INVESTIGATIONS ON VOLTAGE STABILITY IMPROVEMENT WITH STATCOM IN MULTIAREA SYSTEM USING FLC

First Govindasamy SUNDAR Second Sajan J MATHEW
Dept. of Electrical and Electronics Engineering
Sri Shakthi Institute of Engineering and Technology, Tamil Nadu, India.
sund_geee@yahoo.co.in[1], sajanjmathew04@gmail.com[2],

Third Balakrishnan PRABAKARAN
Dept. of Electrical and Electronics Engineering
Sri Shakthi Institute of Engineering and Technology, Tamil Nadu, India.
bp.siet@gmail.com

Abstract: *This paper deals with model, simulates and develop a multi area system with and without fault. So as to carry out improvement in power system stability during heavy load condition, by adding STATCOM controllers. The main contribution of this paper is (i) use of STATCOM to enhance transient stability and produce better voltage regulation (ii) analyzing the application of nonlinear control theory for stabilizing controller in a closed loop system. PI and fuzzy controller are used for controlling the STATCOM and the simulation results are obtained. The results indicate that there is improvement in the response of the closed loop system by using fuzzy logic controllers. The simulation results are validated setting up a prototype.*

Key words: *Static synchronous compensator (STATCOM), Fuzzy logic Controller (FLC), Voltage stability, Multi area system, Voltage regulation.*

1. Introduction

The system stability is a term in which AC power system remains in a condition of synchronized. System disturbances occur due to loading and switching operations. Large disturbances are due to faults, loss of a generation and loss of load. The problem of analyzing large disturbances called as transient stability analysis [1]. Voltage stability problems occur due to change in voltage level caused by transients. The variation in the voltage at the grid side leads to rotor angle deviation which in turn leads to the stability problem. The voltage and power angle are allowed to vary only for certain limits. Beyond that limit the system becomes unstable and the continuity of the system will be influenced [2].

FACTS devices are developed for power system to improve the performance and dynamic controllability of the system. Here, STATCOM one of the FACTS device is used and fuzzy logic controller is implemented for switching operation [3]. Reactive power compensation a major power system stability concern and STATCOM plays vital role in controlling the reactive power flow in the network, stability angle and the fluctuation in voltages. The active and reactive components of STATCOM current are controlled normally by using PI controller. When voltage collapse occurs at the bus, the STATCOM supplies almost constant reactive power without disturbing the system stability limit and maintain the system profile within the limit.

The fuzzy logic controller has been used in many applications where real time integration is required. It is a nonlinear controller so it is inert to the topology of the system, operating condition changes and parameters. This feature is an added specialty to the power system [4]. In this paper, STATCOM is designed along with the fuzzy logic controller to improve the transient stability of AC power systems [5]. The literature does not deal with fuzzy logic controlled STATCOM in two area system. This work proposes FLC for the control of STATCOM in multi area system as thirty bus systems under the consideration, with and without fault.

2. STATCOM

STATCOM exhibits constant current characteristics when the voltage is low/high under/over the limit [6]. The STATCOM regulates voltage at its terminals by controlling the amount of reactive power injected into or absorbed from the power system. For purely reactive power flow, the three phase voltages of STATCOM must be maintained in phase with the system voltages [7].

A STATCOM can improve power-system Performance like:

1. The dynamic voltage control in transmission and distribution systems,
2. The transient stability;
3. The voltage flicker control; and
4. The control of not only reactive power but also (if needed) active power in the connected line, requiring a DC energy source.

Furthermore, a STATCOM does the following:

1. It occupies a small footprint, since replacing passive banks of circuit elements by compact electronic converters;
2. It offers modular, factory-built equipment, thereby reducing site work and Commissioning time; and
3. It uses encapsulated electronic converters, thereby minimizing environmental impact.
The operating principle of STATCOM is explained in the Fig.1 showing the active and reactive power transfer between a power system and a VSC and Fig. 2. Shows the V-I characteristics of STATCOM. In this figure, V1 denotes the power system voltage to be controlled and V2 is the voltage produced by the VSC [8].

