Voltage Sag Compensation Using D-STATCOM and DVR in Distribution System

Mohd Ridhwan Bin Abdul Rani
Faculty of Electrical Engineering
Universiti Teknologi MARA Malaysia
40450 Shah Alam, Selangor, Malaysia
Email: ewan_prs@yahoo.com

Abstract — **This paper presents the compensation of voltage sag in distribution system using Distribution Static Compensator (D-STATCOM) and Dynamic Voltage Restorer (DVR). Both models are based on the Voltage Source Converter (VSC) principle. D-STATCOM injects a current into the system to mitigate the voltage sags and DVR inject the voltage into the system to mitigate the voltage sags. The performance of DVR and D-STATCOM was studied by varying the supply voltage and fault resistance. The simulations were performed using MATLAB SIMULINK version R2010.**

Keywords- D-STATCOM, DVR, Voltage Sag, Voltage source converter (VSC), sensitive load, energy storage, MATLAB SIMULINK

I. INTRODUCTION

Power Quality is in general a broad concept and is associated with electrical distribution and utilization systems that experience any voltage, current or frequency deviation from normal operation. For ideal electrical systems, the supplied power should have a perfect current and voltage sinusoidal waveforms. In reality, it is the electric utilities control the voltage levels and quality. The load profile dictates the shape of the current waveform [1].

Sag is often set by two parameters, depth or magnitude and duration. The term sag has been used for many years to describe a short duration event in between of 10 ms to 1 min with a reduction in rms voltage magnitude [2]. Sag magnitude is the net rms voltage during the fault. It measure in percent or in per unit of system nominal voltage. On the other hand, the sag duration is the time of drop voltage comparing its nominal value The sag duration is dependent on the over current protection equipment and how long the fault current is allowed to flow. The voltage sag magnitude is ranged from 10% - 90% of nominal voltage and within duration from half cycle to 1 min [3-4]. IEC 61000-4-30 defines voltage sag as a temporary reduction of the voltage at a point of the electrical system below a threshold [4].

With the increasing of new technology, a lot of mitigation techniques have been developed to improve voltage sag. They range from inexpensive equipment which provides less protection to devices that need higher price but can protect to almost all power quality problems [5]. The types of protection equipment advisable to be used for customer's installation are Uninterruptible Power Supply (UPS), Dip Proofing Inverter (DPI), Dynamic Voltage Restorer (DVR), Voltage Dip Compensator (VDC) and Distribution Static Compensator (D-STATCOM).

The main objective of this paper is to study the voltage sag phenomenon in distribution system caused by three phase short circuit fault. The DVR and D-STATCOM are used to compensate the voltage sag in distribution system. The second objective is to study the performance of a D-STATCOM and DVR by varying the supply voltage and fault resistance.

II. VOLTAGE SAG MITIGATION TECHNIQUES

A. Dynamic Voltage Restorer (DVR) and Distribution Static Compensator (D-STATCOM)

DVR is a series voltage controller connected in series with the protected load as shown in Figure 1. Usually the connection is made via transformer, but the configurations with direct connection via power electronics also exist. 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 taken from the energy storage [3].

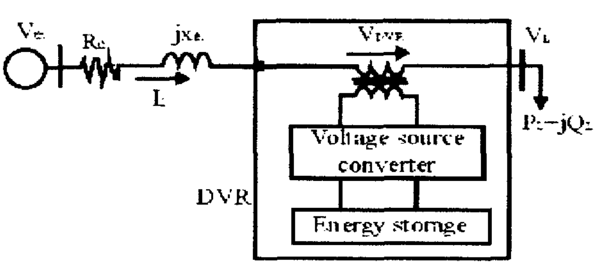


Figure 1. Schematic Diagram of DVR

D-STATCOM consists of a two-level VSC, a dc energy storage device, controller and a coupling transformer connected in shunt to the distribution network. Figure 2 shows the schematic diagram of D-STATCOM [6].

