COLLATION OF DVR AND D-STATCOM USING FUZZY INFERENCE SYSTEMS

[1]M.R.Mohanraj, [2]V.P.Suresh
Assistant Professor, Department of EEE, Excel College of Technology,

[3] R.Kavin
Assistant Professor, Department of EEE Excel College of Engineering & Technology,

[4]R.Manikandan, [5]D.Balaji
UG Student, Department of EEE, Excel College of Engineering & Technology,

ABSTRACT

Over the recent period of time power quality problems have been remarked as a prominent issue with regard to promoting delicate and miniature electronic devices where Voltage sag problem is the most frequently occurring and detrimental power quality problems. At present, a wide range of very flexible controllers, which capitalize on newly available power electronics components, are emerging for custom power applications to correcting the voltage sag in a distributed system.Among these, D-STATCOM and the DVR are most effective devices, along with controlling methods namely Sugeno Fuzzy Controller (SFC), Mamdani Fuzzy Controller (MFC) and PI controller. A DVR injects a voltage in series with the system voltage and a D-STATCOM injects a current into the system to correct the voltage sag. The outcomes of D-STATCOM using SFC, demonstrated in two and three phases compensated 96%and 93% voltage sag difficulties and DVR showed that SFC was able successfully to overcome the voltage sag 98.05%, 96.40% and 94.20% at single-phase, two-phase and three-phase respectively. DVR using SFC showed to be better performance for solving voltage sag problem compared with D-STATCOM with SFC controller Techniques .

KEYWORDS Voltage Sag, Dynamic Voltage Restorer (DVR), Sugeno-type Fuzzy Logic controller(SFC), Mamdani type Fuzzy logic controller(MFC), Proportional Integral Controller (PI), MATLAB.

I. INTRODUCTION

Power quality is one of major concern in the present era. Power quality problems comprise a wide range of disturbances such as voltage sag, swell, flicker, harmonics, distortion, impulse, transient and interruptions. Among this one of the most common power quality problems today is voltage dips(5). The IEC electro technical vocabulary, IEC 60050- 604, 1998 defines a voltage sag as any “sudden reduction of the voltage at a point in the electrical system, followed by voltage recovery after a short period of time, from half a cycle to a few seconds”. Likewise, in more explicitly, a sag as defined by IEEE Standard 1159, IEEE Recommended Practice for Monitoring Electric Power Quality, is “a decrease in RMS voltage or current at the power frequency for durations from 0.5 cycles to 1 minute,(4) reported as the remaining voltage”. Typical values are between 0.1 p.u and 0. 9 p.u. Typical fault clearing times range from three to thirty cycles depending on the fault current magnitude and the type of over current de ection and interruption. Actually, Voltage sags are appearing due to faults, motor starting , and transformer energizing.

Since there is no standard solution which will work for every site, each mitigation action must be carefully planned and evaluated. There are different ways to mitigate voltage dips in transmission and distribution systems. At present, a wide range of very flexible controllers, which capitalize on newly available power electronics components, are emerging for custom power applications. Among these, the distribution static compensator and the dynamic voltage restorer are most effective devices, both of them based on the VSC principle. A new PWM-based control scheme has been implemented to control the electronic valves in the two-level VSC used in the D-STATCOM and DVR(2) .

II. VOLTAGE SOURCE CONVERTERS

A voltage-source converter is a power electronic device, which can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. Voltage source converters are commonly used in adjustable-speed drives, but can also be used to mitigate voltage sag in distribution system. The VSC is used to either completely replace the voltage or to inject the 'missing voltage'. The 'missing voltage' is the difference between the nominal voltage and the actual. The converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage. Normally the VSC is not only used for voltage sag mitigation, but also for other power quality issues, e.g. swell and harmonics.(1,2)

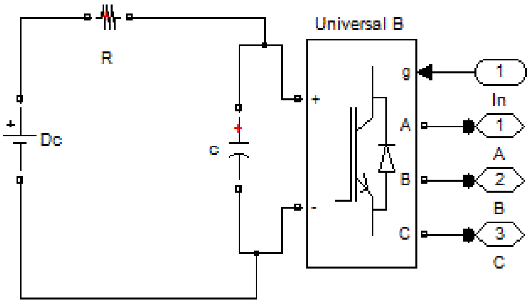


Fig 1 Circuit Diagram of Voltage Source Converter

Fig 1 shows the DC source is connected in parallel with the DC capacitor. This DC capacitor could be charged by a battery source or could be recharged by the converter itself.

III. BASIC THEORY

A. D-STATCOM

A distribution static compensator (D-STATCOM) is the most efficient and effective modern custom power device used in power distribution system. Its appeal includes lower cost, smaller size, and its fast dynamic response to the disturbance(2,1). D-STATCOM consists of a voltage source converter (VSC), a DC energy storage device (ESD), a coupling transformer connected in shunt to the distribution system through a coupling transformer. The VSC converts the DC voltage across the storage device into a set of three phase AC output voltages. These voltages are in phase and coupled with the AC system through the reluctance of the coupling transformer. Suitable adjustment of the phase and magnitude of the D-STATCOM output voltages allows effective control of active and reactive power exchanges between the D-STATCOM and the AC system(10). Such configuration allows the device to absorb or generate controllable active and reactive power. As shown in figure 2.

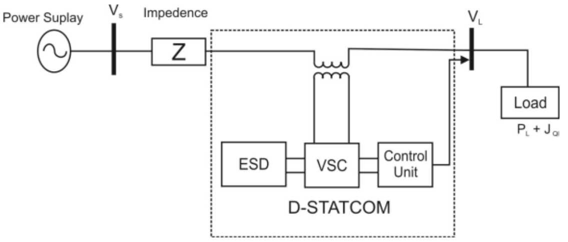


Fig 2 Schematic Representation of D-STATCOM.

The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes:

1. Voltage regulation and compensation of reactive power;
2. Correction of power factor; and
3. Elimination of current harmonics.

Here, such device is employed to provide continuous voltage regulation using an indirectly controlled converter.

IV. TEST SYSTEM

Fig 3 shows the test system used to carry out the various D-STATCOM simulations.

