STATCOM

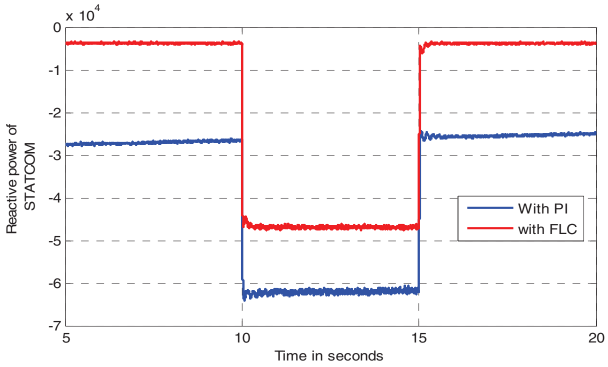


Fig. 10. Reactive power of STATCOM with linear load

The performance of STATCOM when subjected to dynamic load is discussed in this section. The dynamic load considered in this work is a squirrel cage induction motor. The motor is started at time 7 s and at 10 s the motor is subjected to a load torque of 70 N.m. Fig. 13 shows the load bus voltage during dynamic load variations. The steady state error overshoot, undershoot and settling time are more with PI controllers as compared to fuzzy logic controller. With all the evaluation results and analysis it is clear that fuzzy logic controller shows robust performance as compared to PI controllers. The performance of the controllers is compared and given in Table-II, III and IV.

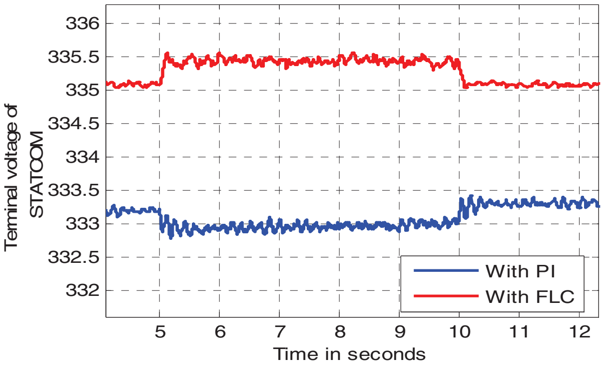


Fig. 11. Terminal voltage of STATCOM with nonlinear load

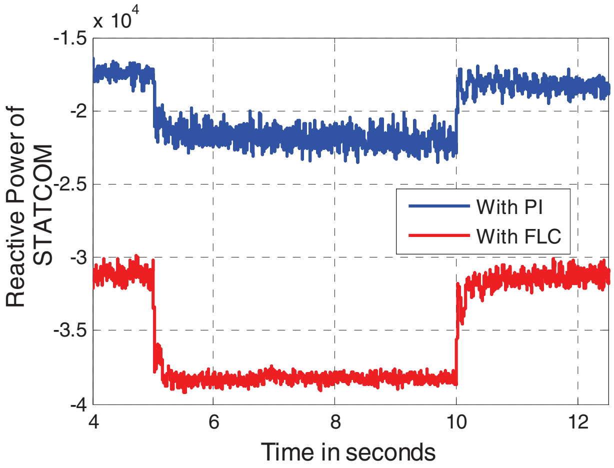


Fig. 12. Reactive power STATCOM with nonlinear load

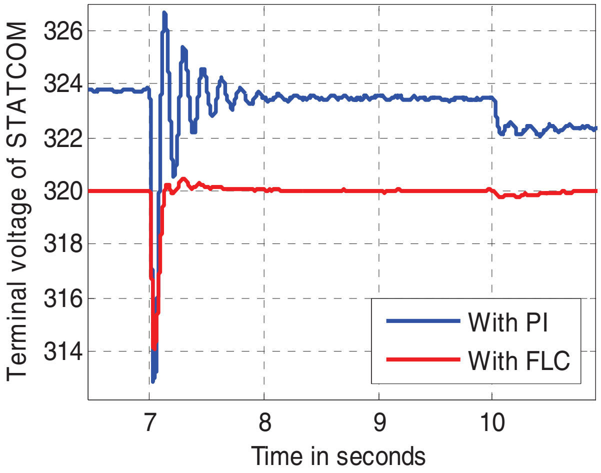


Fig. 13. Terminal voltage of STATCOM with Dynamic load

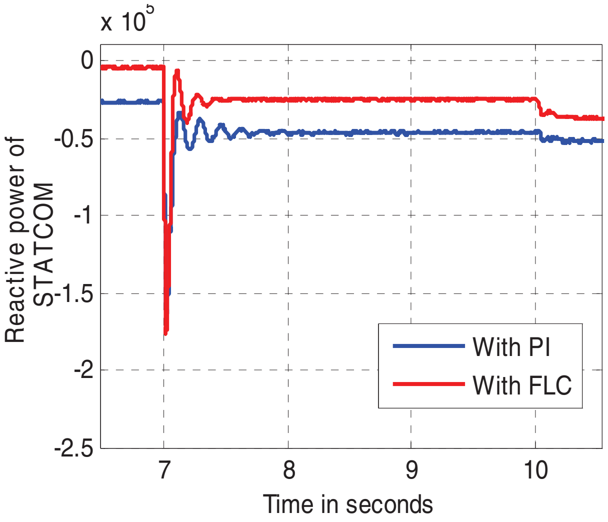


Fig. 14. Reactive power of STATCOM with Dynamic load

TABLE II. PERFORMANCE DETAILS WITH LINEAR LOAD

Controller	**V_t in volts**	**Steady state error in volts**		**Deviation in volts**	**Overshoot In volts**	**Under shoot In volts**
		Before load change	*After load change*			
PI	320	3.74	2.35	1.39	0.28	0.25
FLC	320	0	0	0	0	0.13

TABLE III. PERFORMANCE DETAILS WITH NONLINEAR LOAD

Controller	**Steady state error in volts**		**Deviation in volts**	**Overshoot In volts**	**Under shoot In volts**
	Before load change	*After load change*			
PI	1.8	2	0.2	0.12	0.1
FLC	0.1	0.4	0.3	0.15	0.05

TABLE IV. PERFORMANCE DETAILS WITH DYNAMIC LOAD

Controller	**During starting**				**After loading**		
	Steady state error	*overshoot*	*Undershoot*	*Settling time*	*Steady state error*	*overshoot*	*Undershoot*
PI	3.5	3.19	10.62	1.1	2.4	0.26	0.17
FLC	0	0.26	5.9	0.13	0	0.15	0.23

VI. CONCLUSION

The voltage profile of the single alternator based radial microgrid system is improved using a STATCOM. The controllers used for the control of STATCOM i.e. PI and fuzzy logic controller are designed in this work. The performances of both the controller are evaluated under three different load conditions such as linear RL load, nonlinear load and dynamic load. It is found that the steady state error is more with PI controller where as fuzzy logic controller gives accurate results without any steady state error. Again the overshoots, undershoots and settling time are also less with fuzzy logic controllers. The voltage deviation due to load change with fuzzy logic controllers is much less than conventional PI controllers. These all performances prove that fuzzy logic controller gives robust performance as compared to conventional PI controller in all types of load conditions.

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