A STUDY ON OPTIMIZING TECHNIQUES FOR THE SIZING OF DG IN DISTRIBUTION SYSTEM

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***Abstract*—Recent changes in the electric utility infrastructure created the opportunities for many technological innovations including the application of DG in order to achieve a variety of benefits. To achieve the benefits, factors such as the capacity of the units and the best location have to be considered. This problem was addressed in this study by the development of the techniques to optimize the output of the DG in order to obtain maximum benefits from its installation. The proposed technique was capable to effectively improve the system performance in terms of system losses. This paper presents the comparative study on the performance of the optimization techniques for determining the optimal sizing of DG using Evolutionary Programming and Artificial Immune System. The proposed technique was tested on IEEE Reliability Test systems namely the IEEE 69-bus and the program was developed using the MATLAB programming software.**

***Keywords* — Distributed generator; Evolutionary programming (EP); Artificial Immune System**

I. INTRODUCTION

The terms of DG implies the use of any modular technology that is sited throughout a utility service area or interconnected to the distribution or sub-transmission system to lower the cost of service. DGs are normally small generating sets, connected to the grid or feeding power islands, based on technologies such as internal combustion engines, small and micro gas turbines, fuel cells, photovoltaic and wind plants [1, 2, and 3]. The introduction of DG on the distribution network can significantly impact to the flow of power, voltage conditions and power quality at customers and utility equipment [4].

The increase in penetration of distributed generation in distribution network requires the system engineers to properly plan the implementation of DG. Determining the suitable location and sizing of a distributed generator is important in order to ensure for maximum benefits to be obtained from the implementation of DG. The great attention should be considered in determining the allocation and sizing of DG since non-optimal places and sizing of DG can result in an increase in the system losses. This paper presents the comparative study on the performance of the optimization techniques in order to determine the optimal sizing of DG using EP and AIS.

II. METHODOLOGY

The optimal size of the distributed generator is determined by having the kW output (P_g) of the distributed generator as the variable to be optimized. The kVar output of the distributed generator was determined using (2) and the power factor of the system was set to be 0.85.

$$x_i = P_g \quad (1)$$

$$Q_g = P_g \times \tan^{-1}\theta \quad (2)$$

$$\cos\theta = 0.85$$

θ = Power factor angle

The operation of the distributed generator is considered to be at steady state and therefore, the distributed generator is modelled as injected active and reactive power, P_g and Q_g respectively [5]. The number of variables depends on the number of distributed generators or compensating capacitor to be installed in the systems.

A. Evolutionary Programming

Evolutionary Programming originally was conceived by Lawrence J. Fogel in 1960 as an alternative approach to artificial intelligence [6]. Evolutionary Programming (EP) has been employed in the field of design search and optimization more thoroughly after the exposure from Fogel [7] when it was first implemented in the prediction of finite states machines. EP has been applied for a variety of power engineering problems, e.g. optimal distribution system planning [8], operation optimization [6] and distribution network reconfiguration [9, 10].

In this study, the EP optimization technique was used to determine the optimal sizing in the distribution system with aims to reduce the system losses and also to improve the voltage profile. Ref [5] shows the algorithm for EP optimization technique in order to determine the optimal sizing of DG. Figure 1 shows the flowchart of EP technique in order to obtain the optimal size of DG.

B. *Artificial Immune System*

The Artificial Immune System (AIS) is a new Computational Intelligence (CI) approach that is inspired in the vertebrate immune system and has produced efficient computational tools for solving problems [11]. Figure 2 shows the flowchart of project methodology for implementation of AIS. The mutation process implemented based on (3).

$$X_{i+mj} = X_y + N\left(0, \beta\left(X_{jmax} - X_{jmin}\right)\left(f_i / f_{max}\right)\right) \quad (3)$$

Where:

X_{imj} = mutated parents (offspring)
X_y = parents
N = Gaussian random variable with mean μ and variance γ
B = mutation scale, B ⱡ
X_{jmax} = maximum random number for every variable
X_{jmin} = minimum random number for every variable
f_i = fitness for the i_{th} random number
f_{max} = maximum fitness

Step 1 Initialization of population

For the purpose of determining the optimal sizing of DG, the random numbers represent the kW output (P_g) of distributed generator as the variable to be optimized. The size of DG is to be set in the interval of 0MW-3MW. The number of variables depends on the number of distributed generators to be installed in the systems.