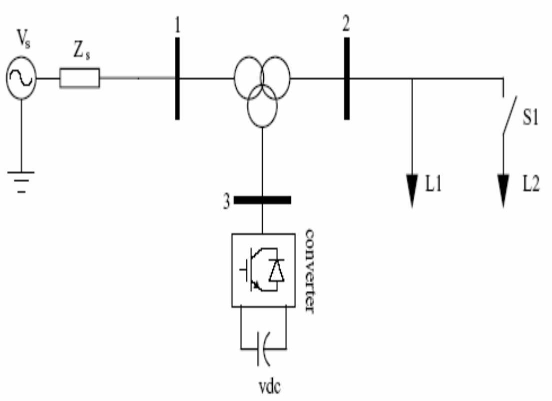


Fig 3 Single line diagram of the test system for D-STATCOM.

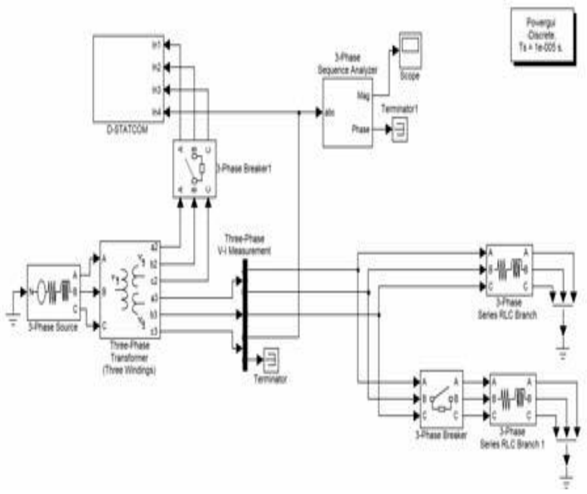


Fig 4 Simulink model of D-STATCOM test system.

Fig 4 shows the test system implemented in MATLAB SIMULINK. The test system 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 kVA varying load is connected to the 11 kV, secondary side of the transformer(5,6). 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. To show the effectiveness of this controller in providing continuous voltage regulation(2,6), simulations were carried out with and without D-STATCOM connected to the system.

The D-STATCOM model which is incorporated in the transmission system for voltage regulation is as shown in Fig 5.

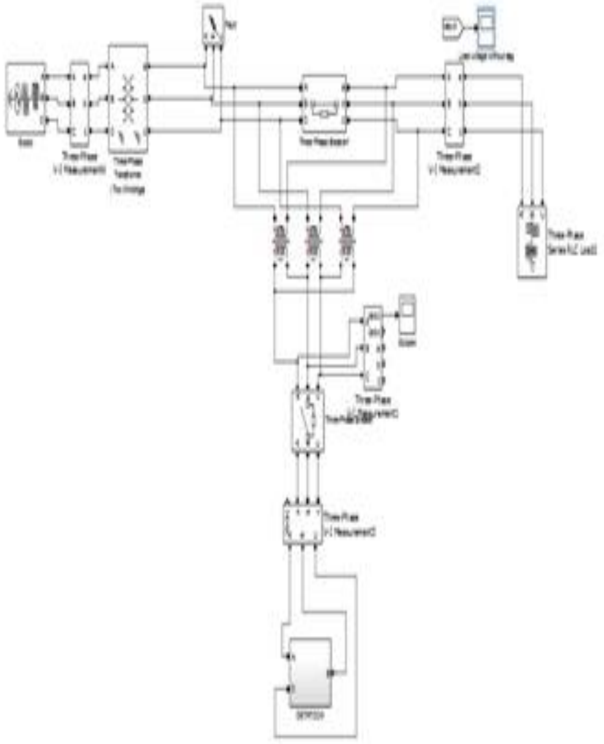


Fig 5 Simulink model of D-STATCOM.

B.DYNAMIC VOLTAGE RESTORER

The series voltage controller is connected in series with the protected load as shown in Fig.1. Usually the connection is made via a transformer, but configurations with direct connection via power electronics also exist(1,2). The resulting voltage at the load bus bar equals the sum of the grid voltage and the injected voltage from the DVR. The converter generates the reactive power needed while the active power is taken from the energy storage(7,8).

The energy storage can be different depending on the needs of compensating.

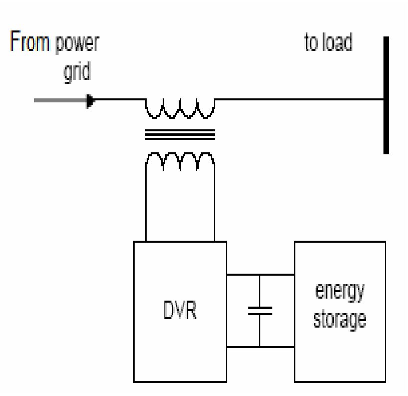


Fig 6 standard configuration of DVR.

A DVR is also referred as the Series Voltage Booster, is a device that utilitzes soild state power electronic components. DVR is a device that injects dynamically controlled voltage in series to the bus voltage by booster transformer(2,6).DVR injected the missing current in series with line that load voltage maintained at sinusoidal normal situation in power system. The general configuration of the DVR consists of injection voltage transformer, DC energy storage(6), Voltage source inverter, and Control unit as depicted in Fig 7.

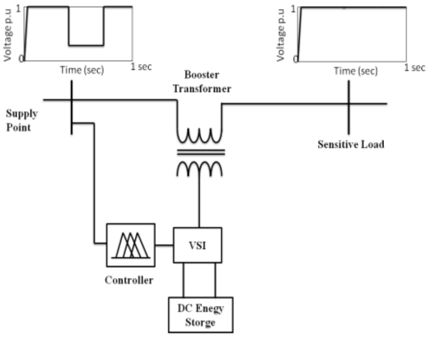


Fig 7 Schematic diagram of a DVR.

Fig 7 shows the basic function of booster transformer is injected current in distribution network. Voltage source inverter can generate a sinusoidal voltage at any needed Magnitude(6), Frequency, and phase angle. The DC energy storage provides the real power requirement of DVR during occurrence of voltage sag. And finally, the goal of Sugeno type Fuzzy Logic and Mamdani type Fuzzy Logic which controls the inverter of DVR, has been discussed in place of conventional PI controller in order to maintain voltage magnitude at the load where a sensitive load is connected in power system.