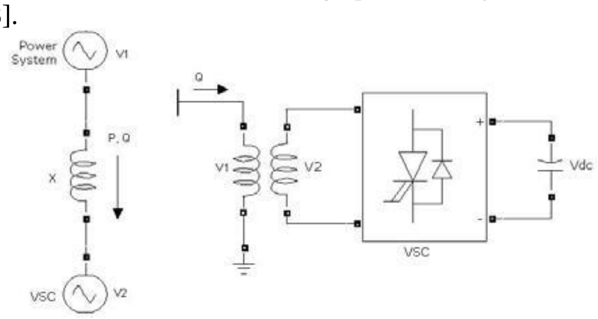

Fig 1.Schematic representation of STATCOM

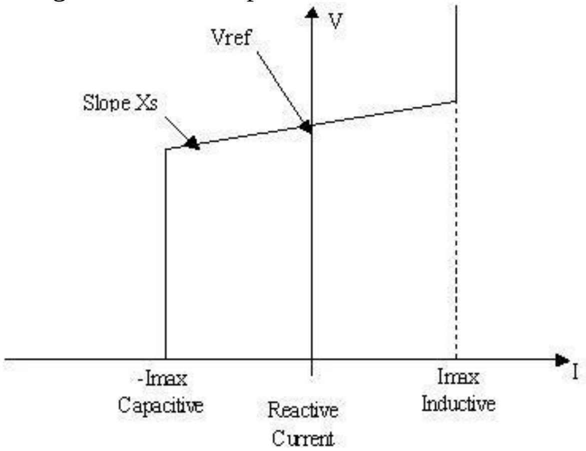

Fig 2. V-I characteristics of STATCOM

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, STATCOM 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. From the DC side capacitor, a three phase voltage is generated by the inverter. This is synchronized with the AC supply. The inductor links this voltage to the AC supply [9].

3. Fuzzy Logic Controller

This is one of the most victorious approaches to design a controller, which utilizes the qualitative information of a system and solves a problem with imprecision or suspicions is the Fuzzy Logic Controller. Fig. 3 shows the basic Fuzzy Logic Controller, which consists of an Input falsification block (binary-to-fuzzy [B/F] conversion), rule base (knowledge base), fuzzy Inference block and output de-fuzzification (fuzzy-to-binary [F/B] conversion). The voltage error and its integer value are fed as the input signals for the fuzzy
Controller [10].

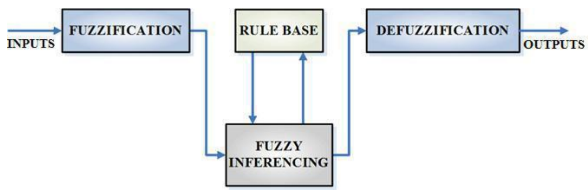

Fig. 3 Basic Fuzzy controllers

Broadly fuzzy logic controller designed is classified into following four states
1) Fuzzification
2) Knowledge base
3) Inference engine
4) De-fuzzification.

The function of fuzzification is a mapping of input to fuzzy logic, i.e. crisps value into fuzzy variables by using membership functions while function of fuzzy logic engine to infer the proper control actions based on given fuzzy rules. Under de-fuzzification, control actions translated into crisp values by using normalized membership functions. In this paper de-fuzzification of the output signal is done by using the centroid method.

Fuzzy based Controller has been designed by taking generator speed and its derivative as input while angle alpha as output [11].
The rules for the proposed FLC voltage controller are follows and same as mentioned in Fig.4 and Fig.5,
i) If Ve‘ is ENVVH‘ Then I‘ is INVVH‘
ii) If Ve‘ is ENVH‘ Then I‘ is INVH‘
iii) If Ve‘ is ENH‘ Then I‘ is INH‘
iv) If Ve‘ is ENM‘ Then I‘ is INM‘
v) If Ve‘ is ENL‘ Then I‘ is INL‘
vi) If Ve‘ is EZ‘ Then I‘ is IZ‘
vii) If Ve‘ is EPL‘ Then I‘ is IPL‘
viii) If Ve‘ is EPM‘ Then I‘ is IPM‘
ix) If Ve‘ is EPH‘ Then I‘ is IPH‘
x) If Ve‘ is EPVH‘ Then I‘ is IPVH‘ knowledge into fuzzy rules. In addition, it has inherent abilities to deal with imprecise or noisy data; thus, it is able to extend its control capability even to those operating conditions where linear control techniques fail (i.e., large parameter variations). The FLC voltage regulator is fed

by one input that is voltage error (Ve).

