RESEARCH ARTICLE OPEN ACCESS

# Fuzzy Logic Control of D-Statcom for Power Quality Improvement

D. Prasad* T. Sandeep Kumar** Dr.B.Venkata Prasanth*** Dr.K.S.G.Sankar****
*Department of Electrical and Electronics Engineering, QISCET, ONGOLE
**Department of Electrical and Electronics Engineering, QISCET, ONGOLE
***Department of Electrical and Electronics Engineering, QISCET, ONGOLE
****Department of Electrical and Electronics Engineering, QISCET, ONGOLE

**ABSTRACT**
A Power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure or a mis-operation of end user equipments. Utility distribution networks, sensitive industrial loads and critical commercial operations suffer from various types of outages and service interruptions which can cost significant financial losses. With the restructuring of power systems and with shifting trend towards distributed and dispersed generation, the issue of power quality is going to take newer dimensions. This paper presents the Fuzzy Logic control of D-statcom to enhancement of voltage sags, harmonic distortion and low power factor using Distribution Static Compensator (D-STATCOM) with LCL Passive Filter in distribution system. The model is based on the Voltage Source Converter (VSC) principle. The D-STATCOM injects a current into the system to mitigate the voltage sags.LCL Passive Filter was then added to D-STATCOM to improve harmonic distortion and low power factor. Time domain simulations are used to verify the operation of the D-statcom with various faults and fault resistance.

**Keywords-** D-STATCOM, Voltage Sags, Voltage Source Converter (VSC), LCL Passive Filter, Total harmonics Distortion (THD)

## I. INTRODUCTION

Power quality is certainly a major concern in the present era. It becomes especially important with the insertion of sophisticated devices, whose performance is very sensitive to the quality of power supply. A Power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure or a mis-operation of end user equipments. Modern industrial processes are mainly based on electronic devices such as PLC's, power electronic devices, drives etc., and since their controls are sensitive to disturbances such as voltage sag , swell and harmonics , voltage sag is most important power quality problems It contributes more than 80% of power quality (PQ) problems that exist in power systems, and more concern problems faced by many industries and utilities. By definition, a voltage sag is an rms (root mean square) reduction in the AC voltage at the power frequency, for duration from a half-cycle to a few seconds. Voltage sag is caused by a fault in the utility system, a fault within the customer's facility or a large increase of the load current, like starting a motor or transformer energizing. Typical faults are single-phase or multiple-phase short circuits, which leads to high currents. The high current results in a voltage drop over the network impedance. Voltage sags are not tolerated by sensitive equipments used in modern industrial plants such as process controllers; programmable logic controllers (PLC), adjustable speed drive (ASD) and robotics. Various methods have been applied to reduce or mitigate voltage sags. The conventional methods are by using capacitor banks, introduction of new parallel feeders and by installing uninterruptible power supplies (UPS). However, the PQ problems are not solved completely due to uncontrollable reactive power compensation and high costs of new feeders and UPS. The D-STATCOM has emerged as a promising device to provide not only for voltage sags mitigation but a host of other power quality solutions such as voltage stabilization, flicker suppression, power factor correction and harmonic control. In this paper, the configuration and design of the DSTATCOM with LCL Passive Filter are analyzed. It is connected in shunt or parallel to the 11 kV test distribution System. It also is design to enhance the power quality such as voltage sags, harmonic distortion and low power factor in distribution system . This paper is divided into several sections. Section II describes about the voltage sag and swell. Section III indicates the Modeling and Controlling of D-statcom. Fuzzy logic controller is discussed in section IV and System Implementation and Simulation results are discussed in sections V and VI respectively.

