Fuzzy Logic Control Method for D-STATCOM to Mitigate Voltage Sags and Swells

Rakesh M N
Assistant Professor, Electrical and Electronics Engineering
R.N.S Institute of Technology
Bengaluru, Karnataka, India
mn.rakesh@yahoo.com

S G Srivani
Associate Professor ,Electrical and Electronics Engineering
R.V.College of Engineering
Bengaluru, Karnataka,India
srivani.sg@gmail.com

Abstract— **This paper presents a robust control scheme to vary the gate pulse pattern of the switching devices of D-STATCOM, a custom power device used to maintain the voltage profile of a distribution system dynamically. The work is carried out on IEEE 13 bus industrial distribution system with a shunt compensating device. The system receives 69KV from the grid and distribution feeder is rated for 13.8KV. D-STATCOM is realized using eight 6 pulse insulated Gate Bipolar Transistor (IGBT) voltage source inverters(VSI) for reactive power compensation and voltage stabilization for the cases of voltage sag and swell. The control strategy used in this work is fuzzy logic controller (FLC). FLC overcomes the drawbacks of conventional controllers like Proportional integral (PI) and proportional integral derivative (PID) controllers and provides a dynamic control action to vary the gate signals given to the power electronic switches which provides voltage support to the load bus thus mitigating power quality issues such as voltage sag or swell caused due to varying load patterns. FLC do not require precise mathematical modeling of the system as in the case of PI and PID controllers. A test distribution network, subjected to sensitive load variation is simulated with and without compensation. The response obtained clearly demonstrates the effectiveness and robustness in voltage stability and power quality issues. The simulation work is carried out in MATLAB/Simulink environment.**

Keywords—D-STATCOM, Power Quality, Fuzzy Logic

I. INTRODUCTION

Power quality(PQ) issues such as voltage sag and swell contributes more than 80% that exist in power systems. Sensitive equipments such as Variable speed drives (VSD) used in modern industrial plants are sensitive to voltage sag[1]. Conventional methods such as usage of capacitor banks, introduction of new parallel feeders to mitigate voltage sag could not solve the issue satisfactorily due to uncontrolled reactive power compensation and high cost incurred to install parallel feeders. Flexible AC transmission systems (FACTS) provide proven technical solution to these operating challenges. One such device which is located in shunt with distribution network is static synchronous compensator D-STATCOM [1].For realization of shunt compensating device cost effective high power VSI are necessary. Multi level inverters with higher operating range are built due to effective operation at lower switching frequencies, generating very low harmonic component symmetrical output voltages than conventional two pulse inverters[2].

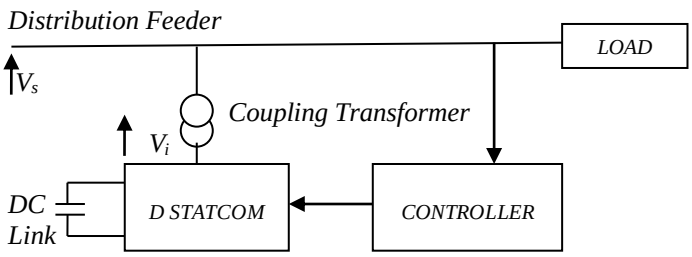
This paper deals with cascaded multilevel converterer model. There are three topologies of multilevel inverters: cascaded, flying capacitor and diode clamped. The benefits of multilevel inverter configurations are they draw input current with low distortion, do not require harmonic filters [3]. In this work diode clamped, 48 pulse voltage source inverter is designed. Multilevel configurations can be realized using four, 12-pulse inverters with four phase shifting transformers [4]. For effective harmonic neutralization, 48 pulse converters is built using eight 6 pulse inverters with eight phase shifting transformers. Voltage generated by each six pulse circuits are applied to secondary windings of eight zig-zag phase shifting transformers.

In this paper, using fuzzy logic controller (FLC) a closed loop control scheme is designed for dynamic operation of D-STATCOM. Unlike PI and PID controllers FLC do not require any mathematical modeling and any effects of any uncertainities, disturbances and unmodelled dynamics of the system can be compensated [2].