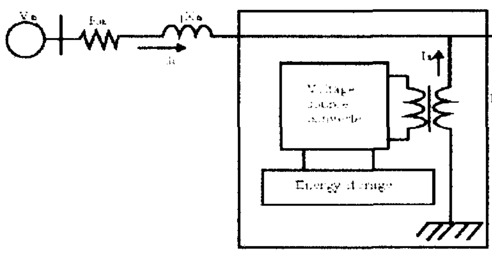


Figure 2. Schematic Diagram of D-STATCOM

B. Energy Storage

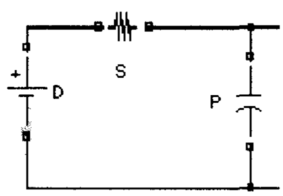


Figure 3. Circuit diagram of DC storage

Besides injecting voltage, the energy storage can also generate active power to the load. The energy storage in this circuit is given by a capacitor. During normal condition capacitor will be charged by the DC supply voltage. When voltage sag occurs in the system, the capacitor will discharged to maintain the load voltage. DVR and D-STATCOM has limitation in magnitude and duration to compensate voltage sag.

C. Voltage Source Converter (VSC)

A Voltage Source Converter (VSC) is a power electronic device which can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. The VSC is used to inject the voltage sags, VSC as a switching device [8].

The function of VSC is to switch a dc input voltage to a symmetric output voltage of desired magnitude and frequency, it uses Pulse Width Modulation (PWM) control signal for producing an ac output voltage. The turn- on and turn- off of IGBT is controlled by injecting pulses into it. Pulses 1, 3 and 5 are respectively for the upper switches of the first, second and third arm. Pulses 2, 4 and 6 are for the lower switches.

D. Controller

Figure 4 shows the block diagram of Controller system. The controller system is partially part of distribution system.

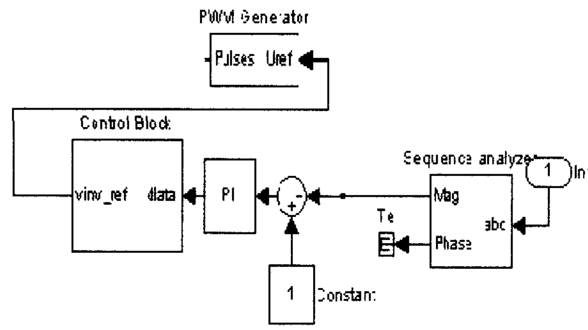


Figure 4. Block Diagram of Controller System

Proportional-integral controller (PI Controller) is a feedback controller which drives the system to be controlled with a weighted sum of the error signal (difference between the output and desired set point) and the integral of that value.

PI controller will process the error signal to zero. The load r.m.s voltage is brought back to the reference voltage by comparing the reference voltage with the r.m.s voltages that had been measured at the load point. It is also used to control the flow of the reactive power from the DC capacitor storage circuit [8].

PWM generator is the device that generates the Sinusoidal PWM waveform or signal. To operate PWM generator, the angle is summed with the phase angle of the balance supply voltages equally at 120 degrees. Therefore, it can produce the desired synchronizing signal that is required. PWM generator also received the error signal angle from PI controller. The modulated signal is compared against a triangle signal in order to generate the switching signals for VSC valves [8].

E. Three Phase Transformer

Three Phase transformer functions to connect DVR to the distribution network in series with the protected load and three phase transformers is to connect D-STATCOM to distribution network in shunt with the protected load. It couples the injected compensating voltages that generated by VSC to the incoming supply. After the compensating, the resulting voltage at the load bus bar is the sum of the grid voltage from the supply and the injecting voltage by booster transformer.

III. METHODOLOGY

Figure 5 below shows the flowchart for the methodology carried out to implement voltage sag compensation using DVR and D-STATCOM in distribution system.