## II. VOLTAGE SAGS/SWELLS

Voltage sags/swells caused by unsymmetrical line-to line, single line to ground (SLG), double-line-to-ground and symmetrical three phase faults effects on sensitive loads, the DVR injects the independent voltages to restore and maintained sensitive to its nominal value The injection power of the DVR with zero or minimum power for compensation purposes can be achieved by choosing an appropriate amplitude and phase angle [9].Voltage sags can occur at any instant of time, with amplitudes ranging from 10-90% and a duration lasting for half a cycle to one minute [2]. Voltage swell, on the other hand, is defined as an increase in rms voltage or current at the power frequency for durations from 0.5 cycles to 1 minute. Typical magnitudes are between 1.1 and 1.8 up. Swell magnitude is also described by its remaining voltage, in this case, always greater than 1.0. [3]. IEEE 519-1992 and IEEE 1159-1995 describe the voltage sags/swells as shown in Figure 1.

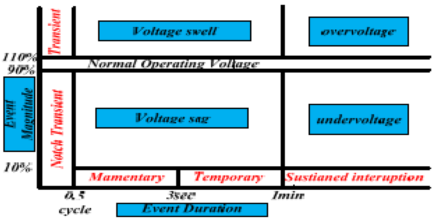


Fig. 1. Voltage reduction standard of IEEE 1159-1995

Due to the fact that voltage swells are less common in distribution systems, they are not as important as voltage sags. Voltage sag and swell can cause sensitive equipment (such as found in semiconductor or chemical plants) to fail, or shutdown, as well as create a large current unbalance that could blow fuses or trip breakers. These effects can be very expensive for customers, ranging from minor quality variations to produce downtime and equipment damage [4].

## III. MODELING AND CONTROL OF D- STATCOM

DSTATCOM [1] is a voltage source converter (VSC) that is connected in shunt with the distribution system by means of a tie reactance connected to compensate the load current. In general, a coupling transformer is installed between the distribution system and the DSTATCOM for isolating the DSTATCOM from the distribution system. In addition, the device needs to be installed as close to the sensitive load as possible to maximize the compensating capability. Being a shunt connected device, the DSTATCOM mainly injects reactive power to the system. The role of DSTATCOM is specifically appreciated in case of a weak AC system [2]. The main components of DSTATCOM are – a VSC (voltage source converter), controller, filter, and energy storage device. The system scheme of DSTATCOM is shown in Figure 2. These are briefly described as follows:

***A. Isolation transformer***: It connects the DSTATCOM to the distribution network and its main purpose is to maintain isolation between the DSTATCOM circuit and the distribution network.

***B. Voltage source converter****:* A voltage source converter consists of a storage device and devices of switching, generating a sinusoidal voltage at any required frequency, magnitude and phase angle. In the DSTATCOM application, this temporarily replaces the supply voltage or generates the part of the supply voltage which is absent and injects the compensating current into the distribution network depending upon the amount of unbalance or distortion. In this work, an IGBT is used as the switching device.

$$I_{out} = I_L - I_S = I_L - \frac{V_{th} - V_L}{Z_{th}} \quad \text{--1}$$

$$I_{out} < \gamma = I_L < (-\theta) - \frac{V_{th}}{Z_{th}} < (\delta - \beta) + \frac{V_L}{Z_{th}} < (-\beta) \quad 2$$

$I_{out}$ = output current $I_L$ = load current

$I_s$ = source current $V_{th}$ = Thevenin Voltage

$V_L$ = load voltage $Z_{th}$ = impedance

***C. DC charging unit:*** This unit charges the energy source after a compensation event and also maintains the dc link voltage at the nominal value.

***D. Harmonic filters****:* The main function of harmonic filter is to filter out the unwanted harmonics generated by the VSC and hence, keep the harmonic level within the permissible limit. Energy storage unit: Energy storage units like flywheels, batteries, superconducting magnetic energy Storage (SMES) and super capacitors store energy. It serves as the real power requirements of the system when DSTATCOM is used for compensation [3]. In case, no energy source is connected to the DC bus, then the average power exchanged by the DSTATCOM is zero assuming the switches, reactors, and capacitors to be ideal. Figure 2 represents the schematic scheme of DSTATCOM in which the shunt injected current Ish corrects the voltage sag by adjusting the voltage drop across the system impedance Zth and value of Ish can be controlled by altering the output voltage of the converter [4].