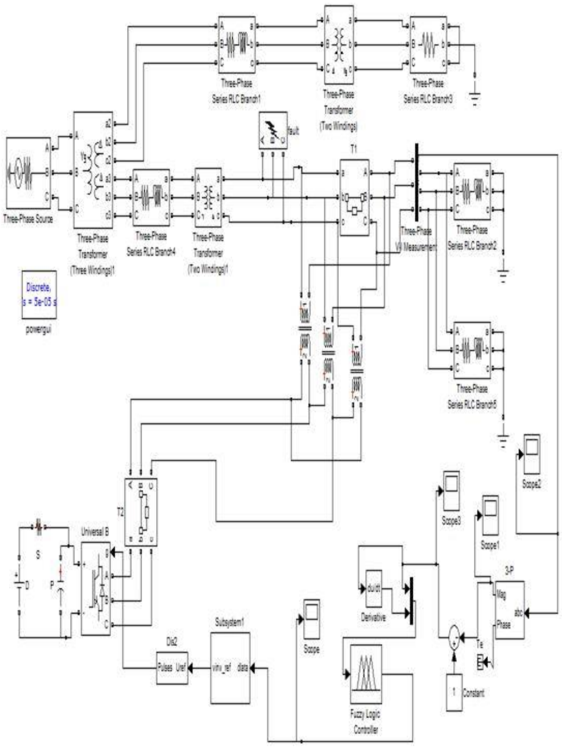


Fig 8 Matlab/Simulink Power Circuit Model of DVR

C. PROPORTIONAL INTEGRATIVE (PI) CONTROLLER

The aim of the control a proportional integrative (PI) scheme is to maintain constant voltage magnitude at the point where a sensitive load is connected, under system disturbances. The control system only measures the rms voltage at the load point, i.e., no reactive power measurements are required. The VSC switching strategy is based on a sinusoidal PWM technique which offers simplicity and good response. Since custom power is a relatively low-power application(7,10), PWM methods offer a more flexible option than the Fundamental Frequency Switching (FFS) methods favoured in flexible alternating Current transmission systems (FACTS) applications. Besides, high switching frequencies can be used to improve on the efficiency of the converter, without incurring significant switching losses.

The controller input is an error signal obtained from the reference voltage and the value rms of the terminal voltage measured. Such error is processed by a PI controller the output is the angle δ, which is provided to the PWM signal generator. It is important to note that in this case, indirectly controlled converter, there is active and reactive power exchange with the network simultaneously: an error signal is obtained by comparing the reference voltage with the rms voltage measured at the load point. The PI controller process the error signal generates the required angle to drive the error to zero, i.e., the load rms voltage is brought back to the reference voltage.As shown in figure 9.

PI Controller (proportional-integral controller) is a close loop controller which drives the plant to be controlled with a weighted sum of error and integral that value. PI Controller has the benefit of Steady-state error to be zero for a step input.

Output of comparator = V ref – V in

Where,

V ref: Equal 1 per unit voltage reference.

V in : Voltage in 1 per unit at the load terminals.

PI controller input is an actuating signal which is the difference between the V ref and Vin Output of the controller block the angles. The angle provides to PWM signal generator to obtain desired firing sequence. Fig. 9 is shown medal of PI controller in MATLAB(8,9).

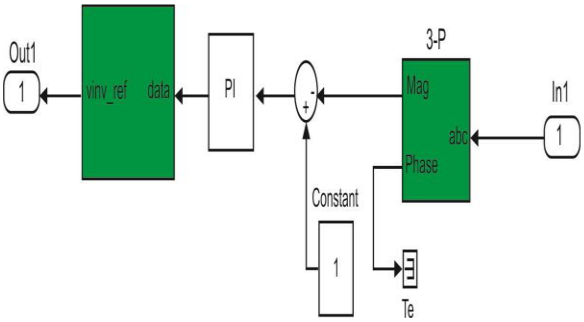


Fig 9 Simulink Model of PI Controller.

D.FUZZY INFERENCE SYSTEM (FIS)

Fuzzy inference systems (FIS) are one of the most famous applications of fuzzy logic and fuzzy set theory. They can be helpful to achieve classification tasks, offline process simulation and diagnosis, online decision support tools and process control. The strength of FIS relies on their twofold identity. On the one hand, they are able to handle linguistic concepts. On the other hand, they are universal approximates able to perform nonlinear mappings between inputs and outputs. These two characteristics have been used to design two kinds of FIS. (3,4)The first kind of FIS to appear focused on the ability of fuzzy logic to model natural language. These FIS contain fuzzy rules built from expert knowledge and they are called fuzzy expert systems or fuzzy controllers, depending on their final use. Prior to FIS, expert knowledge was already used to build expert systems for simulation purposes. These expert systems were based on classical Boolean logic and were not well suited to managing the progressiveness in the underlying process phenomena(3). Fuzzy logic allows grading rules to be introduced into expert knowledge based simulators. It also points out the limitations of human knowledge, particularly the difficulties in formalizing interactions in complex processes. Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions can be made, or patterns discerned.

The fuzzy inference system is shown in Fig 10.

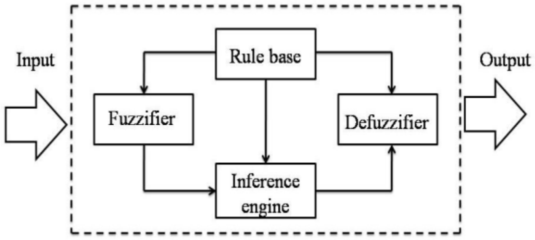


Fig 10 The Basic Elements of a FLC

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. The error and error rate are defined as:

$$\text{Error} = \text{Vref} - \text{VS}$$

$$\text{Error rate} = \text{error}(n) - \text{error}(n-1)$$

Where is,
Vref is voltage References.
VSis voltage Source.
Error is Error supply.
Error rate is Error rate supply.

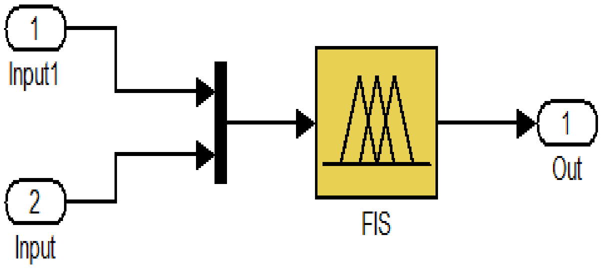


Fig 11(FLC) Scheme

Fig 10 shows the basic element of FLC, which comprises four principal components a fuzzification, a Rule base, Inference engine, and defuzzification .