II. D-STATCOM

D-STATCOM is static counterpart of synchronous condenser and in principle performs the same regulation function of static voltage controllers (SVC), but in a robust manner. Major attributes of STATCOM are quick response time, higher flexibility in operation under various conditions. It regulates bus voltage magnitude by absorbing or generating reactive power to grid dynamically[3]. Fig. 1 shows VSI converts an input DC voltage to an AC at fundamental frequency. These voltages are in phase and coupled with grid electromagnetically through coupling transformer.

Typical six pulse inverter is shown in Fig. 2. A 24 pulse inverter can be obtained by connecting four such inverters in series. For high power applications, low distortion 48 pulse inverters are preferred, which is realized using eight six pulse inverters.



V_i Output of VSI, V_s System voltage.

Fig.1 D-STATCOM representation

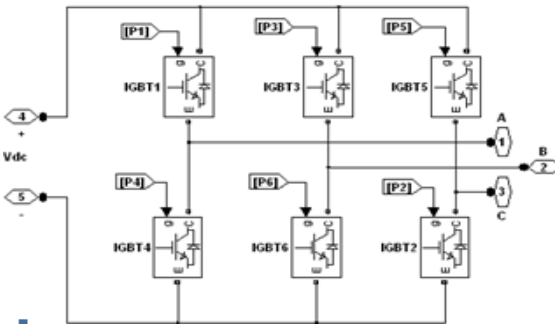


Fig. 2 Typical six pulse inverter

In this paper 48-pulse operation is realized with eight six pulse groups, with one set of transformers of one 24-pulse converter phase shifted from other by 7.5 degrees, or one set shifted by +3.75 degrees and the other by -3.75 degrees. With 48-pulse operation, ac filters should not be necessary [4]. Fig. 3 shows the output of 48 pulse IGBT based voltage source inverter built using eight 6 pulse inverters.

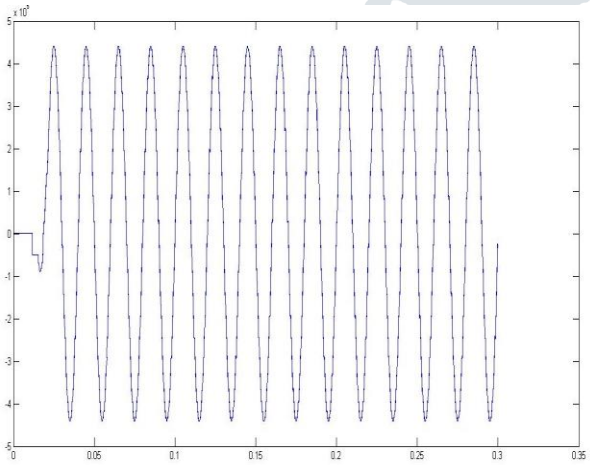


Fig. 3 Output of 48 pulse IGBT based VSI.

III. CONTROL SCHEME FOR D-STATCOM

To maintain the voltage profile of a node in a power system dynamically, gate pulse pattern of switching devices in D-STATCOM has to be varied. The line voltage are sensed at a particular node and using park's transformation d-q components are obtained. Park's transformation computes the direct axis, quadratic axis, and zero sequence quantities in a two-axis rotating reference frame for a three-phase sinusoidal signal. The following transformation is used

$$V_d = \frac{2}{3}\left(V_a \sin(\omega t) + V_b \sin\left(\omega t - 2\pi/3\right) + V_c \sin\left(\omega t + 2\pi/3\right)\right) \quad (1)$$

$$V_q = \frac{2}{3}\left(V_a \cos(\omega t) + V_b \cos\left(\omega t - 2\pi/3\right) + V_c \cos\left(\omega t + 2\pi/3\right)\right) \quad (2)$$

$$V_0 = \frac{1}{3}\left(V_a + V_b + V_c\right) \quad (3)$$

Reference voltage V_{ref} is compared with actual voltage component $\sqrt{V_d^2 + V_q^2}$ to get the error signal. Error signal is given as input to FLC. Fig. 4 represents the control scheme.