$$L_g = \frac{E_n}{2\sqrt{6} i_{ripm} f_{sw}}$$

$$L_c = \frac{L_g}{2}$$

$$C_f = \frac{L + L_g}{L L_g (2\pi f_{res})^2}$$

--3,4,5

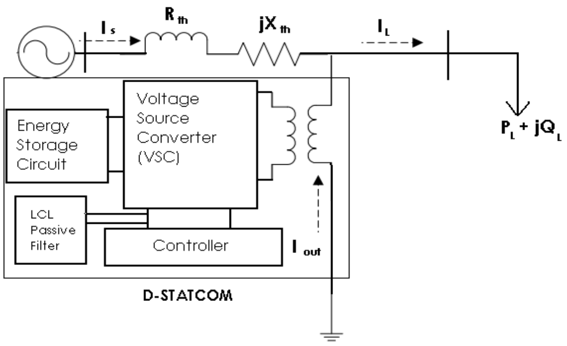


Fig 2: System scheme for d- statcom

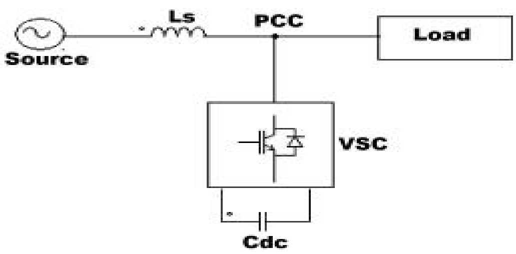


Fig 3: Basic structure of d-statcom

***E. Control system:***

The effectiveness of the DSTATCOM in correcting the fault depends on the value of Zth or fault level of the load bus. When the shunt supplied current Ish is set in quadrature with VL, the desired correction of voltage can be achieved without injecting any active power into the system. Alternatively, when the value of Ish is decreased, the same correction of voltage can be achieved with minimum apparent power injection into the system. The contribution of the DSTATCOM to the load bus voltage equals the injected current times the impedance seen from the device also, that is the source impedance in parallel with the load impedance. The ability of the STATCOM to compensate the voltage dip is limited by this available parallel impedance. It helps to reduce the voltage fluctuations at the PCC (point of common coupling) [5], [6]. Voltage dips can be mitigated by DSTATCOM, which is based on a shunt connected voltage source converter. VSC with pulse-width modulation (PWM) offers fast and reliable control for voltage dips mitigation.

## IV. FUZZY LOGIC CONTROLLER

The Fuzzy Logic Controller (FLC) is used as controller in the proposed model. The Fuzzy Logic tool was introduced in 1965, also by Lotfi Zadeh, and is a mathematical tool for dealing with uncertainty. It offers to a soft computing partnership ‗the important concept of computing with words‘. It provides a technique to deal with imprecision and information granularity. The fuzzy theory provides a mechanism for representing linguistic constructs such as 'many' 'low' 'medium' 'often' 'few'. In general, the fuzzy logic provides an inference structure that enables appropriate human reasoning capabilities. In fuzzy logic, basic control is determined by a set of linguistic rules which are determined by the system. Since numerical variables are converted into linguistic variables, mathematical modeling of the system is not required. The fuzzy logic control is being proposed for controlling the inverter action. FLC is a new addition to control theory and it incorporates a simple, rule based IF X AND Y THEN Z approach to a solving control problem rather than attempting to model a system mathematically

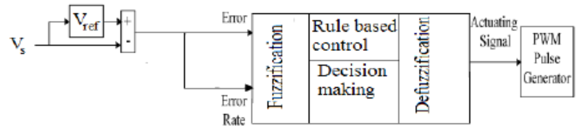


Fig. 5: Block diagram of proposed control system.

***A. Error Calculation:***

The error is calculated from the difference between supply voltage data and the reference voltage data. The error rate is the rate of change of error.