1. The fuzzification interface involves the following functions

a. Measure the values of input variables,

b. Performs a scale mapping that transfers the rang of values of input variables, into corresponding universes of discourse,

c. Performs the function of fuzzification that converts input data into suitable linguistic values.

2. The Knowledge based comprises a knowledge the application domain and attendant control goal. It consists of a “data base” and a “linguistic (fuzzy) Control rule base’’

a. The data base provides necessary definitions, which are used to Defined linguistic control rules and fuzzy data manipulations in fuzzy logic control

b. The Rule base characterizes the control goals and control policy of the domain experts by means of set linguistic control rules.

3. The decision-making logic is the kernel of fuzzy logic control. It has the capability of simulating human decision-making based on fuzzy concepts and inferring fuzzy control action employing fuzzy implication and the rule of inference fuzzy logic.

4. The defuzzification interface performs the following functions:

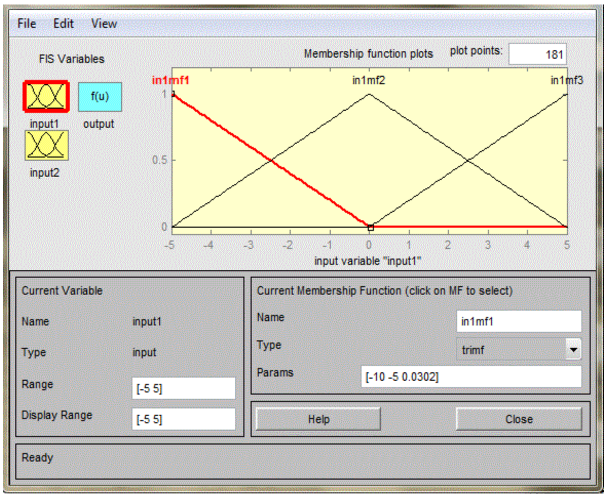
a. A scale mapping, which converts the range of values output variables into corresponding universe of discourse

b. Defizzification, which yields a non-fuzzy control action from an inferred fuzzy control action.

V. SIMULATION RESULTS

A. D-đSTATCOM CONTROL SYSTEM WITH MFC

The design of FCSs with Mamdani FC is usually performed by heuristic means incorporating human skills and ko experience, and it is often carried out by a model-free approach. The immediate shortcoming resulted from the model-free design and Fuzzy Controller tuning concerns the lack of general-purpose design methods. Although the performance indices of such control systems are generally satisfactory, a major problem is the analysis of the structural properties possessed by the FCSs including stability, controllability, parametric sensitivity and robustness .



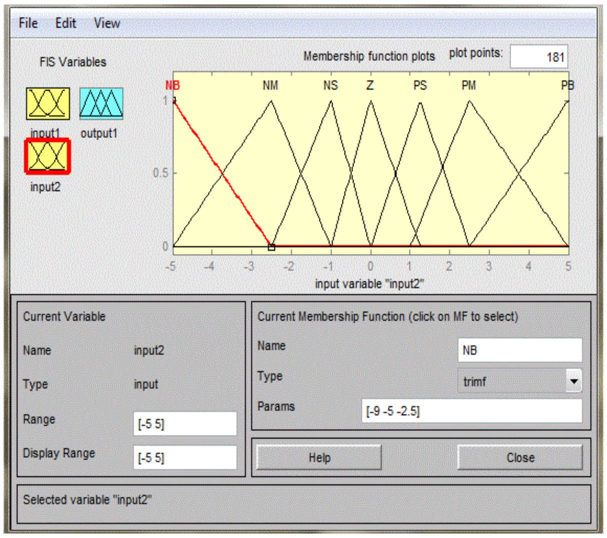
plot points: 181

Name input1
Type input
Range [-5 5]
Display Range [-5 5]

Name in1mf1
Type trimf
Params [-10 -5 0.0302]

Ready

Fig 12 Input1 Membership Function of MFC in MATLAB



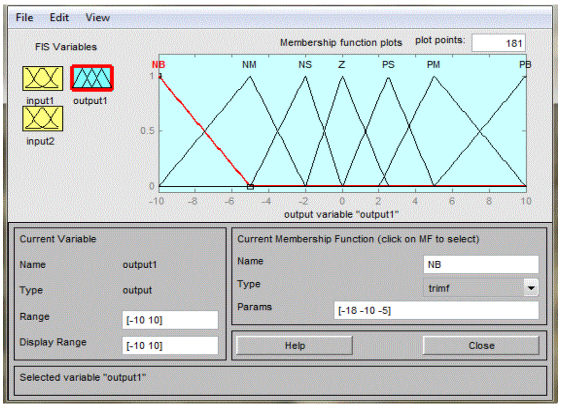
plot points: 181

Name input2
Type input
Range [-5 5]
Display Range [-5 5]

Name NB
Type trimf
Params [-9 -5 -2.5]

Selected variable "input2"

Fig 13 Input2 Membership function of MFC in MATLAB



plot points: 181

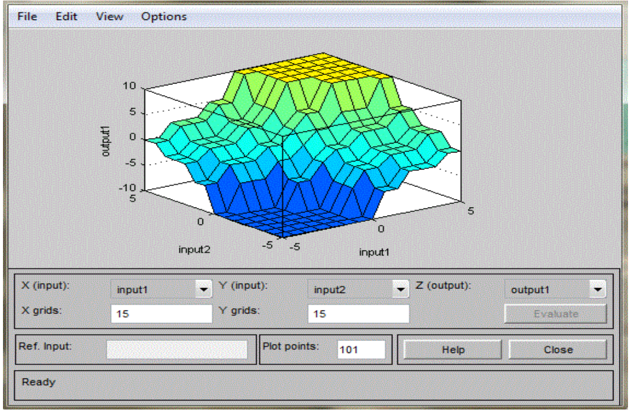
Name output1
Type output
Range [-10 10]
Display Range [-10 10]

Name NB
Type trimf
Params [-18 -10 -5]

Selected variable "output1"

Fig 14 Output Membership Function of MFC in MATLAB

MFC have two inputs and one output, the input consisting of 7 members and output fuzzy consists of 7 members. Where the input variables in the range [-5 5], while the output variable in the range [-10 10]. The Mama fuzzy logic is used; the max-min inference method is applied in this paper. The relation surface between inputs (e, de) and output of SFL is shown in Fig.