Step 2 Evaluation of the fitness value of each population

In order to minimize the network losses, the fitness of the AIS is taken to be the total losses in the distribution system. The total loss was evaluated by solving the load flow program. It was done by calling the load flow program into the AIS as a main program. The optimization also took the consideration of the voltage constraint in the system so that the minimum and maximum voltage would not be exceeded.

Step 3 Clone

In this process, the size of DG and the total losses were cloned.

Step 4 Mutation process

The value of clone was mutated by implementing the mutation operator. Mutation is the only variation operator used for generating the offspring from each parent. The fitness of the offspring was calculated by calling the load flow program.

Step 5 Selection process

The selection process was done by using the priority selection strategy.

Step 6 Convergence test

This procedure is to determine the stopping criteria of the optimization. The convergence criterion is specified by the difference between the maximum and minimum fitness to be less than 0.0001. If the convergence condition is not satisfied, the processes will be repeated.

$$maximum_{fitness} - minimum_{fitness} \leq 0.0001 \quad (4)$$

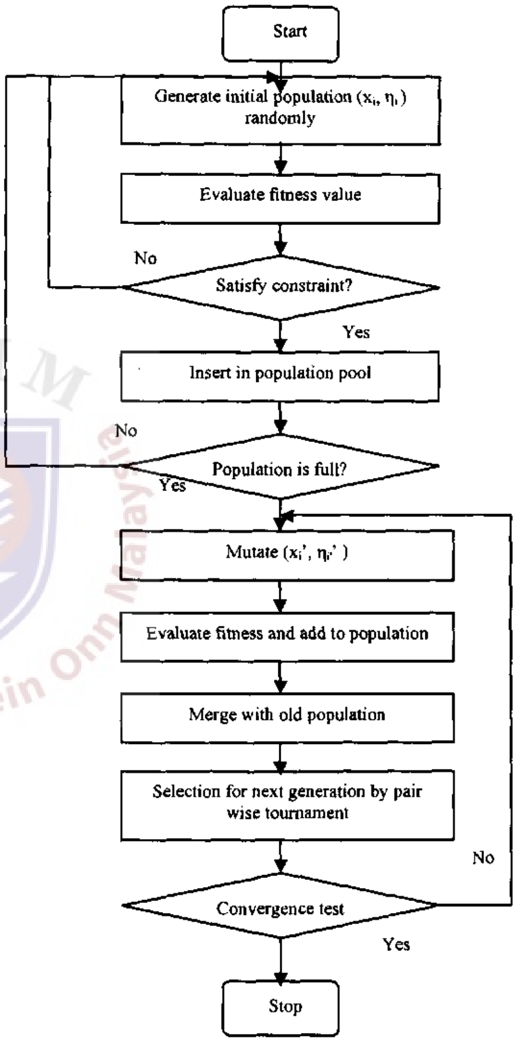

Figure 1: Flowchart for implementation of EP technique in order to obtain the optimal size of DG.

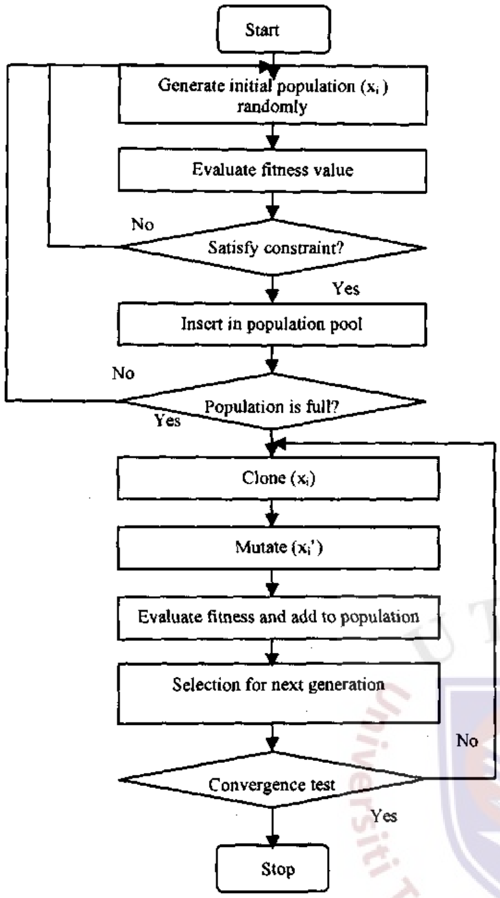

Figure 2: Flowchart for implementation of AIS technique in order to obtain the optimal size of DG.

III. Test System

The proposed techniques were tested on IEEE Reliability Test systems namely the IEEE 69-bus and the program was developed using the MATLAB programming software [12].

