Comparative Analysis Between STATCOM and DVR For Voltage Sag Mitigation

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Abstract—**Voltage sag is the most common type of power quality disturbance in the distribution system. Voltage sag can be caused by abrupt increases in loads such as short circuits or faults, motor starting, or electric heaters turn on, or caused by abrupt increase in source impedance, typically caused by a loose connection [1]. Dynamic Voltage Restorer (DVR) and Static Compensator (STATCOM) is one of the mitigation techniques used to mitigate voltage sag. In this paper, focus is to compare the mitigation techniques between STATCOM and DVR to determine the best technique to improve the voltage sags. Both of the mitigation techniques will be tested on different type of fault. The study will also investigate the effects of harmonic because use the electronic devices. Simulations were carried out using the PSCAD/EMTDC electromagnetic transient programs to examine the performance of the STATCOM and DVR model. At the end of the project the Dynamic Voltage Restorer (DVR) is the best mitigation techniques to improved voltage sag.**

I. INTRODUCTION

Power quality is the ability of utilities to provide electric power without interruption. It is simply the interaction of electrical power with electrical equipment. The issue in electricity power sector delivery is not confined to only energy efficiency and environment but more importantly on quality and continuity of supply or power quality and supply quality. Utility and customer-side disturbance result in terminal voltage fluctuations, transients, and waveform distortions on the electric grid resulting in power quality problems. Lack power quality can effect the safe, reliable and efficient operation of the equipment. Based on records by Tenaga Nasional Berhad (TNB), 80% of power quality complaints in Malaysia were traced to be related to voltage sag [2].

Due to the enhancement of new technology, a lot of devices have been created and developed to mitigate voltage sag in transmission and distribution system such as Unified Power Flow Controller (UPFC), Uninterruptible Power Supply (UPS), synchronous static compensator (STATCOM), and dynamic voltage restorer (DVR). This paper is to compare the best solution to mitigate voltage sag by using STATCOM system and DVR system technique. DVR which acts as a series compensator is used for voltage sag compensation and STATCOM which is a shunt compensator is used for reactive power and voltage sag compensation.

II. VOLTAGE SAG

Voltage sag is the most common power disturbance. Voltage sags are short durations reductions in RMS voltage due to the short circuits, overloads, and starting of large motors [3]. It is a short duration in rms voltage from nominal voltage, happened in a short duration, about 10ms to seconds. According to IEEE Standard 1159-1995, defines voltage sags as an rms variation with a magnitude between 10% and 90% of nominal voltage and duration between 0.5 cycles and one minute [4]. Voltage sag occurs at the adjacent feeder with the unhealthy feeder that cause by two factor which are short circuits due to faults in power system networks and starting motor which draw very high lagging current.

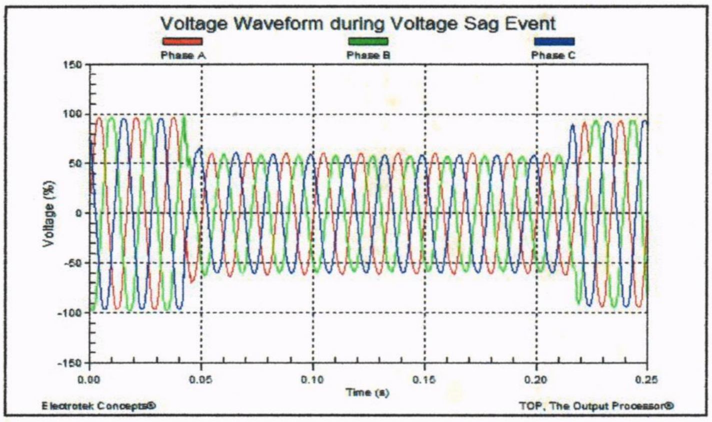

Figure 1: Voltage waveform during voltage sag

Voltage sag can arrive from the utility, however in most cases the majority of sags are generated inside a building. For example, in residential wiring the most common cause of voltage sag is the starting current drawn by refrigerator and air conditioning motors. This voltage sag problem usually effect in industrial and large commercial customers such as the damage of the sensitivity equipments and loss of daily productions and finances. And example of the sensitivity equipments are programmable logic controller (PLC), chiller control and adjustable speed drive (ASD).