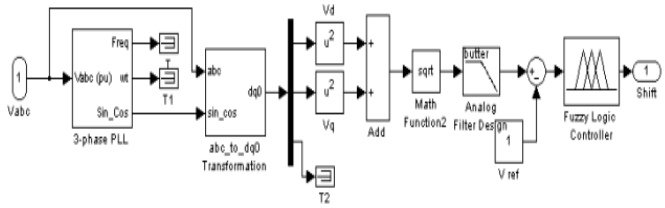


Fig. 4 D-STATCOM closed loop control scheme

Fuzzy logic controller is a non linear controller and its insensitivity to system topology makes it appropriate for power system application[5]. Fig. 5 shows degree of membership function used for fuzzification and defuzzification. Error in RMS value of voltage measured with respect to reference is taken as input variable and gating pattern to switching devices of D-STATCOM is taken as output variable of FLC. Set of fuzzy rules for processing the error signal is shown in Table.1.

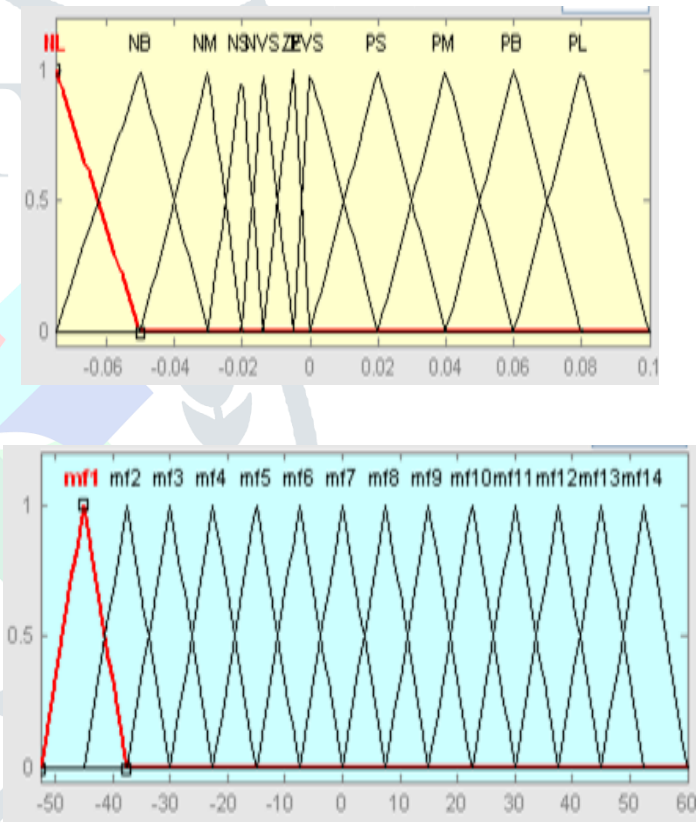


Fig. 5 Membership function of error and output of FLC's

TABLE. 1 FUZZY RULES

Error (Input)	Gate Pulse Variation (Output)
NB - Negative Big	-52.5^0 to -37.5^0
NM- Negative Medium	-45^0 to -30^0
NS - Negative Small	-37.5^0 to -22.5^0
NVS-Negative Very Small	-30^0 to -15^0
ZE - Zero	-22.5^0 to -7.5^0
PVS-Positive Very Small	-15^0 to 0^0
PS- Positive Small	0^0 to 15^0
PM- Positive Medium	7.5^0 to 22.5^0
PB - Positive Big	37.5^0 to 52.5^0
PL - Positive Large	45^0 to 60^0

Gate pulse pattern to trigger the switching devices are set based on the fuzzy rules framed.

