# Modeling and Control a D-STATCOM with Sugeno Fuzzy Controller (SFC) and Mamdani Fuzzy Controller (MFC) For Voltage Sag Mitigation

Mohamed Mohamed Khaleel, and Mohamed Adam Faraj

***Abstract*—** Now-a-days Fuzzy logic control techniques are being used as a promising approach for the assuage of power quality problems. Voltage sag is the most dominating problem in the context of power quality problems. This paper presentation deals with the study of Distribution Static Compensator (D-STATCOM) using Sugeno Fuzzy Controller (SFC), Mamdani Fuzzy Controller (MFC), and PI Controller to minimize the voltage sag. Subsequently, the modeling of D-STATCOM was made with applying three control techniques namely Sugeno Fuzzy Controller (SFC), Mamdani Fuzzy Controller (MFC), and PI Controller respectively. Besides, the simulation study was practiced using Matlab with fuzzy toolbox. The outcomes demonstrated in terms of all phases Sugeno Fuzzy Controller (SFC) revealed the best performance among three methods. Infact, SFC extricated 96%and 95% voltage sag difficulties where two other methods such as MFC and PI controlled compensated 93%, 90%and 85 %, 80%, respectively at two phase and three phase scenario though this difference was not significant at single phase scenario. As a result, SFC and MFC linked to D-STATCOM are to be hypnotized for voltage sag mitigation due to their capability become fends quickly against loads fluctuation in the distribution system.

***Keywords*—** D-Statcom, PI controller, Sugeno Fuzzy Controller (SFC), Mamdani Fuzzy Controller (MFC), Matlab.

## I. INTRODUCTION

THE Flexible Alternative Current System technology is a new area in power engineering. It introduces the modem power electronic technology into traditional ac power system and significantly enhances power system controllability [1]. Power quality is certainly a major concern in present era. It becomes important with insertion of sophisticated device. Whose performance is very sensitive to quality of power supply [2]. The wide usage of nonlinear loads, such as personal computers, variable speed drivers, and the other electronic equipments reduce voltage sag. Power quality is a major problem in industrial and commercial power system. Electronic equipments are very sensitive loads against voltage sag. Voltage sag is a reduction between 10 and 90% in RMS voltage with duration between 0.5 cycles and 1 min [3]. The PI controllers can be built easily and they can add robustness to power systems. However, SFC and MFC are one of the interesting fields where fuzzy theory can be effectively applied in term of controller [4]. D-STATCOM will be used based on a voltage-source converter, which able to control the capacitor. The fuzzy logic controller has very attractive features over conventional controllers. [5]. Those control strategy are very important to the operation of D-STATCOM in order to mitigate voltage sag in distribution system. In general, D-STATCOM is kind of custom power device which has capability of power compensation. In this paper, three of the powerful and famous controller methods are used to control the D-STATCOM (e.g. SFC, MFC, and PI control), are applied in MATLAB Simulation.

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## II. VOLTAGE SOURCE CONVERTER (VSC)

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 [6]. Normally the VSC is not only used for voltage sag mitigation, but also for other power quality issues, e.g. swell and harmonics.

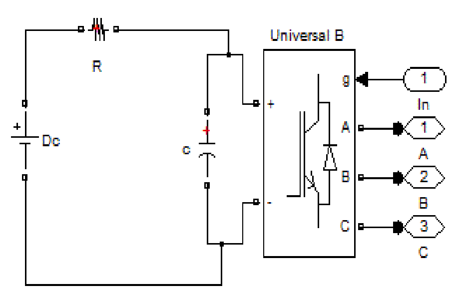


Fig.1 Circuit Diagram of Voltage Source Converter

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. DISTRIBUTION STATIC COMENSATOR

Essentially, the D D-STATCOM system is comprised of three main parts: a VSC, a set of coupling reactors and a controller. The basic principle of a D-STATCOM installed in a power system is the generation of a controllable AC voltage source by a voltage source converter (VSC) connected to a DC capacitor (DC energy storage device) [7].