Nowadays, there are many ways in order to mitigate voltage sag problem. One of the solutions is by minimizing short circuits caused by utility directly which can be done such as with avoid feeder or cable overloading by correct configuration planning. Another ways is using the flexible ac technology (FACTS) devices.

III. THE PRINCIPLE OPERATION OF STATCOM AND DVR SYSTEM

In this paper, focus is to analyzed two mitigation techniques to mitigate voltage sag problem which is Static Compensator (STATCOM) system and Dynamic Voltage Restorer (DVR) system.

A. STATIC COMPENSATOR (STATCOM) SYSTEM

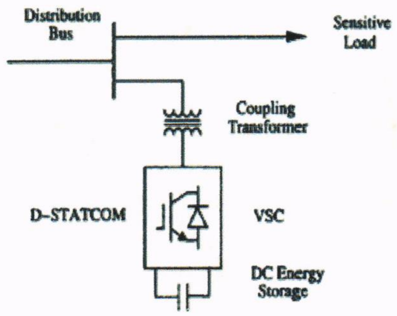

Figure 2: Schematic diagram of the STATCOM

The STATCOM system consist of a two level Voltage Source Controller (VSC), a dc energy storage device, a coupling transformer connected in shunt with the ac system and associated control circuit [5, 6] as shown in Figure 2. Function of this VSC is to converts the DC voltage across the storage device into a set of three phase AC output voltages. The AC voltage are connected in phase and coupled with the AC system through the reactance of the coupling transformer. The phase and magnitude of the STATCOM output voltages will give the effectiveness of controlling the active and reactive power exchanges between the STATCOM and the ac system. From the figure below, the VSC is connected in shunt with the AC system in order to control voltage regulation and compensation of reactive power and also to reduce of current harmonics.

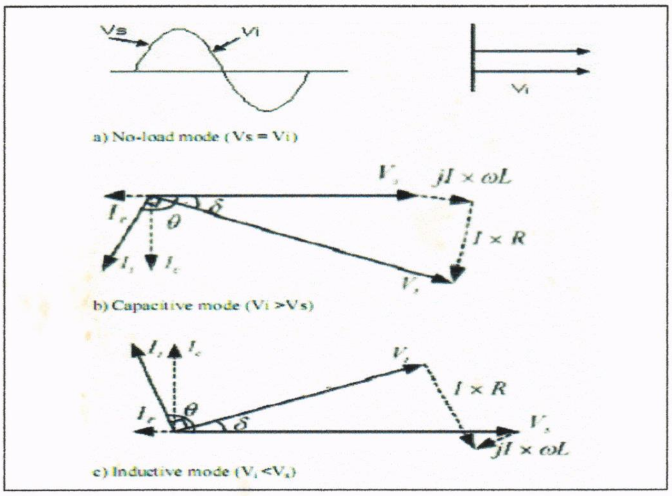

Figure 3: Operation mode of STATCOM

Figure 3 shows the three basic operation modes of Static Compensator output current I, which varies depending upon Vi. If Vi is equal to Vs, the reactive power is zero and STATCOM does not generate or absorb reactive power. When Vi is greater than Vs, the STATCOM shows an inductive reactance connected at its terminal. The current, I flow through the transformer reactance from the STATCOM to the ac system and the device generates capacitive reactive power. If Vs is greater than Vi, the STATCOM shows the system as a capacitive reactance. Then the current flows from the ac system to the STATCOM, resulting in the device absorbing inductive reactive power.