IV. Results and Discussion

The effect of optimal sizing and allocation of the DG on the total losses and voltage profile in the system was observed by installing the DG at bus 61. The comparative study was done in order to see the effectiveness of the proposed techniques in order to determine the optimal size of the DG using EP and AIS.

Table I shows the total losses and minimum voltage in the system without installation of DG. The result shows that, the optimal output of the DG increased as the loading at a load bus was incremented.

TABLE 1.
TOTAL LOSSES AND MINIMUM VOLTAGE IN THE SYSTEM WITHOUT DG

Loading	P_{loss}	Q_{loss}	V_{min}
0.6	0.0755	0.0344	0.9476
0.8	0.1389	0.0632	0.9288
1	0.2249	0.1021	0.9092
1.2	0.3366	0.1525	0.8887
1.4	0.4776	0.2158	0.8672

The result obtained from the simulation of EP and AIS techniques were tabulated in Table 2. From the analysis, it could be observed that the number of iteration of AIS is better than EP.

The graph shown in Figure 2 compares the total losses in the system with DG at bus 61. The result from the EP and AIS optimization techniques shows that the total losses in the system were reduced with the installation of DG.

Similarly, the graph in Figure 3 shows the variation in the minimum voltage with respect to overall load increase in the system when DG was installed at bus 61. It could be observed that allocating DG at bus 61 has given better voltage improvement and hence the voltage profile of the system is maintained at an acceptable range.

TABLE 2.
TOTAL LOSSES AND MINIMUM VOLTAGE IN THE SYSTEM USING EP AND AIS TECHNIQUES

	AIS			EP		
Loading	Total Losses	V_{min}	Iteration	Total Losses	V_{min}	Iteration
0.6	0.0116	0.9839	1	0.0082	0.9839	14
0.8	0.0153	0.9781	2	0.0147	0.9785	20
1	0.0245	0.9724	1	0.0232	0.973	16
1.2	0.0336	0.9669	2	0.0336	0.9674	13
1.4	0.0518	0.9609	2	0.0461	0.9618	21

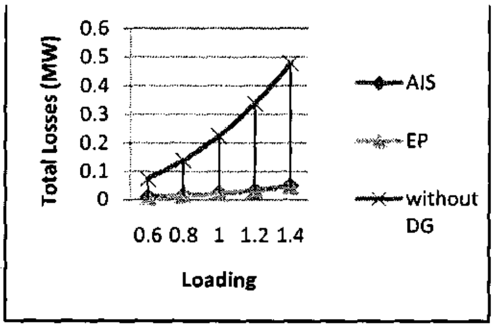

Figure 3: Total losses in the system with DG

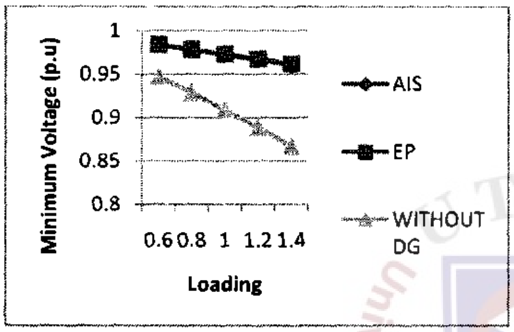

Figure 4: Minimum voltage in the system with DG

Finally the optimal active power to be generated by the DG installed at bus 61 for the range of loading conditions is tabulated in Table 3. It could be observed that higher injected power is required from the DG as the loading was increased in order to minimize the system losses and hence voltage profile improvement in the system.

TABLE 3.

OPTIMAL SIZING OF DG USING EP AND AIS

	AIS		EP	
Loading	P_g	Q_g	P_g	Q_g
0.6	0.9828	0.4978	1.1011	0.5577
0.8	1.5187	0.7693	1.4646	0.7419
1	1.9137	0.9693	1.8366	0.9303
1.2	2.2133	1.1211	2.205	1.1169
1.4	2.7307	1.3832	2.5736	1.3036

V. CONCLUSION

In conclusion, the implementation of DG at the identified location with optimal sizing was successfully tested on the test systems. The results show that the both techniques were capable to minimize the system losses and improve the voltage profile. The result shows that the AIS technique was capable to simulate with the minimum number of iteration compared to EP.

ACKNOWLEDGMENT

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REFERENCES

[1] A. Silvestri,. A. Berizzi and S. Buonanno, "Distribution generation planning using Evolutionary Programming", Electric Power Engineering, Powertech Budapest 99. International Conference, pp. 257, 1999.