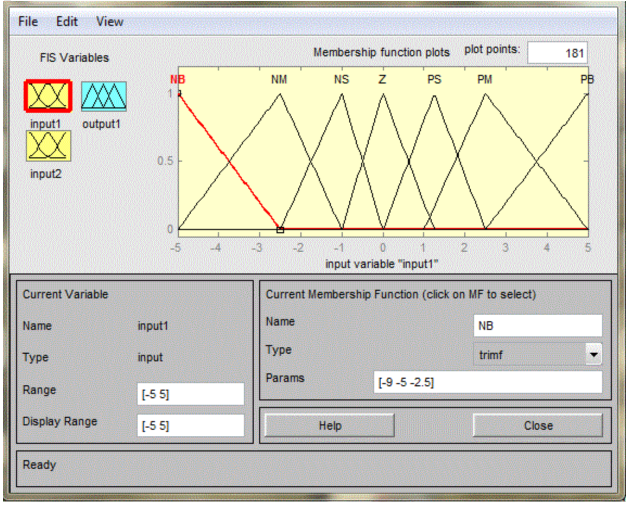
X (input): input1
Y (input): input2
Z (output): output1
X grids: 15
Y grids: 15
Ref. Input:
Plot points: 101

Ready

Fig 15 Control Surface of MFC

B. CONTROL SYSTEM WITH SFC

Sugeno fuzzy models represent fuzzy dynamic models or fuzzy systems. This brings a twofold advantage. First, any model-based technique (including a nonlinear one) can be applied to the fuzzy dynamic models(4). Second, the controller itself can be considered as a fuzzy system. Since the fuzzy model of the nonlinear process is usually based on a set of local linear models which are smoothly merged by the fuzzy model structure, a natural and straightforward approach is to design one local controller for each local model of the process.



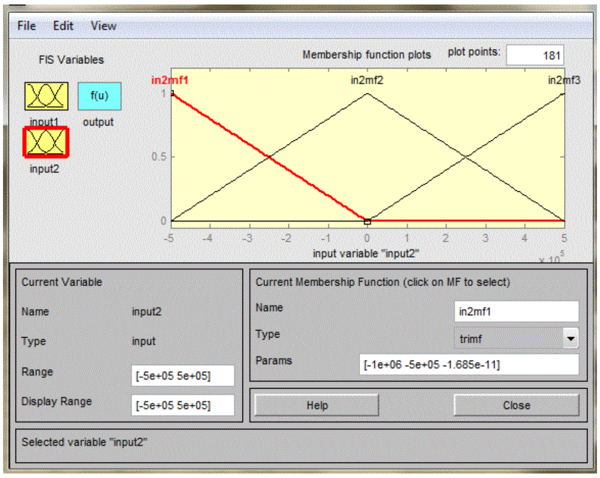
plot points: 181

Name input1
Type input
Range [-5 5]
Display Range [-5 5]

Name NB
Type trimf
Params [-9 -5 -2.5]

Ready

Fig 16 Input1 Membership Function of SFC in MATLAB



plot points: 181

Name input2

Type input

Range [-5e+05 5e+05]

Display Range [-5e+05 5e+05]

Name in2mf1

Type trimf

Params [-1e+06 -5e+05 -1.685e-11]

Selected variable "input2"

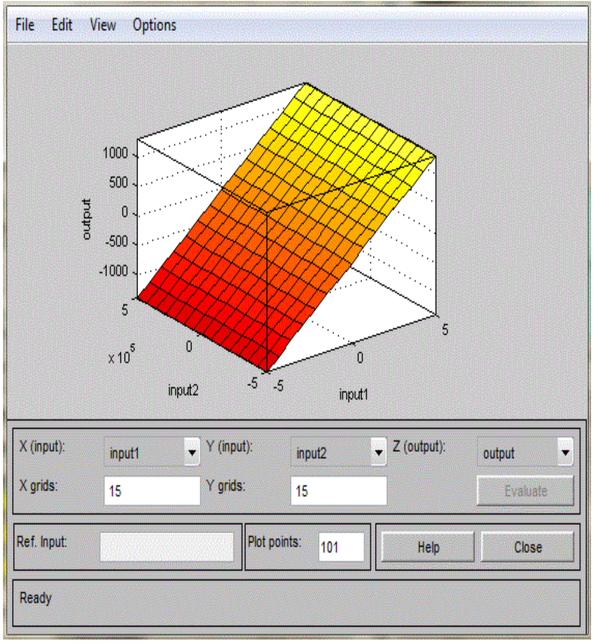
Fig 17 Input2 Membership Function of SFC in MATLAB

SFC consist of two input and one output, only the output in the form of a constant SFC method and not arrange, namely fuzzy {P, Z, N} with range [-1 1], while the output consists of 9 members that each member has a constant value. Output = [A, B, C, D, E, F, G, H, I]

where :

A = -1397, B = -1397, C = -1397, D = -30.42, E = -30.42, F = -30.42, G = 1319, H = 1320, I = 1320.

The SFC is used; the max-min inference method is applied in this paper. The relation surface between inputs (e, de) and output (du) of SFL is shown in Figure.



X (input): input1

Y (input): input2

Z (output): output

X grids: 15

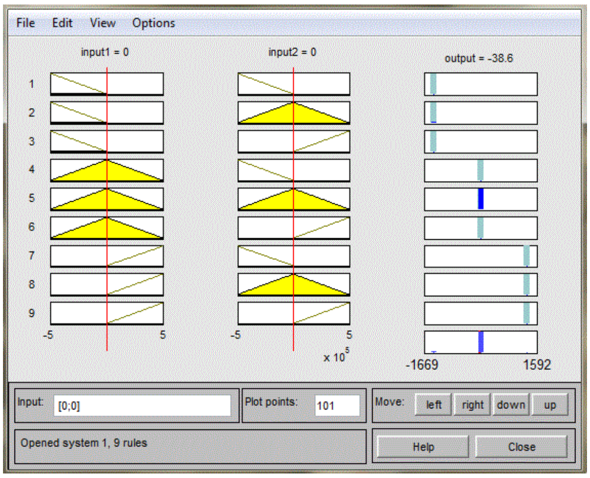
Y grids: 15

Ref. Input:

Plot points: 101

Ready

Fig 18 Control Surface of SFC



input1 = 0

input2 = 0

output = -38.6

Input: [0;0]

Plot points: 101

Opened system 1, 9 rules

Fig 19 Rule Base of SFC

C.THE RESULT OF D-STATCOM

The result consists of distribution system without D-STATCOM and with D-STATCOM(1,10). The D-STATCOM was simulated by using MATLAB. The voltage say occur at the time duration 0.5sec to 0.8sec.