B. DYNAMIC VOLTAGE RESTORER (DVR) SYSTEM

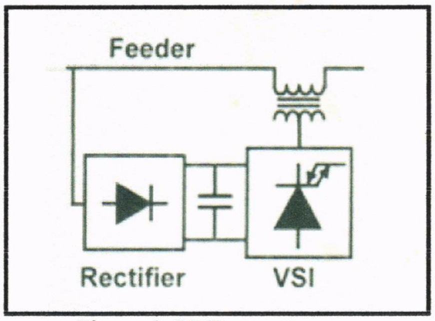

Figure 4: DVR structure

The DVR is a powerful controller commonly used for voltage sags mitigation. DVR system is almost same with the STATCOM system and the different is the coupling transformer is connected in series with the AC system. From figure 4, show that in power system, a capacitor between rectifier and inverter will be charging in normal situation. The capacitor will discharge to maintain load voltage supply when voltage sag happened. In order to maintain load voltage supply, the nominal voltage will be compared with the voltage sag to get a difference voltage that will be injected by DVR system.

The reactive power will be injected by DVR system so that the load voltage supply is maintained.

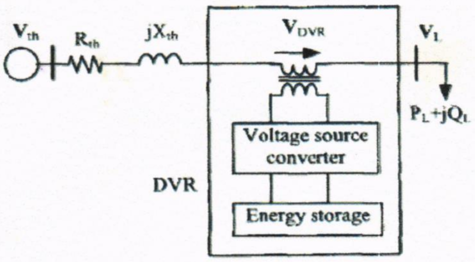

Figure 5: Calculation for DVR voltage injection

Refer to the schematic diagram shown in figure 5.

$$Z_{th} = R_{th} + jX_{th} \qquad (1)$$

$$V_{DVR} + V_{th} = V_L + Z_{th} I_L \qquad (2)$$

When dropped voltage happened at V_L, DVR will inject a series voltage V_{DVR} through the injection transformer so that the desired load voltage magnitude V_L can be maintained. Hence,

$$V_{DVR} = V_L + Z_{th} I_L - V_{th} \qquad (3)$$

$$I_L = \left[\frac{P_L + jQ_L}{V_L} \right]^* \qquad (4)$$

When V_L is considered as a reference, therefore;

$$V_{DVR} \angle\alpha = V_L \angle 0^\circ + Z_{th} I_L \angle\beta - \theta) - V_{th} \angle\delta \qquad (5)$$

Here α, β and δ are the angel of V_{DVR}, Z_{th} and, respectively and θ is the load power factor angle with $\theta = \tan^{-}\left(\frac{Q_L}{P_L}\right)$. The power injection of the DVR can be written as

$$S_{DVR} = V_{DVR} I_L \qquad (6)$$

IV. MATHEMATICS MODEL FOR VOLTAGE SAG CALCULATION

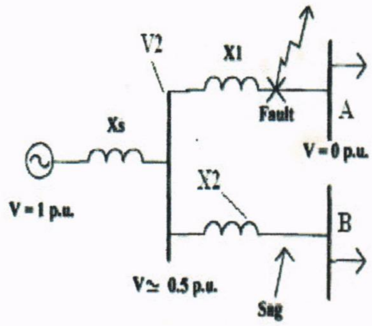

Figure 6: Calculation for voltage sag

In a normal condition which is no fault occur, current through load A and load B (Figure 6) is equal. On feeder 1, when there is a fault occur a high current which is short circuit current will flow. From Kirchhoff's Law, currents flow to feeder 2 will be reduced and therefore a voltage will also drop in feeder 2. This voltage drop is defined as voltage sags.

Assume:

Load A	$= Z_{LOAD\_A}$
Load B	$= Z_{LOAD\_B}$
Feeder 1 Reactance	$= x_1$
Feeder 2 Reactance	$= x_2$
Current from supply source	$= I$
Current in feeder 1	$= I_1$
Current in feeder 2	$= I_2$

Thus,

$$I = I_1 + I_2$$

In normal condition (without fault in system),

$$I = \frac{V_2}{x_2 + Z_{LOAD\_B}} + \frac{V_2}{x_2 + Z_{LOAD\_A}} \qquad (7)$$

When a fault occur in feeder 1, a high current will flow through feeder 1 as well as source current I and therefore voltage in feeder 2 decreased due to increasing of voltage drop across source reactance x_s this makes sag happened.

$$I = \frac{V_2}{x_2 + Z_{LOAD\_B}} + \frac{V_2}{x_1} \text{ (when fault happened)} \qquad (8)$$

Hence,

$$V_2 = V_S - Ix_S \tag{9}$$

and V_2 decreased from nominal value (V_2 become as voltage sag).