***B. Fuzzification:***

Fuzzification is an important concept in the fuzzy logic theory. Fuzzification is the process where the crisp quantities are converted to fuzzy. Thus Fuzzification process may involve assigning membership values for the given crisp quantities. This unit transforms the non-fuzzy (numeric) input variable measurements into the fuzzy set (linguistic) variable that is a clearly defined boundary, without a crisp (answer). In this simulation study, the error and error rate are defined by linguistic variables such as negative big (NB), negative medium (NM), negative small (NM), zero (Z), positive small (PS), positive medium (PM) and positive big (PB) characterized by membership functions given in Fig. 6.

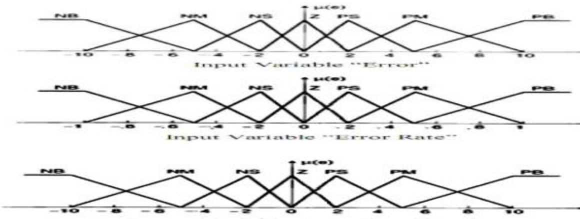

Fig. 6: Membership functions for inputs and output

### *C. Decision Making:*

Fuzzy process is realized by Mamdani method. Mamdani inference method has been used because it can easily obtain the relationship between its inputs and output [11]. The set of rules for fuzzy controller are represented in Table II. There are 49 rules for fuzzy controller. The output membership function for each rule is given by the Min (minimum) operator. The Max operator is used to get the combined fuzzy output from the set of outputs of Min operator .The output is produced by the fuzzy sets and fuzzy logic operations by evaluating all the rules. A simple if-then rule is defined as follows: If error is Z and error rate is Z then output is Z.

Table I

| Ce\e | NB | NM | NS | Z | PS | PM | PB |
|---|---|---|---|---|---|---|---|
| NB | NB | NB | NB | NM | NM | NS | Z |
| NM | NB | NB | NM | NM | NS | Z | PS |
| NS | NB | NM | NM | NS | Z | PS | PM |
| Z | NM | NM | NS | Z | PS | PM | PM |
| PS | NM | NS | Z | PS | PM | PM | PB |
| PM | NS | Z | PS | PM | PM | PB | PB |
| PB | Z | PS | PM | PM | PB | PB | PB |

### *D. Defuzzification:*

It is the process of converting the controller outputs in linguistic labels represented by fuzzy set to real control (analog) signals. Defuzzification means the fuzzy to crisp conversions. The fuzzy results generated cannot be used as such to the applications, hence it is necessary to convert the fuzzy quantities into crisp quantities for further processing. This can be achieved by using Defuzzification process. Centroid method is used for Defuzzification in the present studies.

### *E. Signal Processing:*

The outputs of FLC process are the control signals that are used in generation of switching signals of the PWM inverter by comparing with a carrier signal.

## V. SYSTEM IMPLEMENTATION

To enhance the performance of D-statcom a prototype is designed using MATLAB 2009a version; Fig7 below shows the flow chart of the control strategery of the system