xi) If Ve‘ is EPVVH‘ Then I‘ is IPVVH‘

This paper focuses on fuzzy logic control based on Mamdani's system. This system has four main parts. First, using input membership functions, inputs are fuzzified, then based on rule bases and inference system, outputs are produced and finally the fuzzy outputs are defuzzified and applied to the main control system. Error of inputs from is chosen as input. Fig.4 and Fig.5 shows input and output membership functions [12].

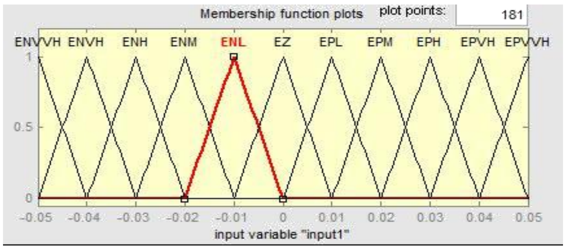

Fig. 4. Input membership function

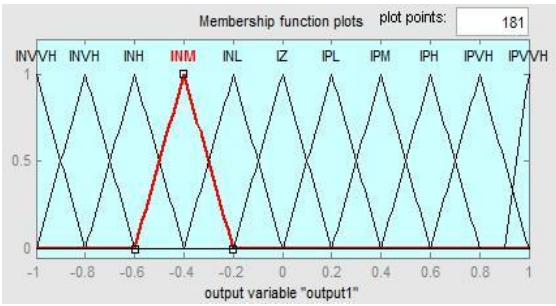

Fig. 5. Output membership function

All the variables of fuzzy subsets for the inputs ε and Δε are defined as seven linguistic variables such as: Positive Big (PB), Positive Medium (PM), Positive Small (PS), Zero (ZE), Negative Small (NS), Negative Medium (NM) and Negative Big (NB)). The membership functions and the universes of the inputs are illustrated in Table 1. For the output variable, the fuzzy subsets of the membership functions have a triangular shape only as it is illustrated [13-14].

Table 1:
Rules of fuzzy logic controller

ε /Δ	*NB*	*NM*	*NS*	*Z*	*PS*	*PM*	*PB*
NB	PB	PB	PM	PM	PS	PS	Z
NM	PB	PB	PM	PM	PS	Z	NS
NS	PM	PM	PM	PS	Z	NS	NM
Z	PM	PS	PS	Z	NS	NM	NM
PS	PS	PS	Z	NS	NS	NM	NM
PM	PS	Z	NS	NM	NM	NM	NB
PM	Z	NS	NS	NM	NM	NB	NB

4. Simulation Result

In this section the proposed system is simulated and its performance is analyzed. In Fig.6 the 30 bus system , 9 buses are generator buses and 21 buses are load buses without STATCOM. Reactive power at bus 4 and at bus 17 is shown in Fig.7and 8 respectively. There is no improvement in the system voltage, of load buses since there is no load compensation device provided with this condition.

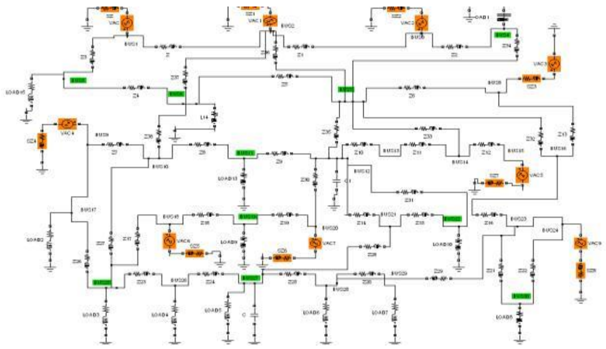

Fig. 6. Thirty Bus systems without STATCOM

The reactive power variation at bus 4 is shown in Fig.7, without connecting compensating device the reactive power is $1.21*10^{5}$ it is improved to $1.22*10^{5}$ with the connection using STATCOM.