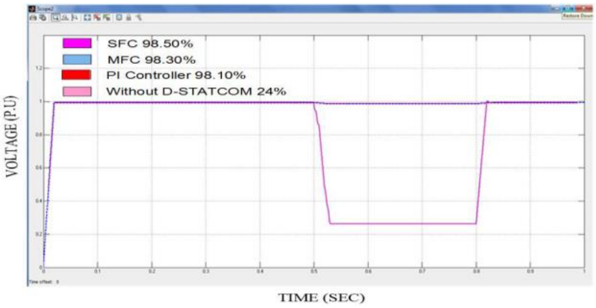


Fig 20 Single Phase Fault Scenario Result of Comparison Use the PI Controller, SFC and MFC

The figure illustrates the single fault scenario result of absence of D-STATCOM(2,4)method and comparison among three other methods namely PI controller, SFC, and MFC.

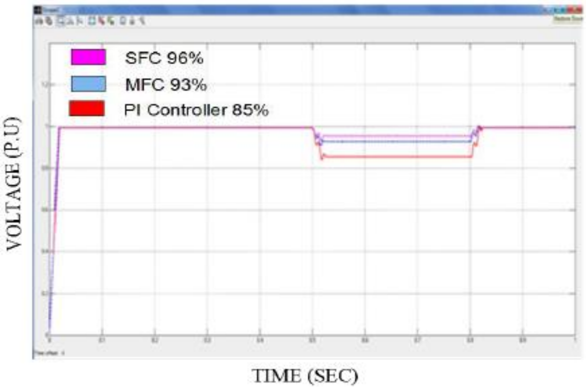


Fig 21 Two Phase Fault Scenario Result of Comparison Use the PI Controller, SFC and MFC

The figure 12 illustrates the two fault scenario result of absence of D-STATCOM method and comparison among three other methods namely PI controller, SFC, and MFC.

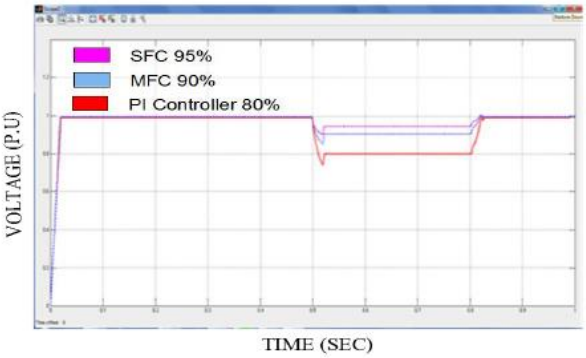


Fig 22 3 Phase Fault Scenario Result of Comparison Use the PI Controller, SFC and MFC

The fig 13 illustrates the three fault scenario result of absence of D-STATCOM method and comparison among three other methods namely PI controller, SFC, and MFC.

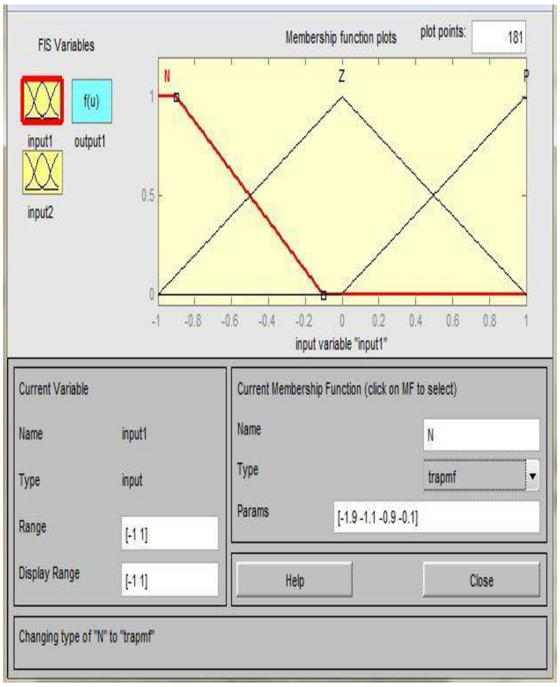
D. DVR CONTROL SYSTEM WITH MFC&SFC

Sugeno-type fuzzy logic controller have been of great attention in the industrial applications. The main idea is based on the use of sector nonlinearity concept, which decomposes a complex nonlinear system into a set of linear subsystems using fuzzy IF-THEN rules(6). A fuzzy logic controller or model uses fuzzy logic rules, which are linguistic if-then statements involving fuzzy sets, fuzzy logic, and fuzzy inference. Fuzzy rules play a key role in representing expert control/modeling knowledge and experience and linking the input variables of fuzzy controller/ models output variable. In this paper, two major type of fuzzy logic rules have been carried out on DVR in order to mitigate voltage sag, namely,(2)(Sugeno-type Fuzzy Logic and Mamdani-type Fuzzy Logic. The most essential difference between Mamdni-type Fuzzy Logic and Sugeno-type Fuzzy Logic is the way of the crisp output generated from the fuzzy inputs(2,4). While Mamdani-type Fuzzy Logic required the technique of defuzzication of fuzzy output on DVR Simulation and combined using aggregation operator from the consequent of each rule of the input that have been used in Simulation. A single if-then rule is written as;

IF —"X" is A, THEN —"Y" is B

Mamdani-type fuzzy logic and Sugeno-type fuzzy logic approaches were considered in order to mitigate voltage sag using DVR. The Membership Function for Mamdan-type Fuzzy Logic and Sugeno-type fuzzy logic is shown below:

E. SIMULATION FOR MFC



plot points: 181

Current Variable

Name input1

Type input

Range [-1 1]

Display Range [-1 1]

Current Membership Function (click on MF to select)