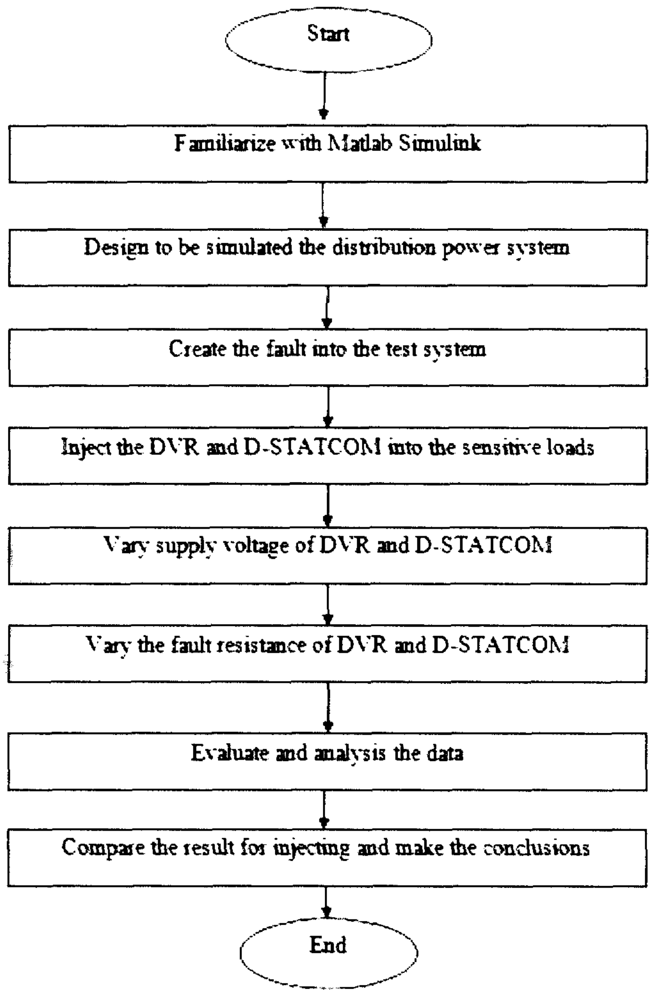


Figure 5. Methodology in mitigating voltage sag

A. *Test System DVR and D-STATCOM*

The test system for the analysis is as shown in Fig 6. A source voltage of 13.8kV, 50Hz frequency is implemented with source impedance of 0.3 ohm. Then, it is fed into two feeders and the voltage is decreased to 11kV to be distributed to customer. Resistive load of 25 ohm is used on feeder 1 whilst feeder 2 is implemented with a series resistance of 0.2 ohm and inductance of 0.2 ohm. Feeder 2 is considered as a sensitive load and feeder 1 is non sensitive load.

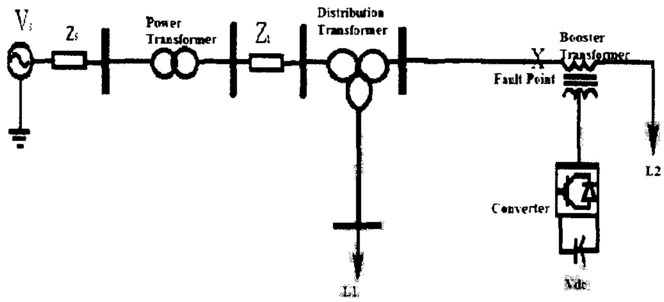


Figure 6. Test System of DVR and D-STATCOM

B. *Design Distribution System using Matlab Simulink*

The distribution system was designed using Matlab Simulink shown in Appendix A for DVR and Appendix B for D-STATCOM. The distribution system consist of three phase source generator, three phase transformer, bus system, three phase breaker, three phase faults and RL load.

C. *Creating Faults and Inserting DVR or D-STATCOM*

Three phase faults were injected into the test system at sensitive load. Then DVR and D-STATCOM is inserted in series with distribution system to mitigate voltage sag caused by three phase Faults (TPG), double line to ground (DLG), Line to Line (LL) and single line to ground (SLG).

D. *Varying the Supply Voltage*

Even through DVR and D-STATCOM is an effective method in mitigating voltage sag, therefore the capability depends on the value of supply voltage. The performance of DVR and D-STATCOM was observed by varying in voltage supply.