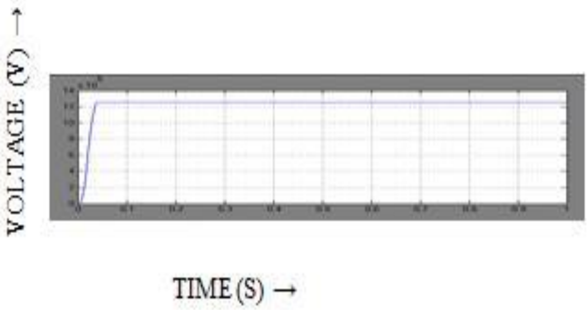

Fig 7. Reactive power at bus 4

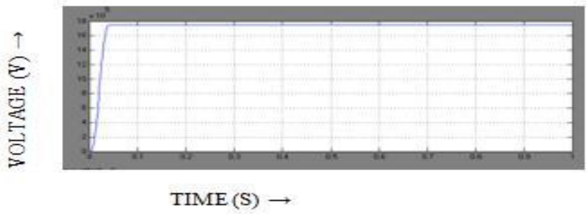

Fig 8. Reactive power at bus 17

30 bus systems with STATCOM are shown in Fig. 9. The real and reactive power at bus 17 and bus 25 are shown in Fig. 10 and Fig.11. The voltage drop occurs due to the load 2. It is compensated by injecting the voltage in the system. The rotor angle ∂ varies from 0.2 to 0.5s in the system without STATCOM. The duration of the time period is reduced to 0.2 to 0.3s with STATCOM and output voltage is improved and thereby the stability of the system is maintained.

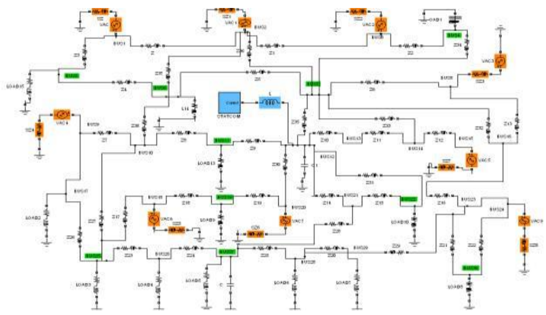

Fig.9 Thirty Bus system with STATCOM

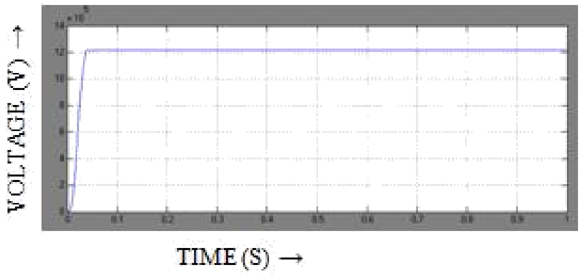

Fig.10 Reactive power at Bus 17

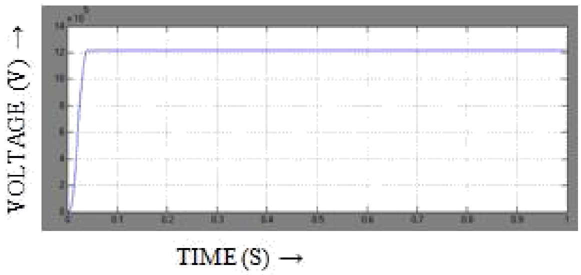

Fig 11. Reactive power at Bus 25

Table 2
Summary of reactive power

Bus	***Reactive power Without STATCOM (MVAR)***	***Reactive power With STATCOM (MVAR)***
Bus-4	1.21	1.22
Bus-5	1.09	1.12
Bus-11	1.00	1.06
Bus-17	1.57	1.573
Bus-19	1.27	1.28
Bus-22	0.97	0.977
Bus-25	1.12	1.27
Bus-27	1.025	1.03
Bus-30	0.89	0.893

The reactive power injection with and without STATCOM in to the various buses are tabulated in Table 2. The closed loop system with PI controller is shown in Fig.12.The output voltages of STATCOM, load1 & load2, real power and reactive powers are shown in Fig.13, 14,15 respectively.