IV. RESULTS AND DISCUSSION

To verify the proposed method in order to mitigate voltage sag and swell, the IEEE 13 bus distribution system is employed. It consists of 13 buses representing medium sized industrial plant [6]. The plant is fed from a utility supply at 69kV and the distribution system of the plant operates at 13.8KV. The system is shown in Fig. 6. A 48 pulse VSI based D-STATCOM is connected in shunt with the system by closing breaker at 0.1s, for maintaining load RMS voltage at 1 p.u. The system is simulated for the cases of voltage sag and swell caused by dynamic loading at bus 12 in the system.

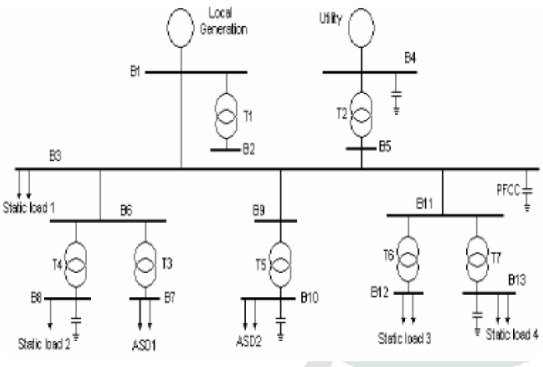


Fig. 6 IEEE 13 bus test system

A. *Simulation results for voltage sag*

The RMS and line voltages V_{abc} at bus 12 and error signal provided as input to FLC are respectively shown in Figs. 7,8 and 9. The case when system operates without D-STATCOM and under addition of load. Voltage drops by almost 20% with respect to reference value. At t=0.1s, the D-STATCOM is connected to the distribution system. Voltage sag at bus 12 is corrected using proposed control scheme. Figs. 10 and 11 show the mitigated RMS and line voltages using control method which provides voltage regulation. Between time periods 0.1s and 0.2 s, D-STATCOM injects the required reactive power to the system, maintaining the voltage profile. The error in voltage reduced by reactive power compensation is shown in Fig. 12.

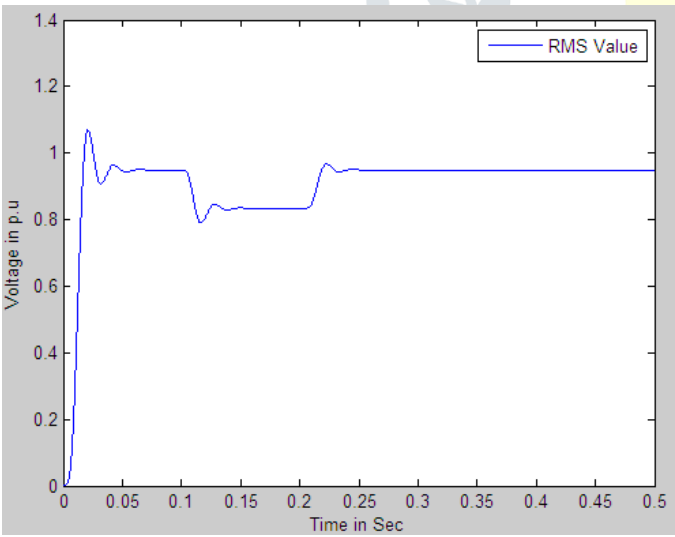


Fig. 7 RMS value of voltage at bus 12 with sag.