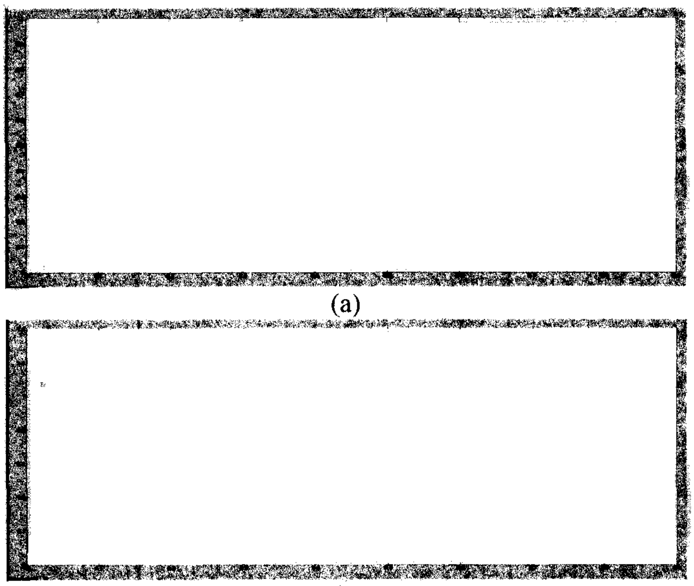
E. *Varying the Faults Resistance*

The value of fault was varies by controlling the value of faults resistance. In this project the performance of DVR and D-STATCOM was observed by varying the value of faults resistance.

IV. RESULTS AND DISCUSSION

A. Simulation Results for Different Types of Fault

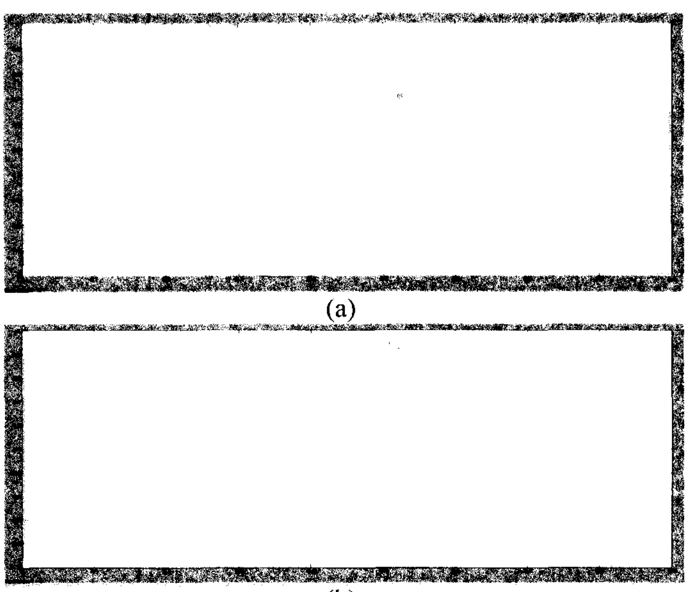
To create distortion in the distribution system, different types of fault such as (TPG), (DLG), (LL), and (SLG) are injected to the circuit.



(a)

(b)

Figure 7. Voltage across sensitive load at rated voltage for TPG faults. (a) Without DVR, (b) With DVR



(a)

(b)

Figure 8. Voltage across sensitive load at rated voltage for TPG faults. (a) Without D-STATCOM, (b) With D-STATCOM

TABLE I.
RESULTS WHEN VARYING DIFFERENT TYPES OF FAULT USING DVR

Fault	Without DVR (p.u)	With DVR (p.u)	Percentage improvement (%)
TPG	0.8343	0.9754	14.11
DLG	0.8946	0.9865	9.19
SLG	0.9346	0.9967	6.21
LL	0.9455	1.0134	6.79

Table I shows the overall results of voltage sag in p.u for varying the different types of fault using DVR. From the table it can be seen that for TPG fault the percentage of voltage sag improved to 14.11 %

The overall results of voltage sag in p.u improved with insertion of DVR. The value of voltage sag improve to 1.0134p.u which is closed to 1p.u.

TABLE II.
RESULTS WHEN VARYING DIFFERENT TYPES OF FAULT USING D-STATCOM.

Fault	Without D-STATCOM (p.u)	With D-STATCOM (p.u)	Percentage improvement (%)
TPG	0.7145	0.9653	25.08
DLG	0.7435	0.9784	23.49
SLG	0.8027	0.9867	18.40
LL	0.9026	1.0027	10.01

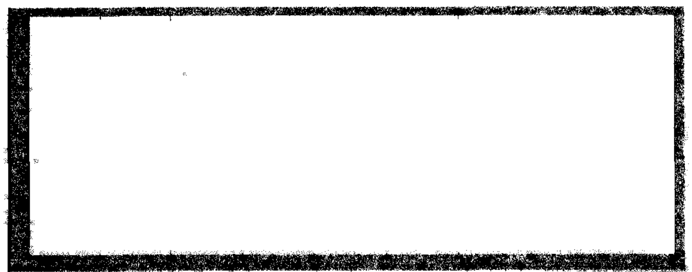
Table II shows the overall results of voltage sag in p.u for varying the different types of fault using D-STATCOM. From the table it can seen that for TPG, fault the percentage of voltage sag improved to 25.08 %

The overall results of voltage sag in p.u improved with insertion of D-STATCOM. The value of voltage sag improve to 1.0027p.u which is closed to 1p.u.