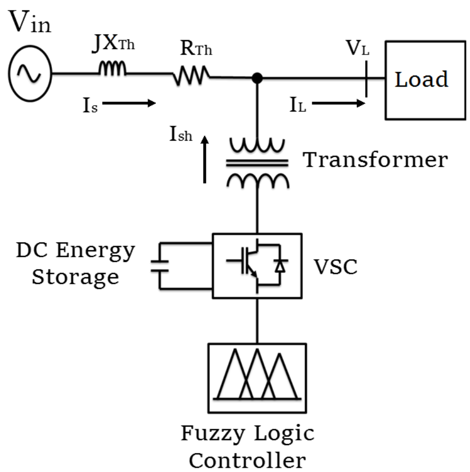


Fig. 1 Structure of D-STATCOM

Fig.1 shows the shunt injected current $I_{sh}$ corrects the voltage sag by adjusting the voltage drop across the system impedance $Z_{th}$. The value of $I_{sh}$ can be controlled by adjusting the output voltage of converter [8]. The shunt injected current Ish can be written as,

$$I_{SH}=I_S-I_L$$

Where,

$$I_S= (V_{TH}-V_L/Z_{TH})$$

Therefore

$$I_{SH}= I_L-I_S=I_L\ (V_{TH}-V_L/Z_{TH})$$

The complex power injection of the D-STATCOM can be expressed as,

$$S_{SH}= V_L\ I_L$$

It may be mentioned that the effectiveness of D-STATCOM is correction voltage sag depends on the value of $Z_{TH}$ or fault level on load bus. When the shunt injected current $I_{SH}$ is kept in quadrature with $V_L$, the desired voltage correction can be achieved without injecting any active power in the system.

## IV. MODELING PICONTROLLER OF D-STATCOM

PI Controller is a feedback controller which drives the plant to be controlled with a weighted sum of the error (difference between output and desired set-point) and the integral of that value. 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. The PI control block diagram is shown in Fig. 3

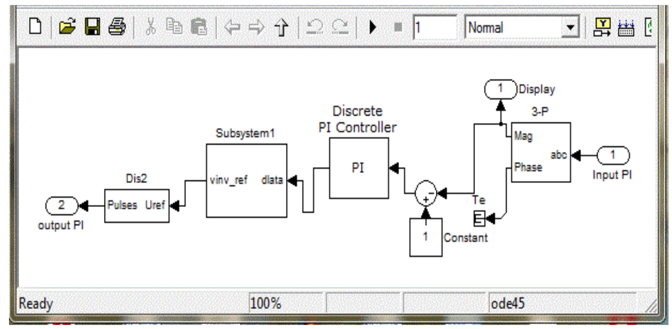


Fig.3 Simulink Model of PI Controller

## V. FUZZY LOGIC CONTOLLER (FLC)

The performance of Fuzzy logic controller is well documented for improvements of voltage sag. The function of fuzzy logic controller is very useful since exact mathematical model of it is not required. The fuzzy logic control system can be divided into four main functional blocks namely Knowledge base, Fuzzification, Inference mechanism and Defuzzification, Rule base. In this paper, a fuzzy logic based feedback controller is employed for controlling the voltage injection of the proposed D-STATCOM.

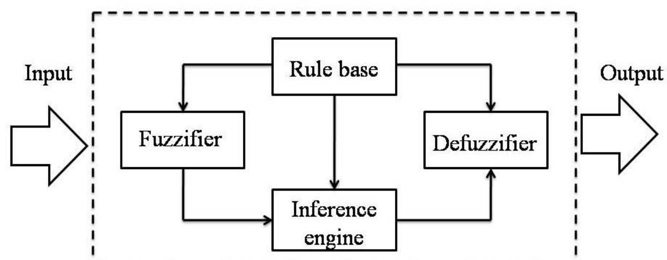


Fig. 4 The Basic Elements of a FLC

The main idea underlying the fuzzy logic control is, to highlight the issues involved, Fig. 1 shows the basic element of FLC, which comprises four principal components: a fuzzification, a Rule base, Inference engine, and defuzzification [9].

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.

*A. Control System With Mfc*

The design of FCSs with Mamdani FC is usually performed by heuristic means incorporating human skills and 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 [10]. The membership function is shown below.