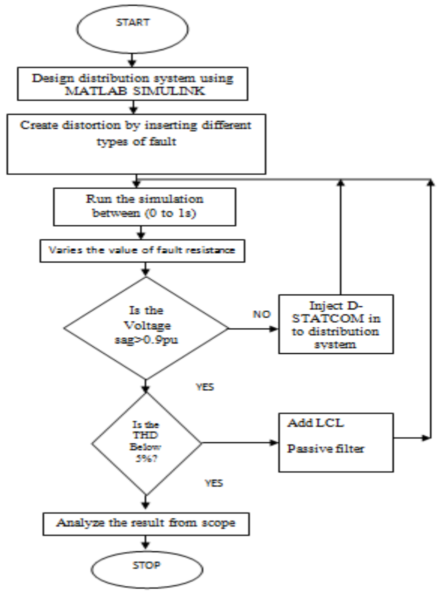

Figure7:.Flowchart of system Implementation

The test system shown in figure 8 comprises a 230kV, 50Hz transmission system, represented by a Thevenin equivalent, feeding into the primary side of a 3-winding transformer connected in Y/Y/Y, 230/11/11 kV. A varying load is connected to the 11 kV, secondary side of the transformer. A two-level D-STATCOM is connected to the 11 kV tertiary winding to provide instantaneous voltage support at the load point. A 750 μF capacitor on the dc side provides the D-STATCOM energy storage capabilities. Breaker 1 is used to control the period of operation of the D-STATCOM and breaker 2 is used to control the connection of load 1 to the system.

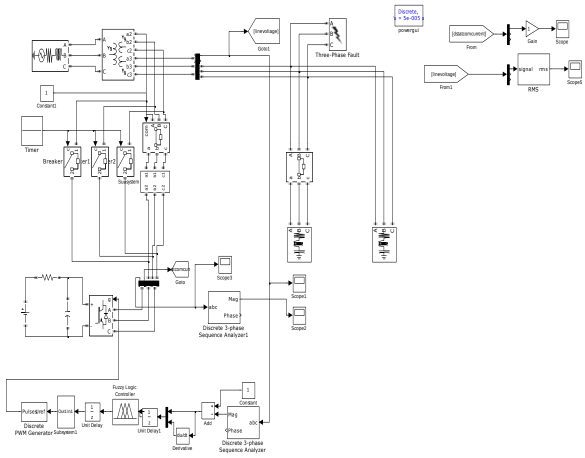
Figure8 Diagram of the test system

## VI. RESULTS AND DISCUSSION

The system is implemented with different faults TLG, DLG,LL,SLG and with different resistance values.

Table II

| Type of Fault | Fault resistance | Without inertia D- Statcom | With inertia D- Statcom |
|---|---|---|---|
| TLG | 0.66 | 0.6600 | 0.99 |
| DLG | 0.7 | 0.7487 | 0.9911 |
| LL | 0.86 | 0.8210 | 1.00 |
| SLG | 0.66 | 0.8259 | 0.992 |

Table II Indicates the overall results of voltages in p.u for different types of faults. From the table it can be observed that the voltage profile is improved with insertion of D-statcom. Fig 9 to Fig 12 shows the RMS voltage value for Different types of Faults and resistance values as shown in the first two columns of table II.

***A. Without insertion of D-STATCOM:***

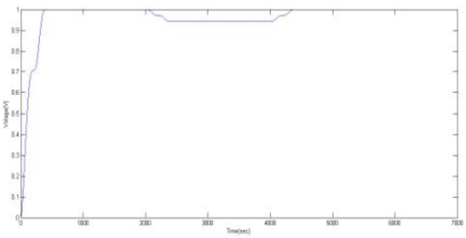

Fig 9. Voltage at load point at TLG

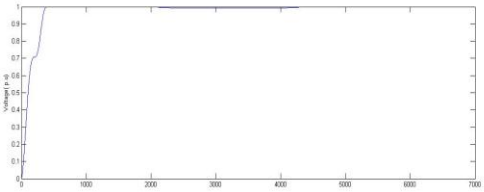

Fig 10. Voltage at load point at DLG

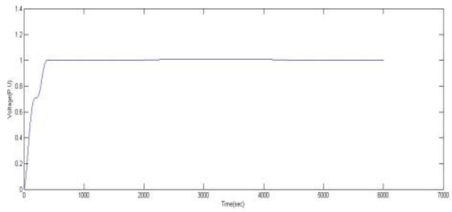

Fig 11. Voltage at load point at SLG

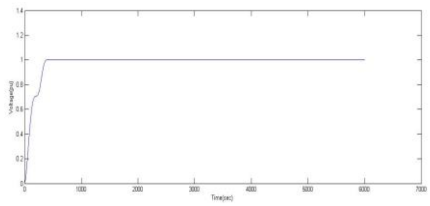

Fig 12. Voltage at load point at LL

***B. With insertion of D-STATCOM:***

From fig 13 to 16 Indicates the wave form of RMS voltage with different Faults and fault resisstances as per table II. And we can observed from fig 13 to 16 that there is a compensation of Voltage sag in the system and the voltage RMS is maintained between 0.9 to 1.0 P.U. and thus say that D-statcom can eliminate the Voltage sag in the distribution systerm.