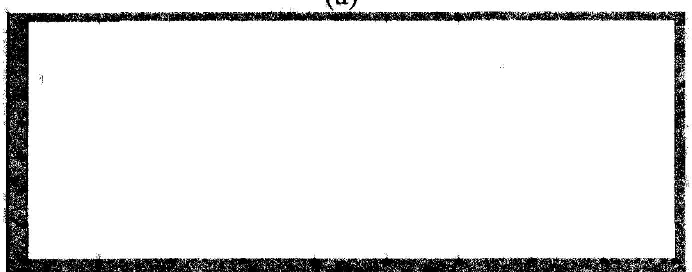
From Table I and Table II, simulation results for both techniques show some differences. By comparing the value of percentage improvement D-STACOM technique is better compared to DVR.

B. Simulation Results by Varying the Voltage Supply.

To study the capability of DVR and D-STATOM system in boosting the drop voltage, the voltage supply was varied from 13.8kV until 6kV.

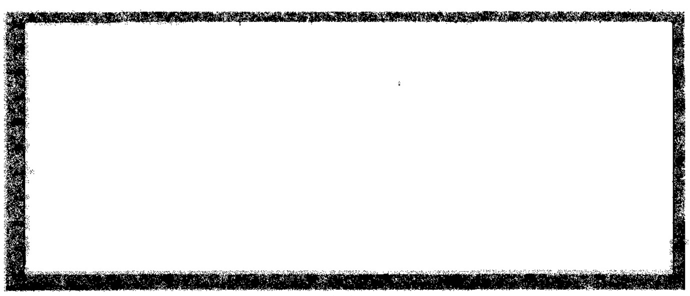


(a)

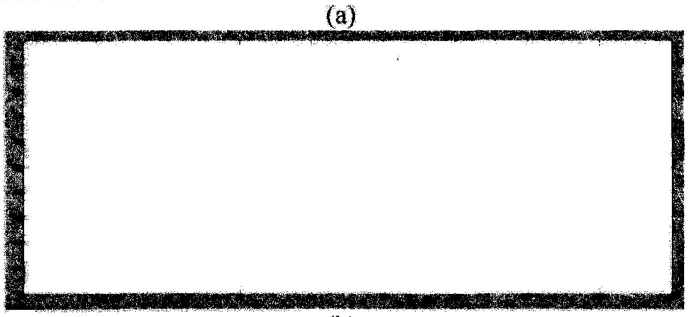


(b)

Figure 9. Voltage across sensitive load at rated voltage for 13.8kV voltage supply.
(a) Without DVR, (b) With DVR



(a)



(b)

Figure 10. Voltage across sensitive load at rated voltage for 13.8kV voltage supply.
(a) Without D-STATCOM, (b) With D-STATCOM

TABLE III.
RESULTS WHEN VARYING THE SUPPLY VOLTAGE USING DVR

Voltage supply (kV)	Without DVR (p.u)	With DVR (p.u)	Percentage of improvement (%)
13.8	0.7578	0.9697	21.19
13.0	0.7424	0.9439	20.15
11.0	0.7219	0.9187	19.68
9.0	0.6785	0.9075	22.90
7.0	0.5754	0.8703	29.49
6.0	0.5198	0.8450	32.52

Table III shows the overall results of voltage sag in p.u by varying the voltage supply using DVR. From the table it can seen that for 6.0kV voltage supply the percentage voltage sag is improved to 32.52 %

The overall results of voltage sags in p.u improved with insertion of DVR. The value of voltage sag improve to 0.9697p.u which is closed to 1p.u.