[2] W. E. Khattam, K. Bhattacharya, Y. Hegazy and M.M.A Salama, "Optimal investment planning for distributed generation in a competitive electricity market", IEEE Transactions On Power Systems, Vol. 19, Issue: 3, pp. 1674 – 1684, Aug 2004.

[3] I. S. Bae, J. O. Kim, J. C. Kim and C. Singh, "Optimal operating strategy for distributed generation considering hourly reliability worth", IEEE Transactions On Power Systems, Vol. 19, Issue: 1 , pp. 287 – 292, Feb. 2004.

[4] P. P.Barker and R. W. D. Mello, "Determining the impact of distributed generation on power system:part 1-radial distribution system", Power Technology Inc, IEEE, pp. 1645-1666, 2000.

[5] S. R Abdul Rahim , T. K. Abdul Rahman, I. Musirin, S. A Azmi, M. F. Mohammed, M. H Hussain, M.Faridun, "Comparing the Network Performance between the Installation of DG and Compensating Capacitor using EP", International Journal of Power, Energy and Artificial Intelligence (IJPEAI): Vol. 1, No. 1, August 2008.

[6] L. J. Fogel, "The Future of Evolutionary Programming", Conference Record Twenty-Fourth Asilomar Conference on Signals, Systems and Computers, Vol. 2, pp. 1036, Nov. 1990.

[7] L. J. Fogel, "Intelligence through simulated evolution- forty years of Evolutionary Programming", John Wiley & Sons,INC, Canada, 1999.

[8] W. M. Lin, C. D. Yang and M. T. Tsay, "Distribution system planning with Evolutionary Programming and reliability cost model", Generation, Transmission and Distribution, IEE Proceedings- , Vol. 147, Issue: 6, pp. 336 – 341, Nov. 2000.

[9] Y. H. Song, G. S. Wang, A. T. Johns and P. Y. Wang, "Evolutionary approach to distribution network reconfiguration for energy saving", Electricity Distribution. Part 1. Contributions. 14th International Conference and Exhibition on (IEE Conf. Pub. No. 438), Vol. 5, pp. 33/1 - 33/8, Jun. 1997.

[10] G. S. Wang, P. Y. Wang, Y. H. Song and A. T. Johns, "Co-ordinated system of fuzzy logic and Evolutionary Programming based network reconfiguration for loss reduction in distribution systems", Proceedings of the Fifth IEEE International Conference on Fuzzy Systems, Vol. 3, pp. 1838 – 1844, Sep. 1996.

[11] S. Ishak, A. F. Abidin and T. K. A. Rahman, 'Static Var Compensator Planning Using Artificial Immune System For Loss Minimization and Voltage Improvement', National Power & Energy Conference (PECon) 2004 Proceedings, Kuala Lumpur, Malaysia.

[12] T. K. A. Rahman, S. R. A. Rahim and I. Musirin, "Optimal Allocation and Sizing of Embedded Generators", IEEE National Power Engineering Conference (PeCon), Malaysia, 29-30 Nov 2004

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Determination of Location and Number of D-STATCOM at the Distribution Network

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***Abstract*— Power quality devices are used to increase/monitor the electric system distribution network. This paper is focus on to determine the location and number of Distribution Static Compensator (D-STATCOM) at 10 bus bar distribution network. By find the optimal number and location of D-STATCOM, it reduced the numbers of D-STATCOM needs in mitigate voltage sag problem. The modal analysis and the time domain simulation are used in determine the best location of D-STATCOM in distribution network.**

Keywords— **D-STATCOM, Modal Analysis, recovery time, PSCAD**

I. INTRODUCTION

Power quality is the ability of utilities to provide electric power without interruption. In recent years, due to increase in critical load an electronic device, customers require high form of power quality than before. The most common power quality problems are voltage sags, harmonics, voltage swell, power interruptions and voltage flicker.

Reactive power compensation is an important issue in electrical power systems where Flexible AC Transmission System (FACTS) devices play an important role in controlling the reactive power flow to the power network. Static Synchronous Compensator (STATCOM) is a member of FACTS family that is connected in shunt with the system. In distribution system, it is also known as D-STATCOM. Recent days, STATCOM commonly located at every critical load in distribution system and it will increase the power quality monitoring cost. Optimal number and location of D-STATCOM will reduce or eliminate power quality problems in distribution system.