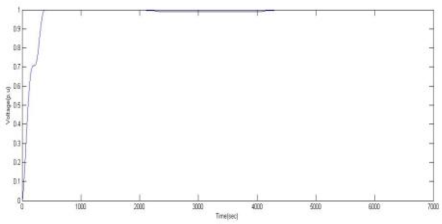

Fig 13. Voltage at load point at TLG

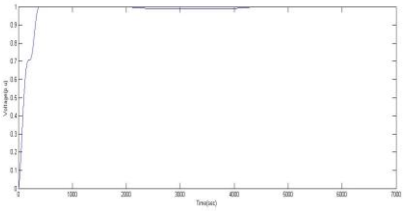

Fig 14. Voltage at load point at DLG

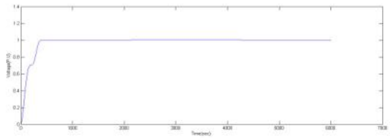

Fig 15. Voltage at load point at SLG

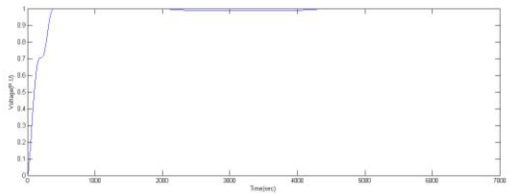

Fig 16. Voltage at load point at LL

***C: D-STATCOM without/with LCL Passive Filter:***

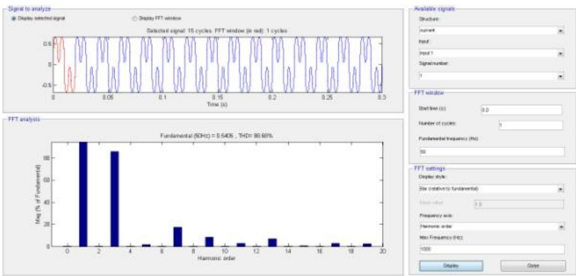

Fig 17: THD of Currents without LCL passive filter

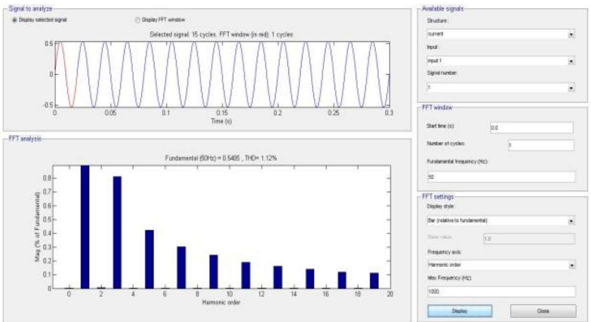

Fig 17: THD of Currents with LCL passive filter

Fig 16 and 17 indicates the THD Values of the currents which are coming from d-statcom, when

LCL filter is not connected the THD value is 88.68% and when the filter is connected the THD is maintained at 1.12%. and we can say that LCL filter is able to eliminate the Harmonics (Switching Harmonics ) which are coming from D-statcom

## VII. CONCLUSION

The simulation results shows that the voltage sags can be mitigate by inserting D-STATCOM to the distribution system. By adding LCL Passive filter to D-STATCOM and Fuzzy Logic, the THD is within the standard Limits. The power factors also increase close to unity. Thus, it can be concluded that by adding D-STATCOM with LCL filter can eliminate voltage sag and can improve Power quality in the distribution system and system can be further extended using Ann.