TABLE IV.
RESULTS WHEN VARYING THE SUPPLY VOLTAGE USING D-STATCOM

Voltage supply (kV)	Without D-STATCOM (p.u)	With D-STATCOM (p.u)	Percentage of improvement (%)
13.8	0.7452	0.9710	22.58
13.0	0.6793	0.9678	28.85
11.0	0.5974	0.9657	36.83
9.0	0.4985	0.9626	46.41
7.0	0.3727	0.9567	58.40
6.0	0.2356	0.9543	71.87

Table IV shows the overall results of voltage sags in p.u by varying the voltage supply using D-STATCOM. From the table it can seen that for 6.0kV voltage supply the percentage voltage sags will be improved to 71.87 %

The overall results of voltage sags in p.u improved with insertion of D-STATCOM. The value of voltage sag improve to 0.9710p.u which is closed to 1p.u.

From Table III and Table IV, simulation results for both techniques show some differences. By comparing the value of percentage improvement D-STACOM technique is better compared to DVR.

C. *Simulation Results by Varying the Fault Resistance*

To study the capability of DVR and D-STATCOM system in boosting the drop voltage, The fault resistance was varied from 0.56 Ω until 0.86 Ω.

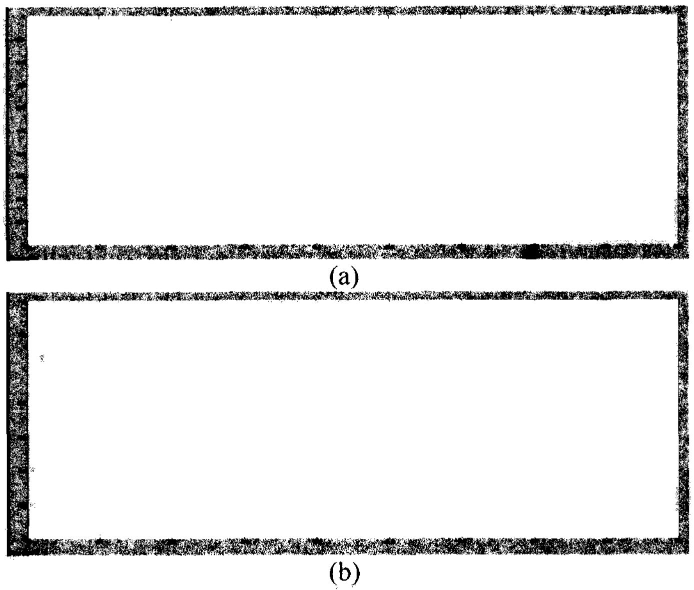


Figure 11. Voltage across sensitive load at rated voltage for 0.56 Ω fault resistance.
(a) Without DVR, (b) With DVR

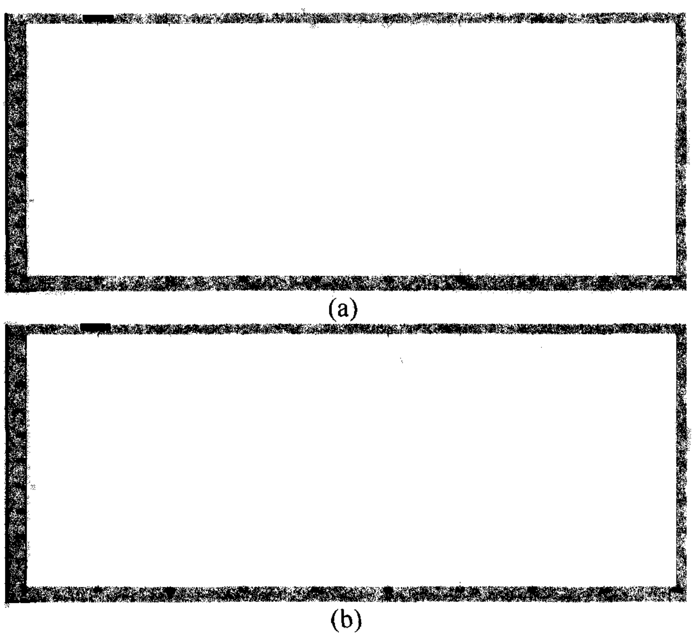


Figure 12. Voltage across sensitive load at rated voltage for 0.56Ω fault resistance.
(a) Without D-STATCOM, (b) With D-STATCOM