A. D-STATCOM Configuration

The most basic configuration of STATCOM consists of two-level Voltage Source Converter (VSC) with a DC energy storage device, a coupling transformer connected in shunt with the AC system and the associated control circuits. Fig. 1 shows the schematic diagram of the D-STATCOM. The VSC converts the DC voltage across the storage device into a set of three phase AC output voltages that are in phase and coupled with the AC system through the reactance of coupling transformer. A key characteristic of this controller is that the active and reactive powers exchanged between the converter and the AC system can be controlled by changing the phase angle between the converter output voltage and the bus voltage at the point of common coupling [1]-[4].

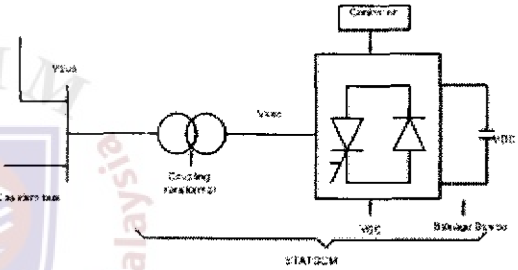


Figure 1. Connection of the STATCOM in AC System

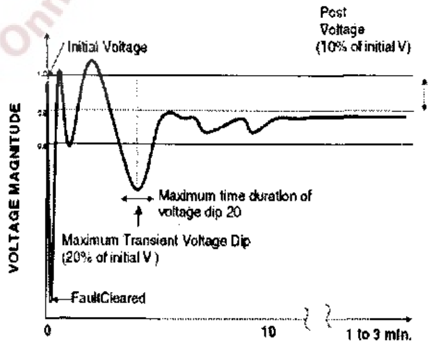


Figure 2. Voltage Stability Criteria

B. Voltage Stability and Voltage Recovery Criteria

Fig. 2 shows the voltage stability criteria where the voltage magnitude should not drop below 80% . As an example if a fault occurs for below 80% of its initial value, and resulting oscillations should not exceed 20 cycles. For 50 Hz system it is about 0.4 s while for the 60Hz system it is about 0.33 s. If this condition occurs it will increase the voltage collapse on the system. Once voltage is recovered, its magnitude should not fall below 0.9 p.u [5]. Fig. 3 shows the Voltage Recovery Criteria. As explain the clearing time for 50Hz system is 0.4 s and this is fall as the ideal for the voltage recovery time. It means that the D-STATCOM that needs to be located must have clearing time for less then 0.4 s

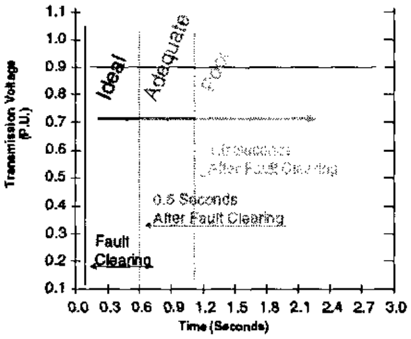


Figure 3. Voltage Recovery Criteria [5]

II. NETWORK DESIGN

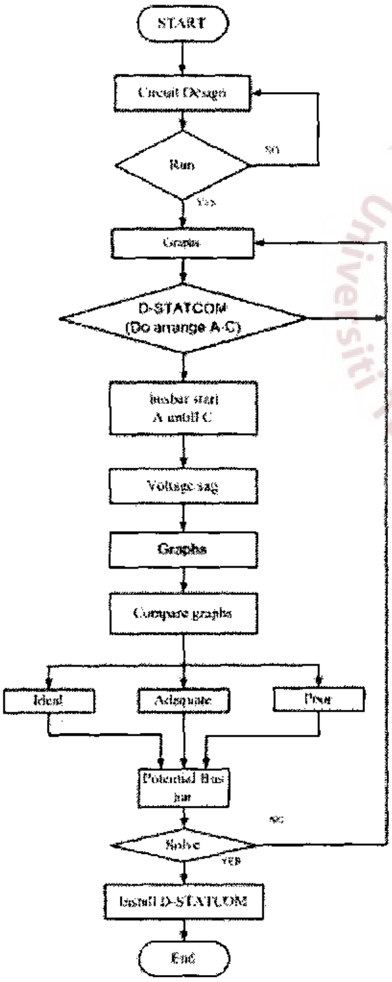


Figure 4. Project Flow-Chart

The distribution network was obtained from Tenaga Nasional Berhad, Batu Pahat, Johor, Malaysia. The overall flow of this paper is summarized in the flow chart as shown in Fig. 4.