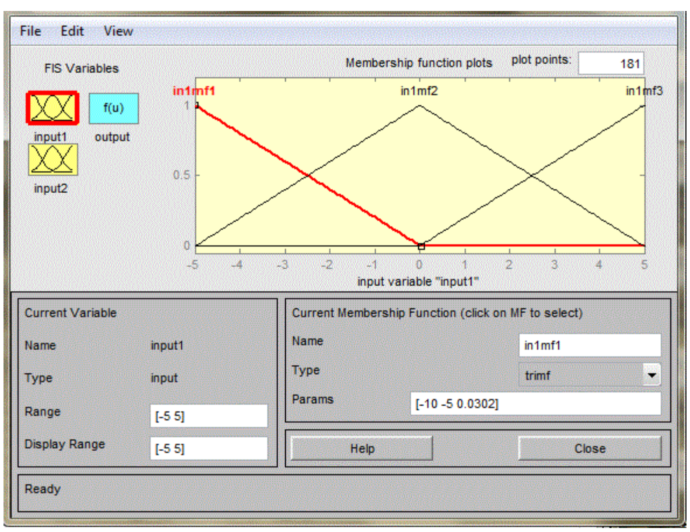


Fig. 5 Input1 Membership Function of MFC in MATLAB

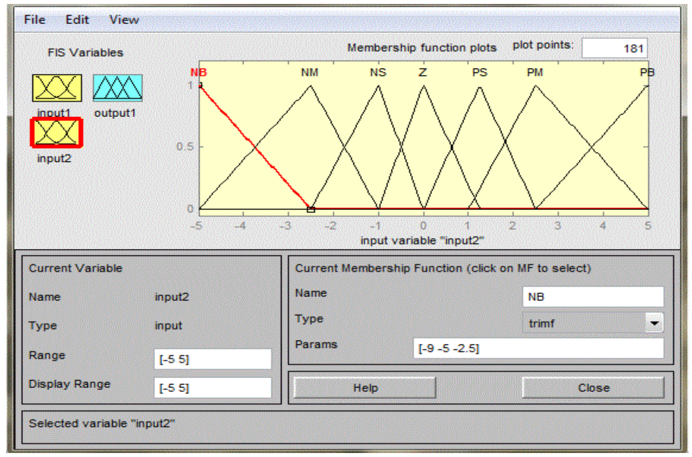


Fig. 6 Input2 Membership function of MFC in MATLAB

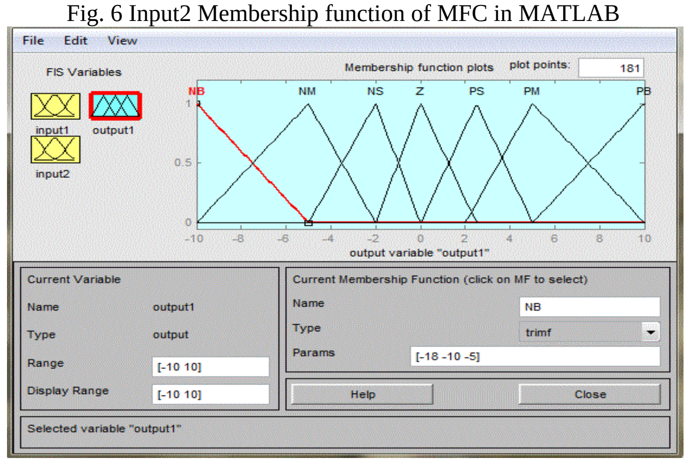


Fig. 7 Output Membership Function of MFC in MATLAB

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 (du) of SFL is shown in Figure 8.

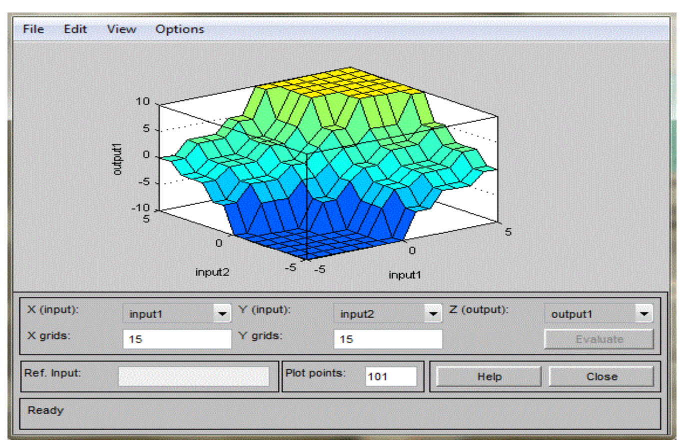


Fig. 8 Control Surface of MFC

TABLE 1
RULE BASE OF MFC

| Error/d_error | NB | NM | NS | Z | PS | PM | PB |
|---|---|---|---|---|---|---|---|
| NB | NB | NB | NB | NB | NM | NS | Z |
| NM | NB | NB | NB | NM | NS | Z | PS |
| NS | NB | NB | NM | NS | Z | PS | PM |
| Z | NB | NM | NS | Z | PS | PM | PB |
| PS | NM | NS | Z | PS | PM | PB | PB |
| PM | NS | Z | PS | PM | PB | PB | PB |
| PB | Z | PS | PM | PB | PB | PB | PB |