TABLE V.
RESULTS WHEN VARYING THE FAULT RESISTANCE USING DVR

Resistance (Ω)	Without DVR (p.u)	With DVR (p.u)	Percentage improvement (%)
0.56	0.8345	0.9523	11.78
0.66	0.8467	0.9643	11.76
0.76	0.8642	0.9753	11.11
0.86	0.8786	0.9864	10.78

Table V shows the overall results of voltage sags in p.u by varying the faults resistance using DVR. From the table it can seen that for 0.86 Ω fault resistance the percentage voltage sags is improved to 11.78 %

The overall results of voltage sag in p.u improved by insertion of DVR. The value of voltage sag improve to 0.9864p.u which is closed to 1p.u.

TABLE VI.
RESULTS WHEN VARYING THE FAULTS RESISTANCE USING D-STATCOM

Resistance (Ω)	Without D-STATCOM (p.u)	With D-STATCOM (p.u)	Percentage Improvement (%)
0.56	0.6346	0.9156	28.10
0.66	0.6874	0.9278	24.04
0.76	0.7086	0.9345	22.59
0.86	0.7378	0.9515	21.37

Table VI shows the overall results of voltage sags in p.u by varying the faults resistance using D-STATCOM. From the table it can seen that for 0.86 Ω fault resistance the percentage voltage sags is improved to 28.10 %

The overall results of voltage sag in p.u improved by insertion of D-STATCOM. The value of voltage sag improve to 0.9515p.u which is closed to 1p.u.

From Table V and Table VI, simulation results for both techniques show some differences. By comparing the value of percentage improvement D-STACOM technique is better compared to DVR.

V. CONCLUSION AND FUTURE DEVELOPMENT

This paper, presents the comparison between DVR and D-STATCOM to compensate the voltage sag in distribution system. From the simulation results, it can be observed that the voltage sags across sensitive load can be mitigating by using both technique. The performance of DVR and D-STATCOM can be improved by varying voltage supply and the fault resistance.

For the future development the (DVR) and (D-STATCOM) can be designed with passive filter to mitigate the harmonic distortion in the distribution system. When harmonic is mitigating thus the power quality problem can be improved.

ACKNOWLEDGEMENT

In the name of ALLAH the most gracious and the most merciful, it is with the deepest gratitude that ALLAH gives strength and ability to complete this project.

The author would like to take this opportunity to express his thanks and appreciations to the project supervisors, Associate Professor Wan Norainin Bin Wan Abdullah for her concern, valuable time, effort, constant encouragement and patience in supervising his project from the beginning until the completion of this technical paper.

REFERENCES

[1] A. M. Sharaf, S Abu-Azab —Power Quality Enhancement of Time Dependent Interharmonic Loads —Proceedings of the Nonth International IEEE Conference on Harmonics and Quality of Power ICHPS'2000, Orlando, FL, October 2000.

[2] J. Smith, "Voltage sag and what to do about them. (Electrical and Power Quality)," in Plant Engineering Article: HighBeam™ Research, August 1, 2002.

[3] S. V. R. Kumar and S. S. Nagaraju, "Power Quality Improvement Using D-Statcom and DVR," International Journal of Electrical and Power Engineering, vol. 1, pp. 368- 376,2007.

[4] P. Boonchiam and N. Mithulananthan, "Understanding of Dynamic Voltage Restorers through MATLAB Simulation," Thammasat Int. J. Sc. Tech., Vol. 11, No. 3, July-Sept 2006.

[5] N. Edomah, "Effects of voltage sags, swell and other disturbances on electrical equipment and their economic implications," in Electricity Distribution, 2009 20th International Conference and Exhibition Power Engneering, 2009, pp. 1-4.

[6] Haque, M.H., —Compensation Of Distribution Systems Voltage sags by DVR and D-STATCOMI, Power Tech Proceedings, 2001 IEEE Porto, Volume 1, PP.10-13, September 2001.

[7] Mahesh Singh, "Modeling and analysis of power quality problems" SSCET BHILAI INDIA.

[8] M. H. Rashid, *Power Electronics Circuits, Devices, and Application*, 3rd ed.,United States of America:Pearson Prentice Hall.2004.