The PSCAD software was used to simulate the network where the single line diagram was converted to electrical network using mathematical formulas. For three phase loads, the active power was considered as load resistance and reactive power was considered as load inductance. The loads was calculated for each bus bar and the three phase voltage (V_{L-L}) from main supply sub-station (MES) is 11kV and apparent power (S) equal to 30MVA. The designed network using PSCAD is shown in Fig. 5 and Fig. 6 for the system without D-STATCOM and the system with D-STATCOM respectively.

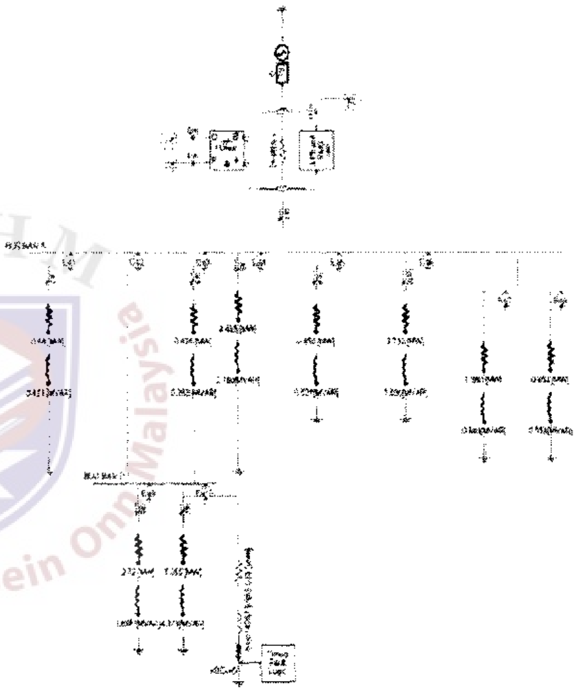


Figure 5. Distribution System without D-STATCOM

The distribution network is divided into three group which are main bus bar A, main bus bar B and main bus bar C and the grouping of buses is shown in Table 1.

TABLE I
GROUPING OF MAIN BUSBAR

Group	No. of Bus
A	Busbar 1, Busbar 2, Busbar 3, Busbar 4 and Busbar 6
B	Busbar 7 and Busbar 8
C	Busbar 9 and Busbar 10

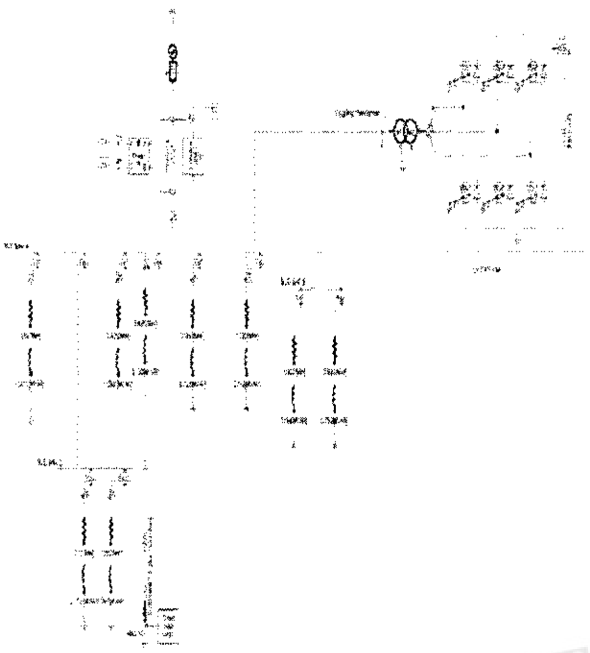


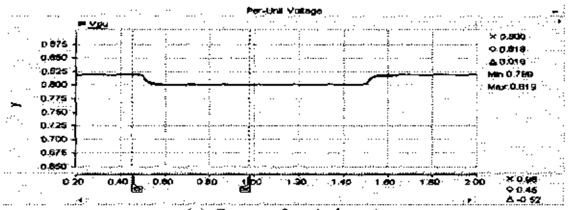
Figure 6. Distribution System with D-STATCOM.

In this simulation, a fault time is set to 1 s and occurs from 0.5 s until 1.5 s. The fault component is connected in shunt to the study distribution system as shown in Fig. 5 and Fig. 6. The simulation is run in two conditions, which are, a network without D-STACOM and a network with D-STATCOM. The network without D-STATCOM is simulated to monitor the voltage at each main group bus bar and the voltage sag that been occurred. Modal analysis is used to identify the best location of D-STATCOM. The idea is to get the time of recovery based on voltage recovery criteria as shown in Fig. 3 where it is classified to ideal, adequate or poor. The ideal bus bar then will be chosen as the best location of D-STATCOM.