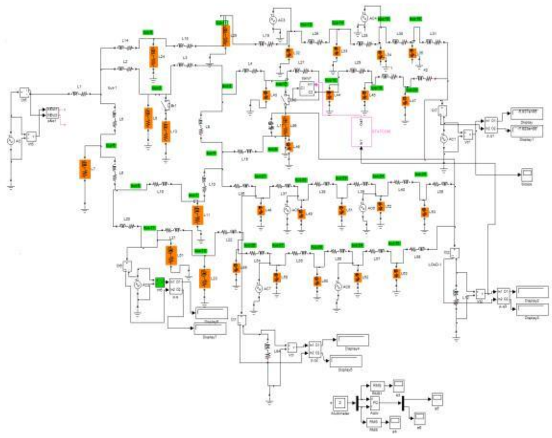

Fig.12. Closed loop thirty bus system with PI controller.

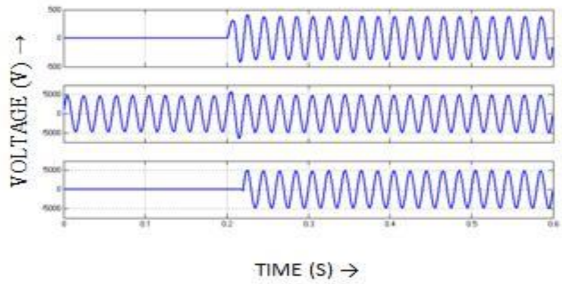

Fig 13. Output voltage of STATCOM, load 1 & load 2

When the load is applied it can be evident from the Fig.14 and Fig.15 that the real power and reactive power value of the system changed for a short duration of time then it is stabilized by the effect of STATCOM.

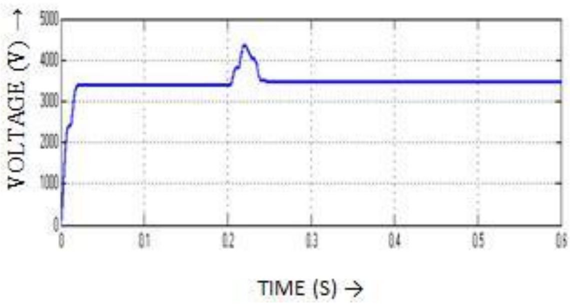

Fig.14. Real Power

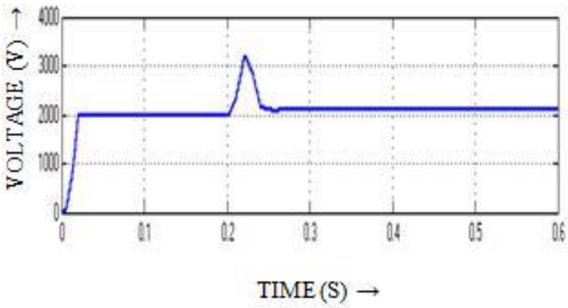

Fig.15. Reactive power

The closed loop system with fuzzy controller is shown in Fig.16. The main disadvantage of conventional PI controller is inability to react the abrupt changes in the error signal, because it is inefficient during nonlinear variation.

The Fuzzy logic controller is much efficient in dealing with nonlinear device. The determination of output control signal is done with an inference engine with a rule base. With the rule base, the value of the output is compared according to the value of the error signal and the rate of error and is given to the system.