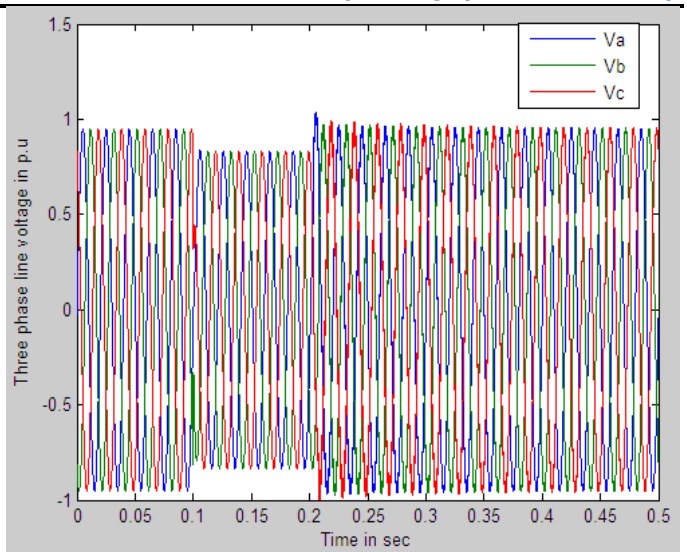


Fig. 8 Three phase line voltage at bus 12 with voltage sag

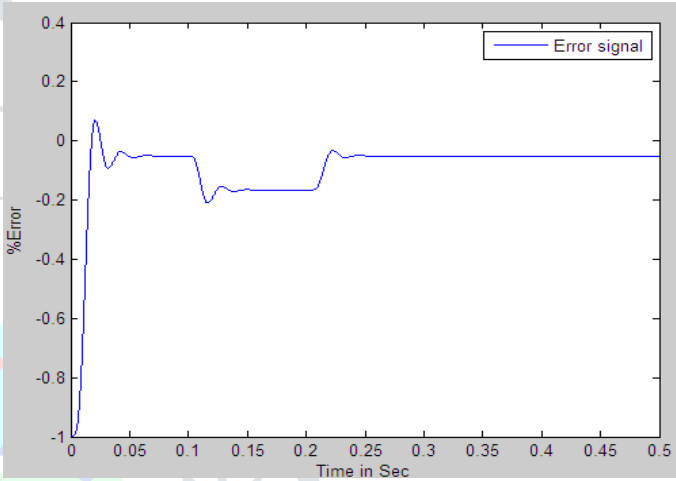


Fig.9 Error signal during voltage sag

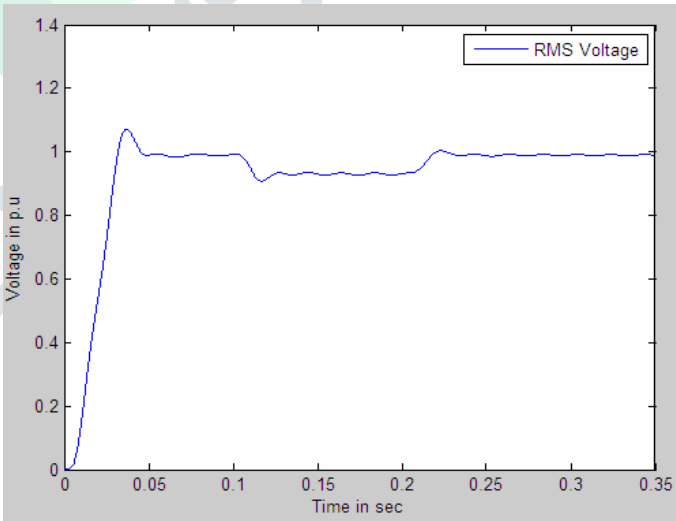


Fig. 10 RMS value of voltage at bus 12 with sag compensated.

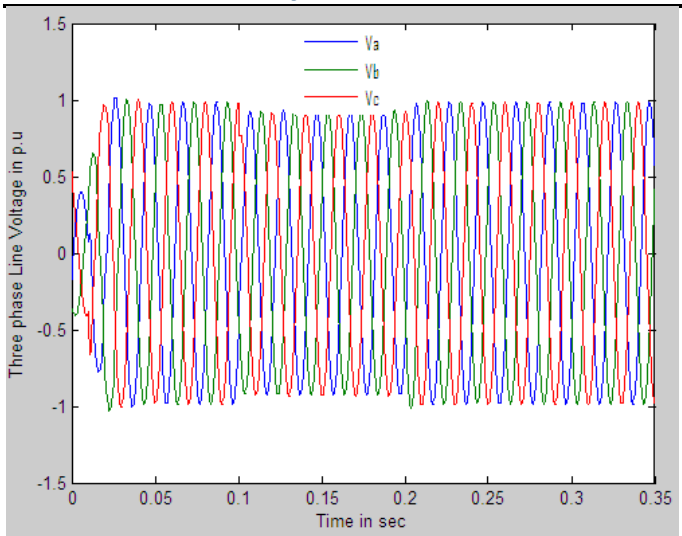


Fig. 11 Three phase line voltage at bus 12 with sag compensated.