## REFERENCES

[1] GYaleinkaya, M.H.J. Bollen, P.A. Crossley, "Characterization of voltage sags in industrial distribution systems", IEEE transactions on industry applications, vol.34, no. 4, July/August, pp. 682-688, 1999.

[2] Haque, M.H., "Compensation of distribution system voltage sag by DVR and D-STATCOM", Power Tech Proceedings, 2001 IEEE Porto, vol.1, pp.10-13, Sept. 2001.

[3] Anaya-Lara O, Acha E., "Modeling and analysis of custom power systems by PSCAD/EMTDC", IEEE Transactions on Power Delivery, Vol.17, Issue: 1, Jan. 2002, Pages:266 – 272

[4] Bollen, M.H.J.," Voltage sags in three-phase systems" Power Engineering Review, IEEE, Vol. 21, Issue: 9, Sept. 2001, pp: 8 - 11, 15.

[5] M.Madrigal, E.Acha., "Modelling of Custom Power Equipment Using Harmonic Domain Techniques", IEEE 2000.

[6] R.Mienski,R.Pawelek and I.Wasiak., "Shunt Compensation for Power Quality Improvement Using a STATCOM controller: Modelling and Simulation", IEEE Proce., Vol.151, No.2, March 2004.

[7] A. Ghosh and G. Ledwich, Power quality enhancement using custom power devices, Massachusetts, USA.: Kluwer Academic Publishers, 2002.

[8] A.L. Olimpo and E. Acha, "Modeling and analysis of custom power systems by PSCAD/EMTDC," IEEE Trans. Power Delivery, vol. 17, no. 1, pp. 266-272, Jan. 2002.

[9] P. Pohjanheimo and E. Lakervi, "Steady state modeling of custom power components in power distribution networks," in Proc. IEEE Power Engineering Society winter Meeting, vol. 4, Jan. 2000, pp. 2949- 2954.

[10] A. Adya, "Application of D-STATCOM for isolated systems", IEEE Region 10 Conference (TENCOM), Vol. 3, Nov. 2004, pp. 351-354.

[11] K. Somsai and T. Kulworawanichpong, "Modeling, simulation and control of D-STATCOM using ATP/EMTP," In Harmonics and Qualityof Power, 2008. ICHQP 2008. 13th International Conference on. pp. 1- 4, 2008.

[12] C. Sumpavakup, and T. Kulworawanichpong, "Distribution Voltage Regulation Under Three-Phase Fault By Using D-STATCOM", The International Conference on Electric Power and Energy Systems (EPES 2008), pp.855-859, July 2008.

[13] E. Acha, Electronic Control in Electrical Power Systems, London, UK.: Butter-Worth-Heinemann, 2001.

**D.PRASAD** has received his B.Tech degree(EEE) from QIS College of Engineering and Technology in the year 2010 under JNTUK. At present he is pursuing his M.Tech from QIS College of Engineering and Technology under JNTUK. His areas of interest are Power systems and Power Electronics.

**T.SANDEEP KUMAR** has received his B.Tech degree (EEE) from Prakasam Engineering College under JNTUH. He has received his M.Tech degree with the specialization of power electronics from PRRM engineering college under JNTUH. Currently he is working as an Assistant Professor in QIS College of Engineering and Technology, Ongole.

**Dr. B.VENKATA PRASANTH** received the B.Tech. degree in Electrical & Electronics Engineering from Sri Krishnadevaraya University & M.Tech. degree in Electrical Power Systems from Jawaharlal Nehru Technological University, Ananthapur, India. He received his Ph.D. degree in Electrical & Electronics Engineering from Jawaharlal Nehru Technological University, Hyderabad, India. He has got a teaching experience of more than 14 years. Currently, he is working as Professor & Head in QIS College of Engineering and Technology, Ongole, India in the Dept. of Electrical & Electronics Engineering.

**Dr.K.S.G.SANKAR** working as professor in QIS College of Engineering and Technology, Ongole.