### 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. 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 [10].

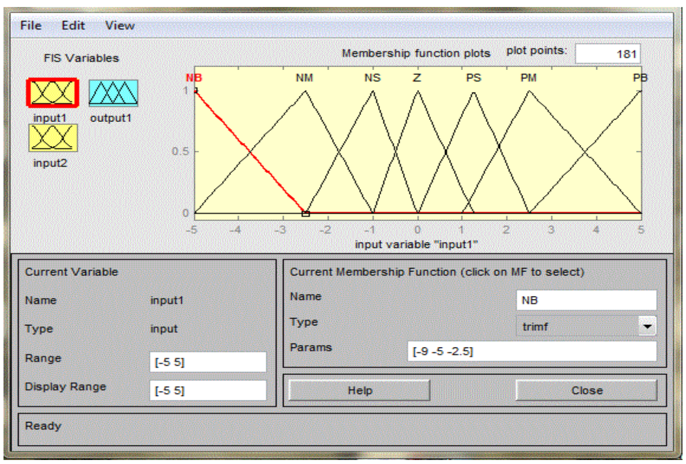


Fig. 9 Inpu1 Membership Function of SFC in MATLAB

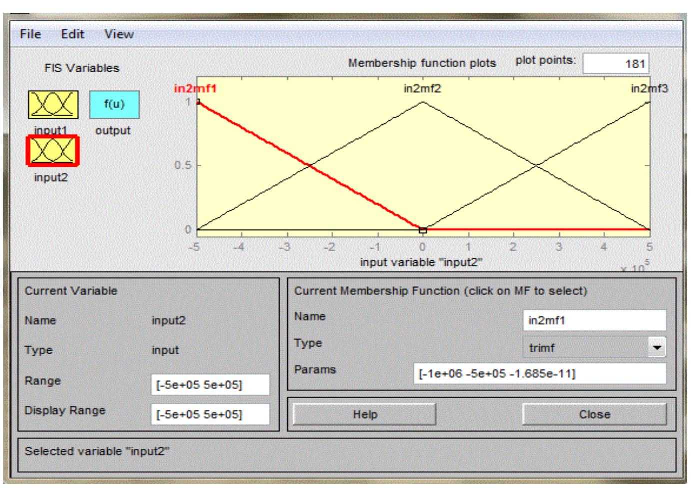


Fig. 10 Input2 Membership Function of SFC in MATLAB

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 8.

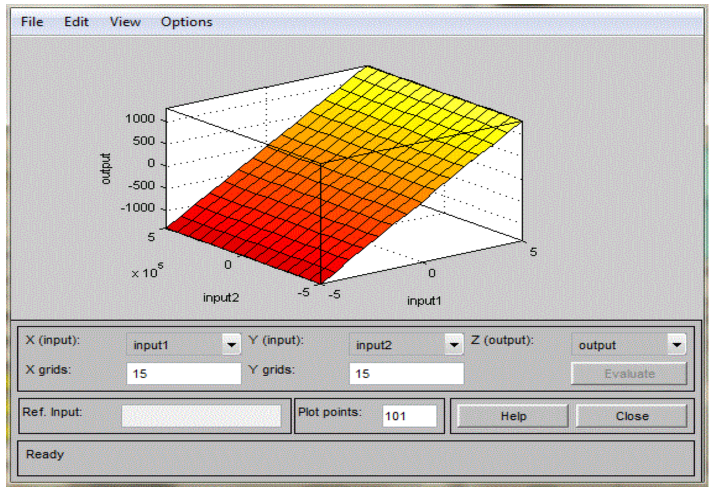


Fig.11 Control Surface of SFC

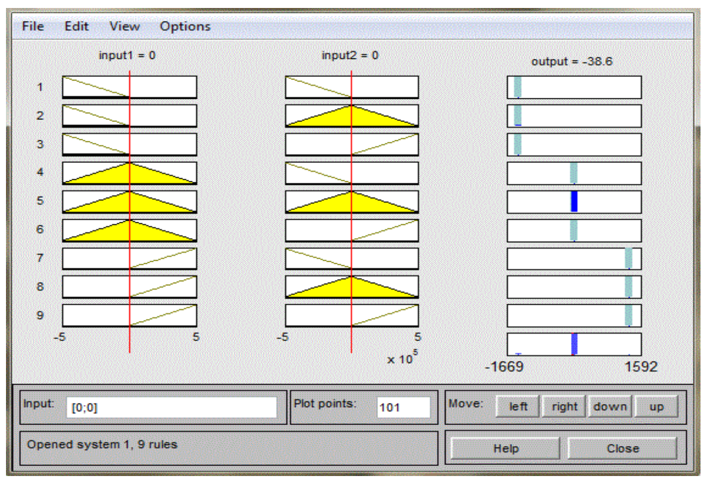


Fig. 12 Rule Base of SFC

### C. Methodology

To enhance the performance of distribution network, D-STATCOM was connected to the distribution system. D-STATCOM was designed using MATLAB with its Fuzzy Logic Toolbox. Fig. 11 below shows the flow chart for methodology:

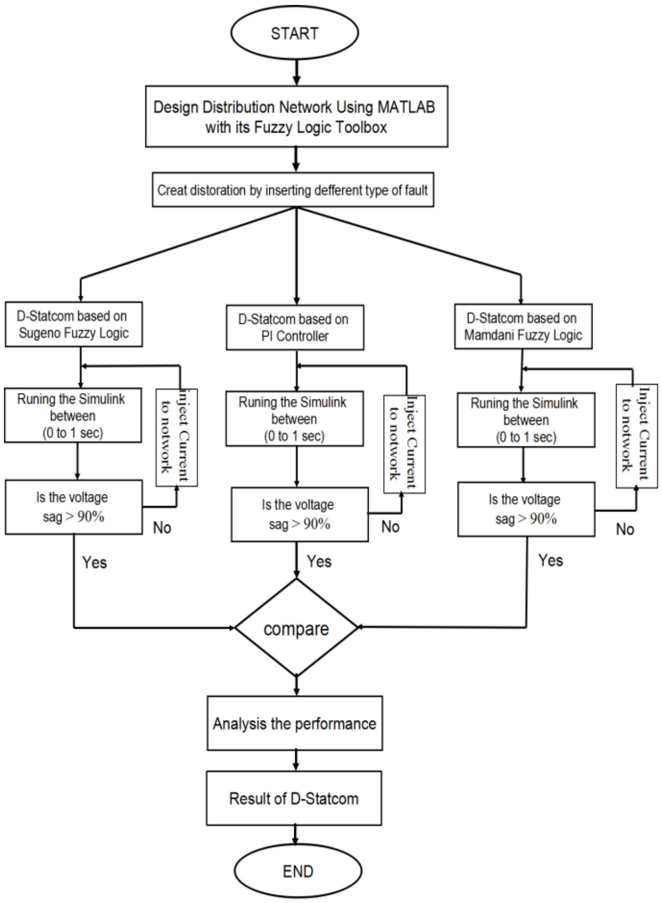


Fig. 13 Flow Chart of Control Methodology

## VI. D-STATCOM TEST SYSTEM

The performance of the designed D-STATCOM, as shown in fig. 14 is evaluated using MATLAB with its Fuzzy Logic Toolbox. Table 2 shows the values of parameters in distribution system.

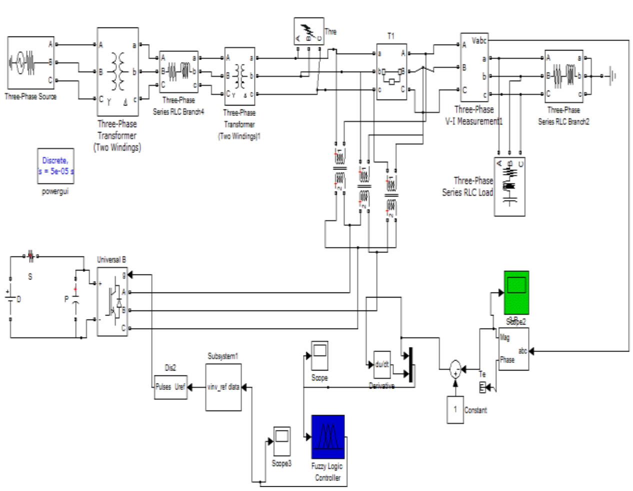

Fig. 14 Simulation Model of D-STATCOM

TABLE II
SYSTEM PARAMETERS

| S. No | System Quantities | Standard |
|---|---|---|
| 1 | Voltage Source | 15kV |
| 2 | Line Frequency | 50HZ |
| 3 | Series Transformer | 1:1 |
| 4 | Load Impedance | 0.36 ohm |
| 5 | DC Voltage source | 2kV |
| 6 | Filter Inductance | 3mH |