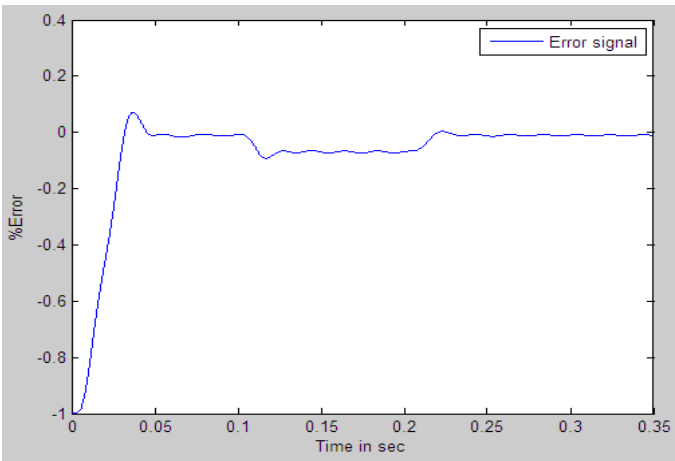


Fig. 12 Error signal after compensation

B. *Simulation results for voltage swell*

Figs.13 and 14 represents RMS and line voltages V_{abc} at bus 12 when the system operates without compensation by the FACTS device with load reduction. Voltage profile increases by 30% with respect to reference value. D-STATCOM with its closed loop control mechanism maintains the voltage at 1 p.u. Figs. 15 and 16 show the corrected RMS voltage and line voltages by FLC applied to STATCOM between 0.1s and 0.2s. Figs. 17 and 18 indicates the error signals before and after compensation.

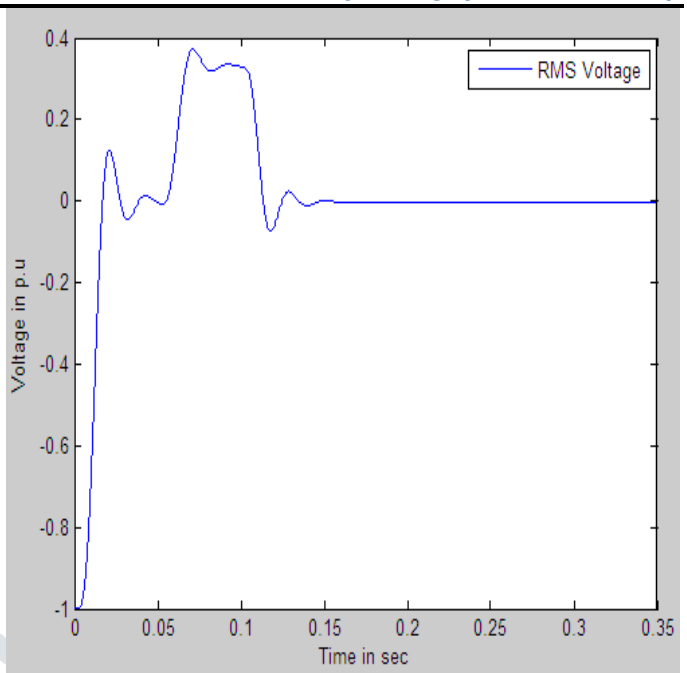


Fig. 13 RMS value of voltage at bus 12 with swell.