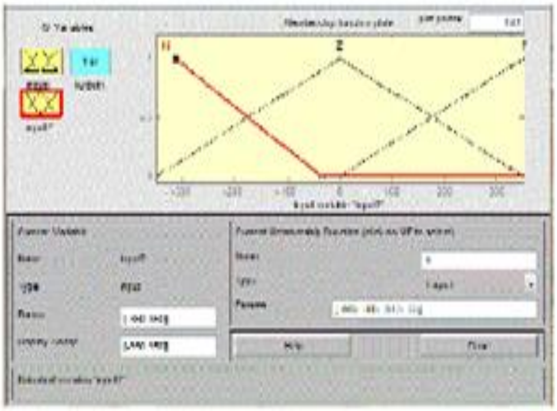
Name N

Type trapmf

Params [-1.9 -1.1 -0.9 -0.1]

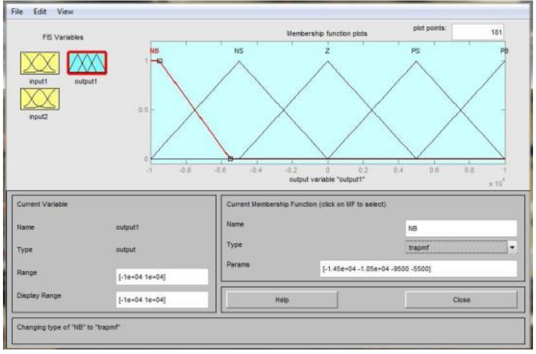
Changing type of "N" to "trapmf"

Fig 23 Membership Function for MFC Logic Input Variable



The output variable of Mamdan-type fuzzy logic also has five membership functions namely; Negative Big, Negative Small, Zero, Positive

Big.



Current Variable
Name output1
Type output
Range [-1e+04 1e+04]
Display Range [-1e+04 1e+04]

Current Membership Function (click on MF to select)
Name NB
Type trapmf
Params [-1.45e+04 -1.05e+04 -9500 -5500]

Changing type of "NB" to "trapmf"

Fig24 Positive Small shown in fig 7 below:

Fig 14 Membership Function for MFC Logic Output Variable

These rules in figure 8 was applied to the inputs and the output of the Mamdani-type fuzzy logic system based on DVR(2,6) controller using Fuzzy Logic Toolbox.

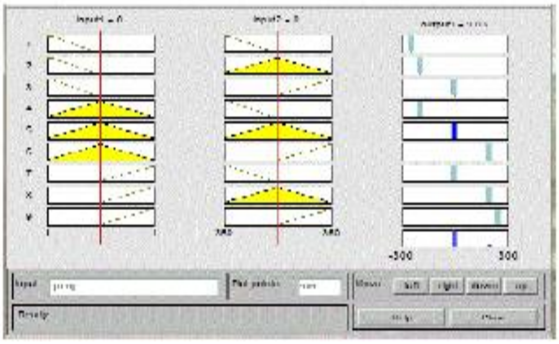
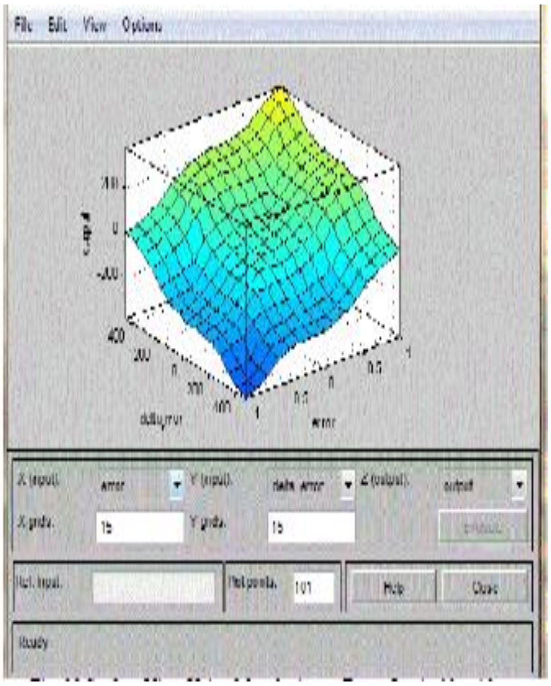


Fig. 25 Mamdani-type based rule viewer for controller



X (input): error
Y (input): delta error
Z (output): output
X grids: 15
Y grids: 15
Plot points: 101

Ready

Fig. 26 Surface View Using Mamdani-type Fuzzy Logic Algorithm

F. SIMULATION FOR SFC

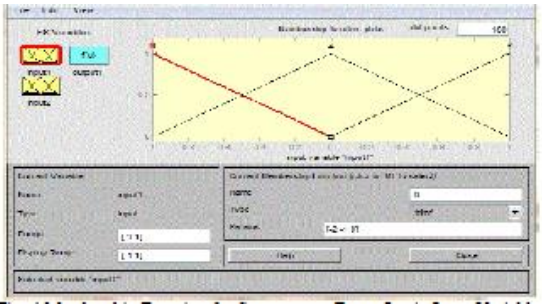
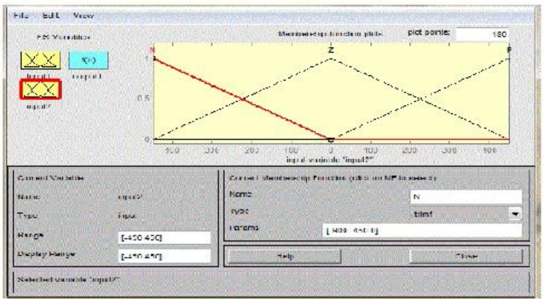


Fig. 27 Membership Function for Sugeno-type Fuzzy Logic Input Variable



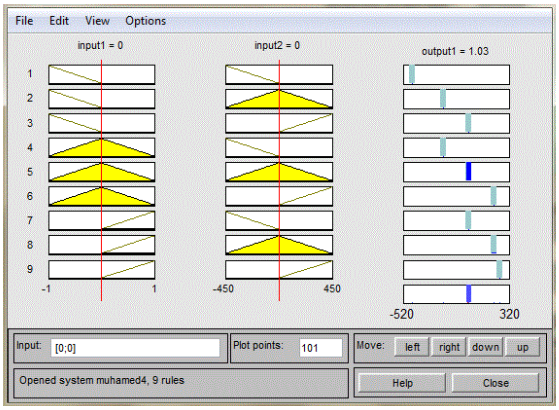
Current Variable
Name input2
Type input
Range [-450 450]
Display Range [-450 450]

Current Membership Function (click on MF to select)
Name N
Type trimf

Selected variable "input2"

Fig.2 8 Membership Function for Sugeno-type Fuzzy Logic Input Variable

These rules in fig 9 was applied to the inputs and the output of the Sugeno-type fuzzy logic system based on DVR (6)controller using Fuzzy Logic Toolbox.