## VII. THE RESULT OF D-STATCOM

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

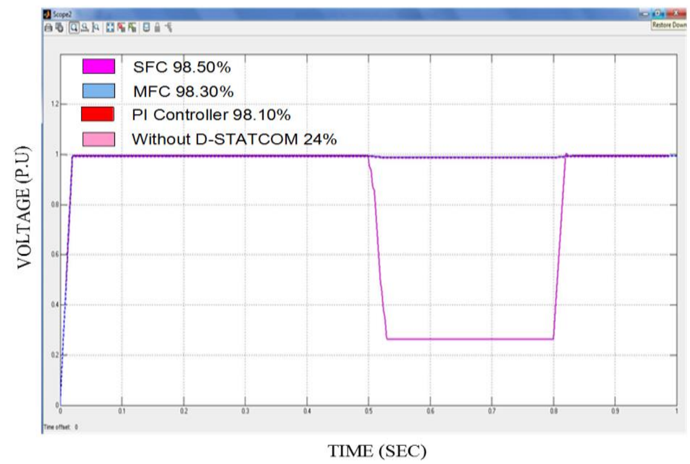


Fig. 15 Single Phase Fault Scenario Result of Comparison Use the PI Controller, SFC and MFC

The figure 15 illustrates the single fault scenario result of absence of D-STATCOM method and comparison among three other methods namely PI controller, SFC, and MFC.

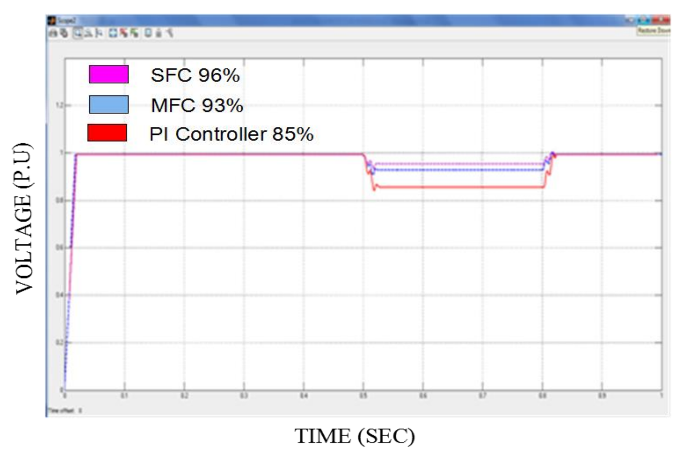


Fig. 16 Two Phase Fault Scenario Result of Comparison Use the PI Controller, SFC and MFC

The figure 16 illustrates the two fault scenario result of absence of D-STATCOM method and comparison among three other methods namely PI controller, SFC, and MFC.

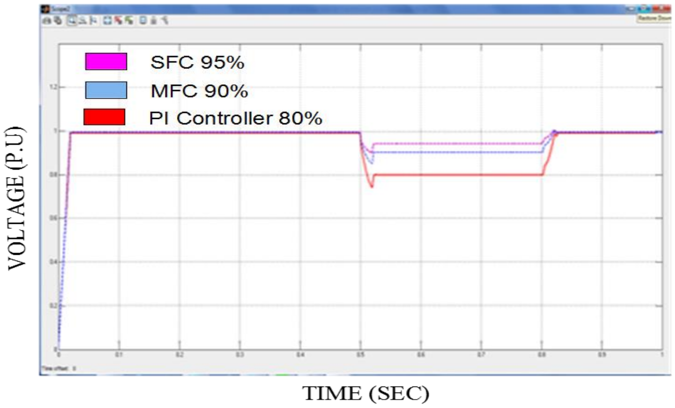


Fig. 17 Three Phase Fault Scenario Result of Comparison Use the PI Controller, SFC and MFC

The figure 17 illustrates the three fault scenario result of absence of D-STATCOM method and comparison among three other methods namely PI controller, SFC, and MFC.

## VIII. Conclusion

In a nutshell, the simulation of D- STATCOM subsuming SFC, MFC and PI was executed successfully. Therefore, the accomplishment of D- STATCOM was analyzed perfectly. The outcomes uncovered that the best performer SFC restored 96%, and 95% voltage sag difficulties where two other methods such as MFC and PI controlled countervailed 93%, 90% and 85 %, 80%, respectively at two phase and three phase scenario though this difference was not significant at single phase scenario. Consequently, the result findings suggested the usage of SFC and MFC integrated with D-STATCOM for the mitigation of voltage sag problems owing to their competency to riposte against loads in the distribution system.

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