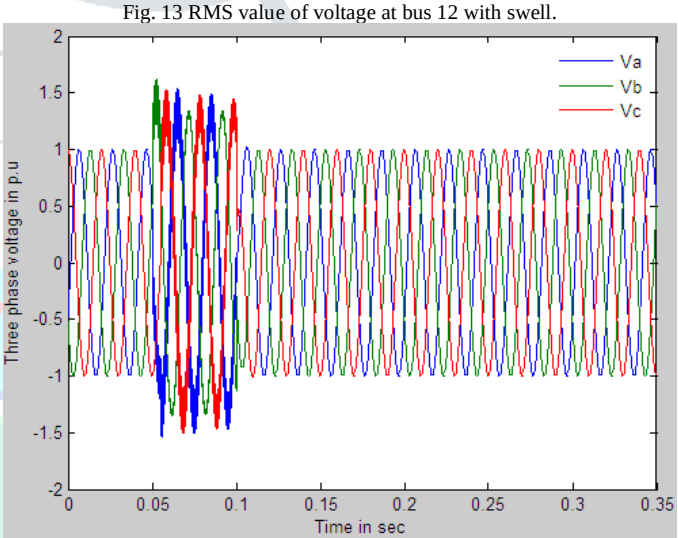


Fig. 14. Three phase line voltage at bus 12 with swell.

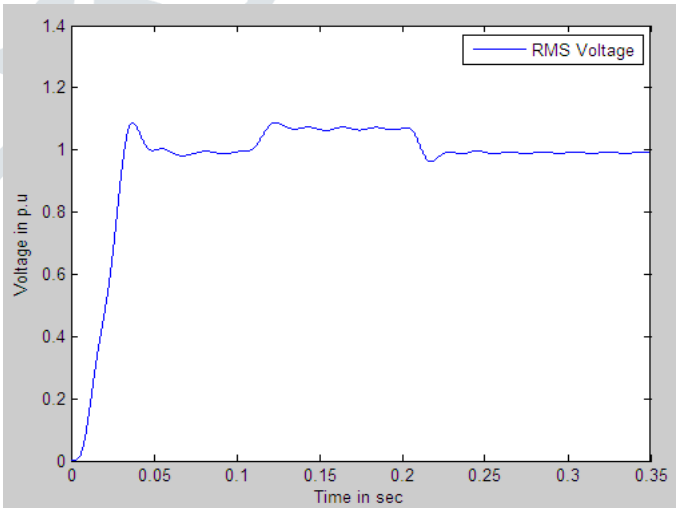


Fig 15. RMS value of voltage at bus 12 with swell compensated.