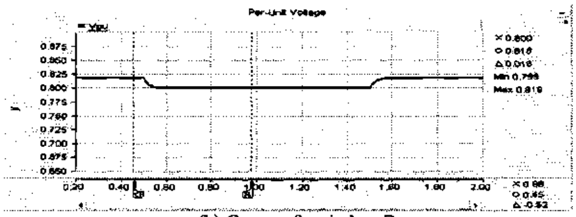
III. RESULTS AND ANALYSIS

A. Result of Simulation Network without D-STATCOM

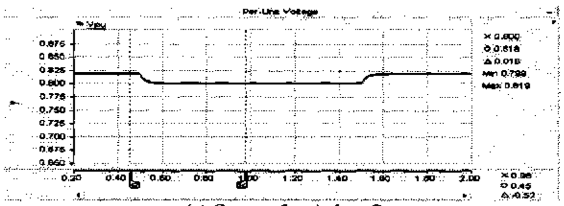
The system was simulated for three seconds with three phase balance fault occurring at time 0.5 s for duration of 1.0 s. The results of simulation are shown in Fig. 7. For the system without D-STATCOM, the load voltage dropped from 0.818 p.u to 0.800 p.u at the group of main bus bar A as shown in Fig. 7(a).



(a) Group of main bus A



(b) Group of main bus B

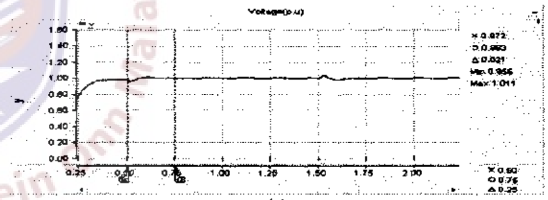


(c) Group of main bus C

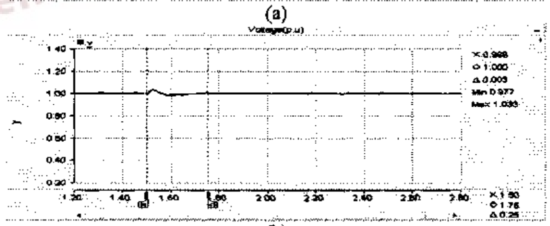
Figure 7. Without D-STATCOM at (a) bus A, (b) bus B, (c) bus C

The voltage dropped starting from 0.5 s until 1.5 s because of faults time is set to start at 0.5 s for the duration of 1 s. After the fault time, the voltage will return constant at the normal condition. This short-term reduction in voltage is called voltage sag. In this simulation, the voltage sag is non-repetitive but in the real network, it can be happen.

B- D-STATCOM Allocated at Bus bar A, B and C for Voltage Sag Compensation.



(a)

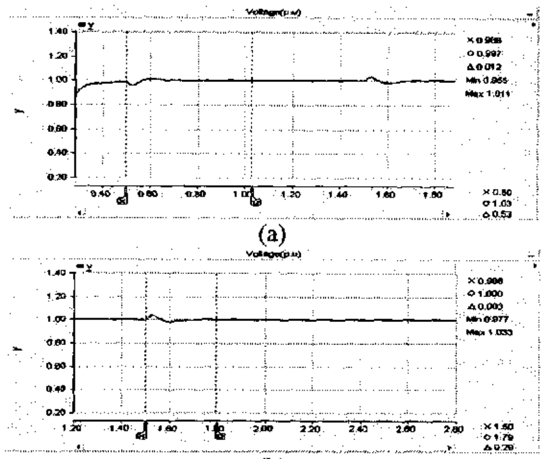


(b)

Figure 8. Load voltage of group main Bus A, a) without D-STATCOM b) with D-STATCOM. c) Time of Recovery

The simulation results of the D-STATCOM at group bus bar A response in term of the load voltage in per unit are shown in Fig 8. For the system with the D-STATCOM connected in the system, the load voltage will increase from 0.800 p.u to 0.993 p.u as shown in Fig. 8(a) while Fig. 8(b) shows the load voltage takes 0.25 s to recover to the rated voltage.

The simulation results of the D-STATCOM at group bus bar B are shown in Fig. 9. For the system with the D-STATCOM connected in the system, the load voltage will increase from 0.800 p.u to 0.997 p.u as shown in Fig. 9(a). Fig. 9(b) shows the load voltage takes for 0.29 s to recover to rated voltage.