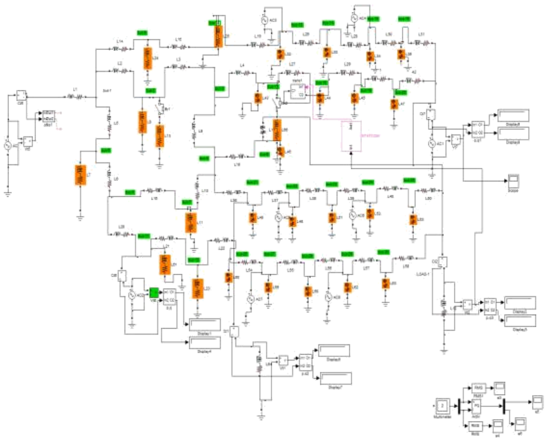

Fig. 16. Closed loop thirty bus system with fuzzy controller

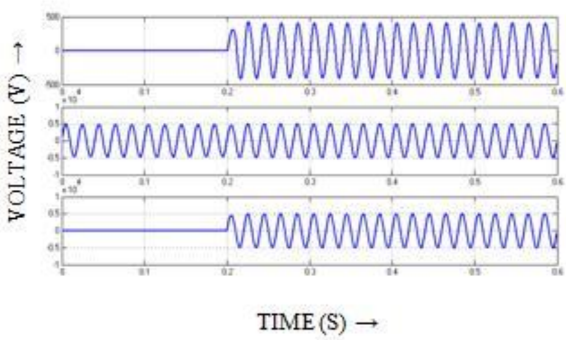

Fig 17. Output voltage of STATCOM, load 1 & load2

The output voltage of STATCOM, load 1 & load 2 with the closed loop fuzzy controller is shown in Fig.17. The settling time (T_s), rising time (T_r) and output (E_{ss}) of PI and Fuzzy Logic Controller in 30 bus systems are tabulated in table 3.

Table 3
Comparison of PI & Fuzzy Logic Controller in 30 bus systems

Controllers	T_s	T_r	E_{ss}
PI controller	0.25	0.23	1.8
FLC	0.21	0	0.06

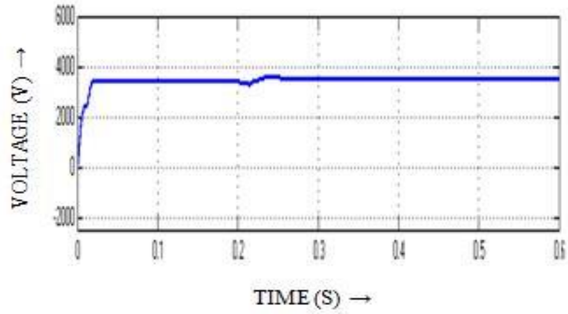

Fig 18. Real power

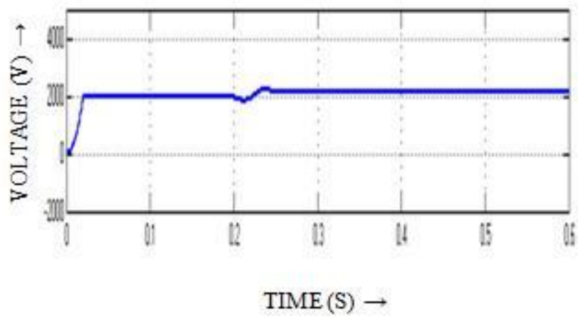

Fig 19. Reactive power

The output of real power and reactive power with the closed loop fuzzy controller is shown in Fig.18 and Fig.19 respectively. Compared to Fig. 14 and Fig.15 with Fig.18 and Fig.19, it is evident that with the use of fuzzy based controllers the fluctuation in the real power and reactive power while a PI controller is almost nullified or reduced by employing the fuzzy controller is more apt to the situation.

5. Hardware details

The experimental setup consists of control circuit, STATCOM and load. The control circuit comprises of the driver circuit for giving pulses to the converter switches.

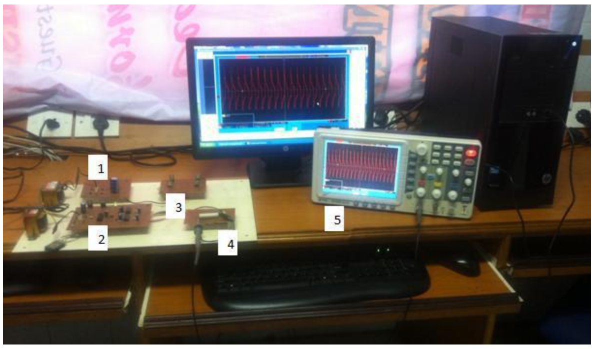

Fig. 20. Hardware setup 1- STATCOM.2-Driver circuit 3-Inverter.4-Load. 5- Digital CRO

The load connected to the converter is linear load 10W as shown in Fig. 20.The STATCOM is connected in parallel and in midpoint for effective operation. Parallel connection is done to inject the reactive power to the system.