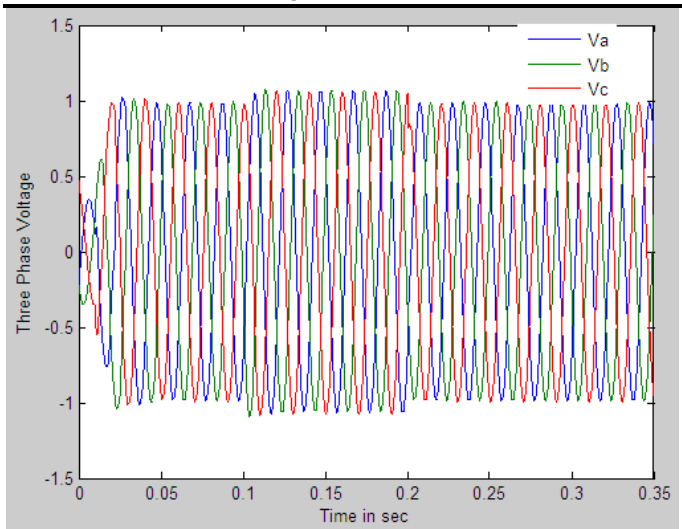


Fig 16. Three phase line voltage at bus 12 with swell compensated

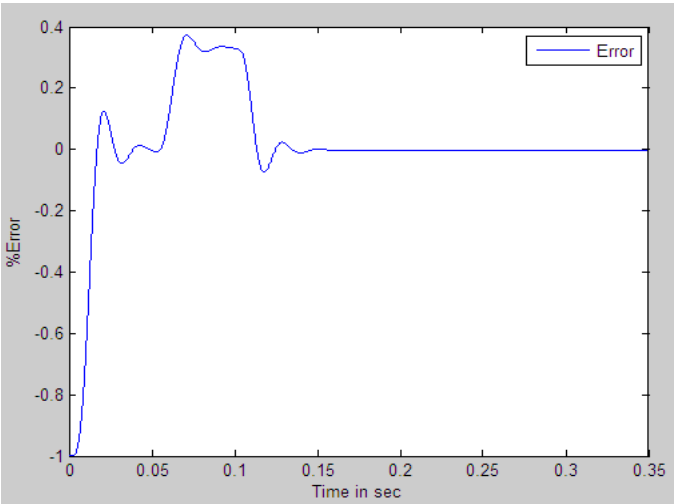


Fig 17. Error signal during voltage swell.

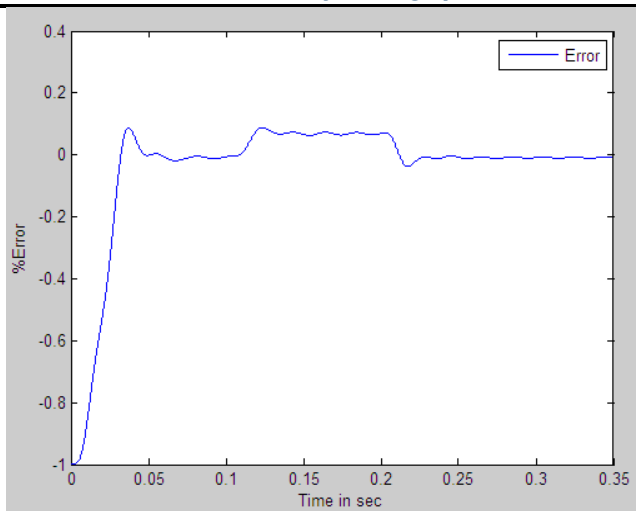


Fig 18. Error signal after voltage swell compensation.

V. CONCLUSION

A 48 pulse multilvel cascaded voltage source inverter was designed to operate as D-STATCOM to adress the power quality issues such as voltage sag and swell dynamically. The compensating device is connected in shunt with the IEEE 13 bus industrial distribution system. A closed loop control scheme using FLC is designed to vary the gating pattern of the switching devices with change in magnitude of the voltage at bus 12 as input to the control system. The distribution system is extensively tested for dynamic load variations and the performance of the control scheme is validated with the results obtained for voltage sag and swell at a given bus.

REFERENCES

[1] Seyed Hossein Hosseini, Member, IEEE, Amin Nazarloo, Student member, IEEE, Ebrahim Babaei, "Super- capacitor based D-STATCOM applied in IEEE 13-bus industrial distributiom system". The 8th Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI) Association of Thailand-Conference 2011, pp 715-718.

[2] B.Geetha Lakshmi, T.Hajmunnisa, P.Dananjayan, "A Fuzzy Logic Controller for enhancing the Transient Stability of 48-Pulse inverter based SSSC", Elecktrica, Vol.10, No.2, 2008, pp 53-58.

[3] Narain.G.Hingorani and Laszlo Gyugyi, "Understanding FACTS,concepts and Technology of Flexible A.C. Transmission Systems", IEEE Press, New York 2000.

[4] M.S.El-Moursi and A.M.Sharaf, Senior Member,IEEE, "Novel Controllers for the 48- pulse VSC STATCOM and SSSC for Voltage Regulation and Reactive Power Compensation", IEEE Transaction on power systems, Vol 20, No.4, November 2005.

[5] Seyed Hossein Hosseini, Reza Rahnavard, Yousef Ebrahimi, "Reactive Power Compensation in Distribution Networks with STATCOM by Fuzzy Logic Theory Application", IEEE Transaction 1-4244-4249-5/06,2006.

[6] Transmission and Distribution Committee, IEEE Power Engineering Society, " Test system for harmonic modeling and simulation", IEEE Trans on Power Delivery, Vol. 14, pp. 579-583, April 1999.