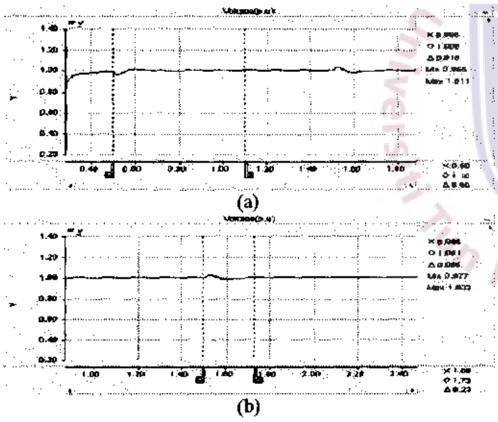


(a)

(b)

Figure 9. Load voltage of group main Bus B , a) With D-STATCOM. b) Time of Recovery

This also happen at the main group bus bar C where it show that the system with the D-STATCOM connected, the load voltage improved from 0.800 p.u to 1.0 p.u as shown in Fig. 10(a), while the time recovery is about 0.23s as demonstrated in Fig. 10(b).



(a)

(b)

Figure 10. Load voltage of main group Bus C , a) With D-STATCOM. b) Time of Recovery

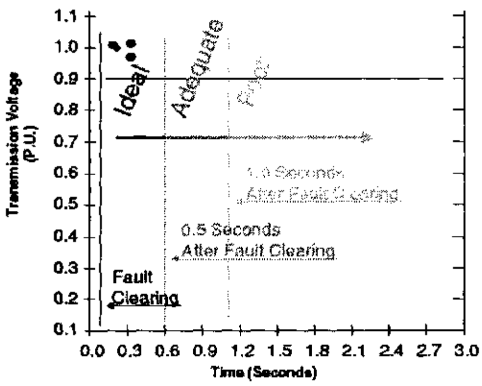


Figure 11. Plot of voltage time recovery

From the results obtained, all the recovery time are plotted at the graph of voltage recovery time as shown in Fig. 11. The plotted graph demonstrates that all the clearing time is fall at the ideal condition means the D-STATCOM can be placed in any point of bus system. The results also presents a spike at the beginning and at the end of fault duration and these are caused by the process of charging and discharging of the capacitor in D-STATCOM circuit.

IV. Conclusion

The simulation results obtained shows that, the D-STATCOM responded well in mitigating voltage sag caused by three-phase balance fault. The summarize data of voltage recoveries, time recoveries and classification of the network are depicted in Table 2.

TABLE 2
SUMMARY OF NETWORK SIMULATION

Location of D - STATCOM (Bus bar)	Voltage (V p.u)		Time of recovery (s)	Classification
	Without D-STA T COM	With D-STA TCOM		
A	0.800	0.993	0.25	Ideal
B	0.800	0.997	0.29	Ideal
C	0.800	1.0	0.23	Ideal

Based on the recovery times, all locations are ideal to install D-STATCOM because voltages are recovered within 0.6s. Although the entire bus bar groups are ideal location, only the best location will be chosen. Therefore, the best solution for the power quality problem (voltage sag) in this distribution network is when D-STATCOM is located at main group bus bar C.

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References

[1] H.G. Sarminto, G. Pampin, J.D. de Leon, "FACTS Solution for Voltage Stability problems in Large Metropolitan Area," 2004 IEEE/PES Power System Conference and Exposition, vol 1, pp.275-282, Oct. 2004.

[2] H. Yonezawa, T.Shimato, M.Tsukada, K. Matsuno, I.Iyoda, J.Paserba, G.F.Reed, "Study of a STATCOM application for voltage stability evaluated by dynamic PV curve and time simulation,"2000 IEEE Power Engineering Society Winter Meeting, vol.2, pp.1471-1476, Jan 2000.

[3] M.F.Kandlawala and A.H.M.A.Rahim, "Power system dynamic performance with STATCOM controller, " 8th annual IEEE technical exchange meeting, April 2001.

[4] Noor Izzri bin Hj Abdul Wahab, "Power Quality Improvement Using Distribution Static Compensator (D-STATCOM) On 11 kV Distribution System", Universiti Putra Malaysia: Msc Thesis. 23-31, 38-72, May 2002.

[5] P.P Barker, J.J. Burke, R.T.Mancao, T.A.Short, C.A. Warren, and C.W.Burns, " Power Quality Monitoring of a Distribution System," IEEE/Trans. Power Del.,vol.9, no.2,pp.1136-1142, Apr.1994.