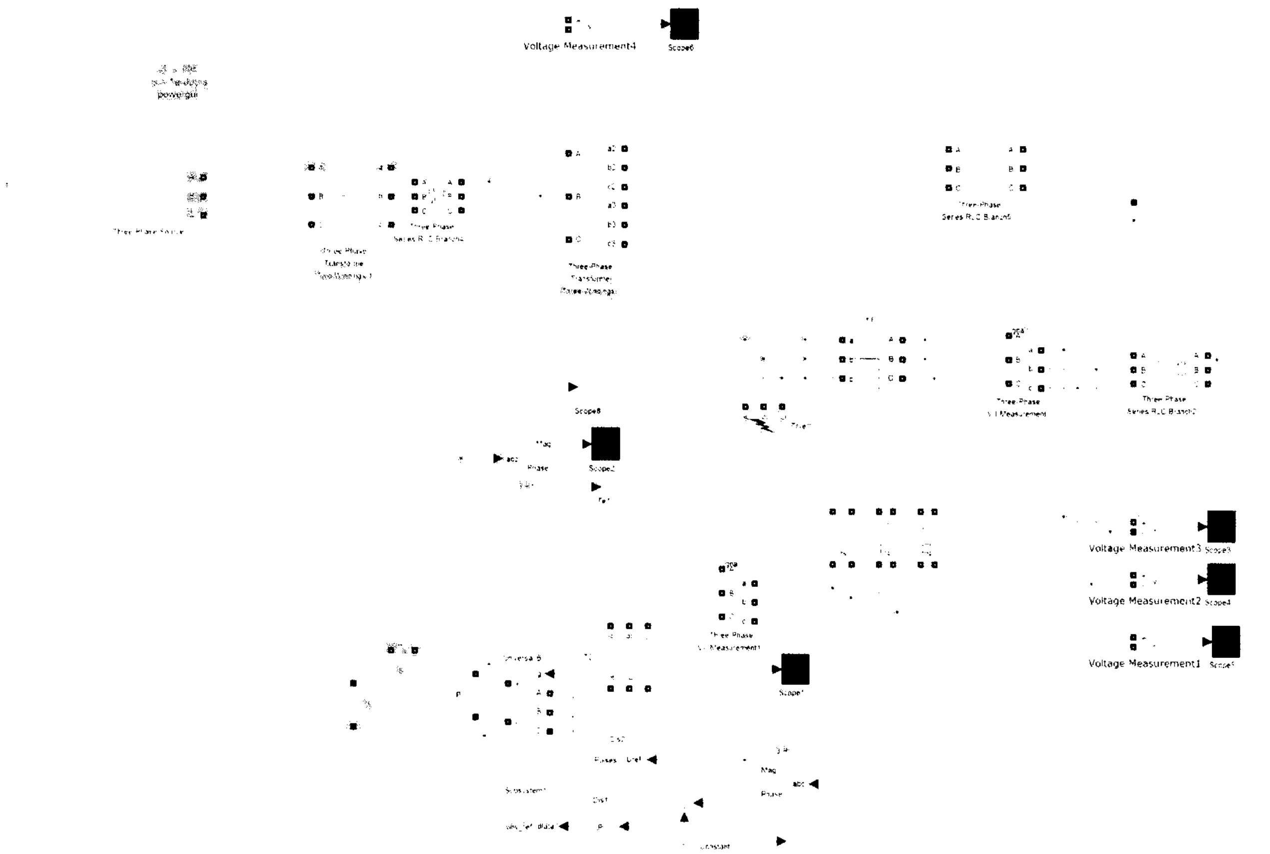
[9] M. F. Faisal, *Voltage Sag Solutions for Industrial Customers*: Engineering Department, Distribution Division TNB, 2007.

[10] R.Meinski, R.Pawelek and I.Wasiak, "Shunt Compensation For Power Quality Improvement Using a STATCOM controller Modeling and Simulation", IEEE Proce, Volume 151, No. 2, March 2004.

APPENDIXES

Appendix A

Test System using Matlab Simulink for DVR (Dynamic Voltage Restorer)



Appendix B

Test System using Matlab Simulink for D-STATCOM (Distribution Static Compensator)