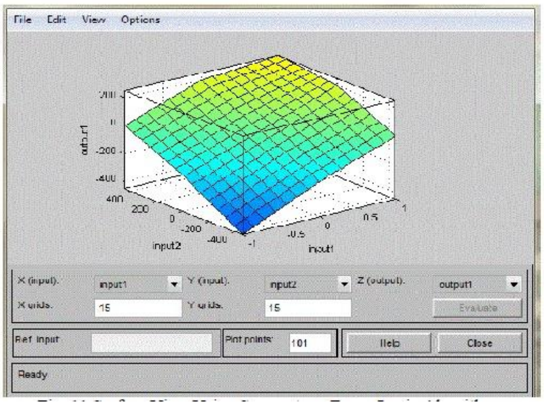


Input: [0;0]
Plot points: 101

Opened system muhamed4, 9 rules

Fig29 Sugeno-type based rule viewer for controller

The surface viewer of Sugenu-type fuzzy logic is presented .



X (input): input1
Y (input): input2
Z (output): output1
X grids: 15
Y grids: 15
Ref. Input:
Plot points: 101
Ready

Fig. 30 Surface View Using Sugrno-type Fuzzy Logic Algorithm

G. SIMULATION FOR PI

The first simulation was done without DVR and a three phase fault is applied to the system for a time duration of 400 ms The second simulation is carried out at the same scenario as above but using DVR with PIcontroller(6). The simulation is carried out at the same scenario as above but has different scenatio usage of DVR with sugeno-type and mamdani-type fuzzy logic

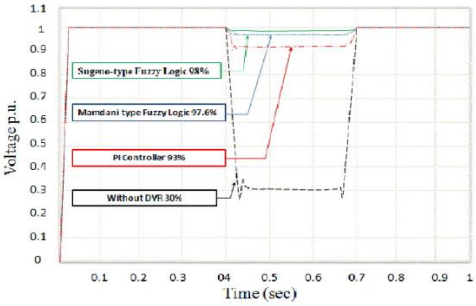


Fig. 30 (a) Single-Phase Comparision of Sugeno-Type Fuzzy Logic, Mamdani-Type Fuzzy Logic, PI Controller, and Without DVR

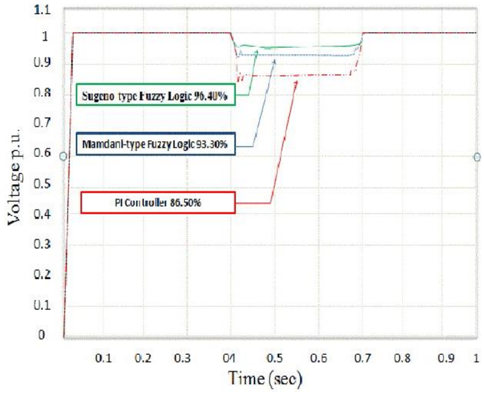


Fig. 30 (b) Two-Phase Comparision of Sugeno-Type Fuzzy Logic, Mamdani-Type Fuzzy Logic, and PI Controller

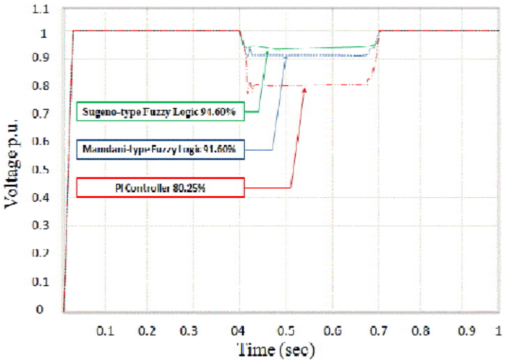


Fig. 30 (c) Three-Phase Comparision of Sugeno-Type Fuzzy Logic, Mamdani-Type Fuzzy Logic, and PI Controller In Matlab/Simulink model

when the fault was introduced at the point of common coupling, voltage sag appears at the period 0.4 to 0.6 secs in the single-phase, two-phase, and three-phase were shown in figures 21 (a),21 (b), and 21 (c).

VI.CONCLUSION

The simulation of D-STATCOM, DVR and PI controllers was executed successfully. The simulation result for D-STATCOM using PI controller 85%,80%,using MFC 93%,90%,using SFC 96%,93% respectively for two and three phase and for DVR using PI controller 93%,86.50%,80.25%,MFC 97.6%,93.3%,91.6% for SFC 98.05%,96.40%,94.20% respectively for single, two and three phases. From the above details the DVR-SFC is more efficient controller to mitigating the voltage sag problem in power system.

REFERENCE

[1] Adepoju, G. A., Komolafe, O.A. “Analysis and Modeling of Static Synchronous Compensator (STATCOM): A comparison of Power Injection and Current Injection Models in Power Flow Study,” International Journal of Advanced Science and Technology Vol. 36, pp. 65–75, 2011.

[2] Janak B. P., Amitkumar S. “Modeling Analysis& Solution of Power Quality Problems Using DVR & DSTATCOM,” IJSRD -International Journal for Scientific Research & Development. Vol. 1, Issue 5, 2013.

[3] Rambabu, E. Praveena, E and Kishore, P. “Mitigation of Harmonics in Distribution System Using D-STATCOM.” International Journal of Scientific & Engineering Research Vol. 2,pp.1-5, 2011.

[4] Patil, D. R., and Madhale, K. “Design and Simulation Studies of D-STATCOM for Voltage Sag, Swell Mitigation.” IRNet Transactions on Electrical and Electronics Engineering: pp. 97-103, 2007.

[5] G. Yaleinkaya, 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.

[6] 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.

[7] 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

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

[9] M.Madrigal, E.Acha., “Modelling of Custom Power Equipment Using Harmonic Domain Techniques”, IEEE 2000.

[10] 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.