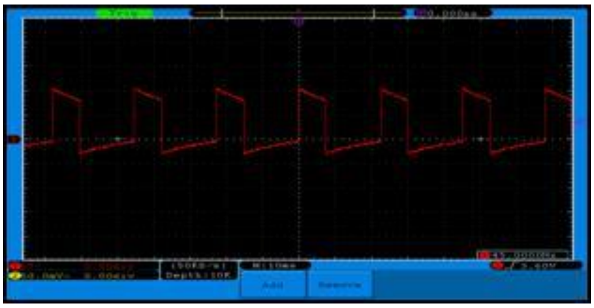

Fig. 21 Driver circuit input voltage

The Fig. 21 represents the input 5V given to the drive circuit. The driver circuit increases the voltage to 10V.Pulses for the time period of 50microsecond is shown in Fig.22.

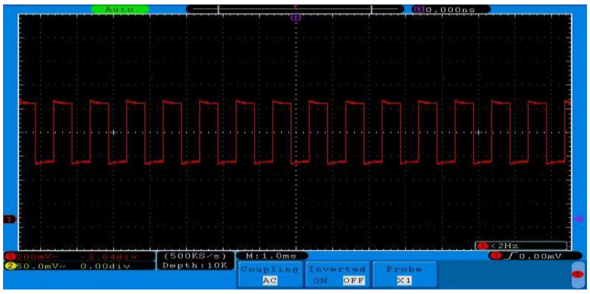

Fig. 22 Driver circuit output voltage

The output voltage waveform from the driver circuit is 10V, which is amplified from 5V for the time period of 50microsecond as shown in Fig.22.

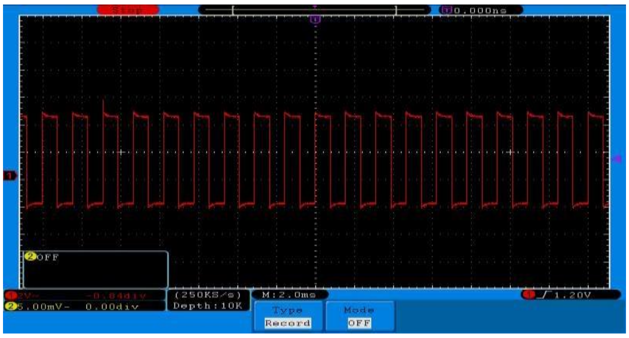

Fig. 23 Input voltage of inverter

The input voltage obtained from the STATCOM is shown in Fig.23, for the time period of 50 microseconds with frequency 24.9 KHz. Output voltage with filter is shown in Fig 24 for the time period of 50 microseconds and 25KHz.The output voltage obtained from the load is 55V.

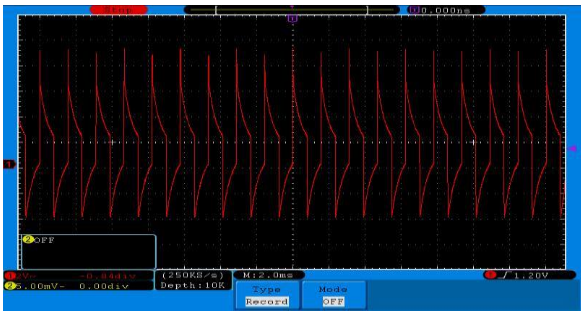

Fig. 24 output voltage of R load with filter

6. Conclusion

A thirty bus system with and without STATCOM along with PI and fuzzy logic controller systems are modeled and simulated successfully. STATCOM can improve the voltage stability there by power system stability, duration of sag which is reduced by the injection of reactive power. Another capstone derived is that the fuzzy based controller suit to the condition more adaptable than PI based controllers. Its response is more accurate than the PI based controllers when the load is applied. The stability of the system is maintained with an uninterrupted flow of power to the load. The hardware is fabricated and tested. The results of hardware closely match with simulation output.

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