V. HARMONIC PERFORMANCE

In power systems, harmonics arise because of nonlinear systems elements such as converters is the direct product of turn -ON and turn -OFF action of switches that result in distortion of the waveforms. In power system, harmonic consume the current capacity of transmission lines, they do not transmit useful power, hence leading to over-heating and overloading of equipment. The study of harmonics is the method to reduce these effects. Total Harmonic Distortion THD, reflects energy of the waveform content and is defined as

$$THD = \frac{\sqrt{\sum_{h=2}^{n} V_h^2}}{V_1} \tag{4}$$

Where:

V_1 = rms value of the fundamental component voltage

V_h = rms value of the *h*th harmonic.

The maximum permissible THD for low voltage application is 5% and the maximum individual voltage harmonic is 3%. Figure 7 below show the harmonic control for both mitigation techniques.

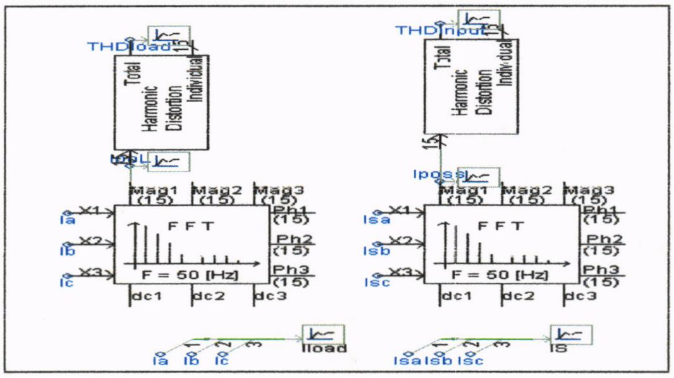

Figure 7: Harmonic Control

VI. SIMULATION MODEL OF STATCOM AND DVR SYTEM

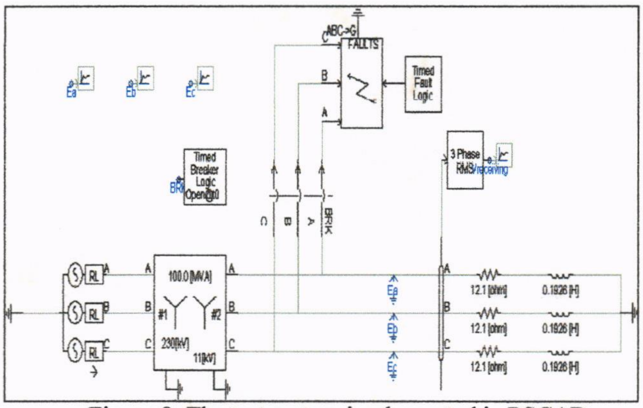

Figure 8: The test system implemented in PSCAD

Figure 8 show the test system implemented in PSCAD to carry out the simulation for the mitigation techniques. The test system comprises of a 230 kilovolt, 50 Hertz transmission system, represented in Thevenin equivalent, feeding into the primary side of a 2-winding transformer. And the load is connected to the 11 kV secondary side of the transformer. This system is using a load of 12.1 ohm and 0.1926 Henry.

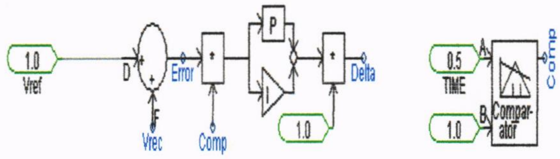

Figure 9: Control System

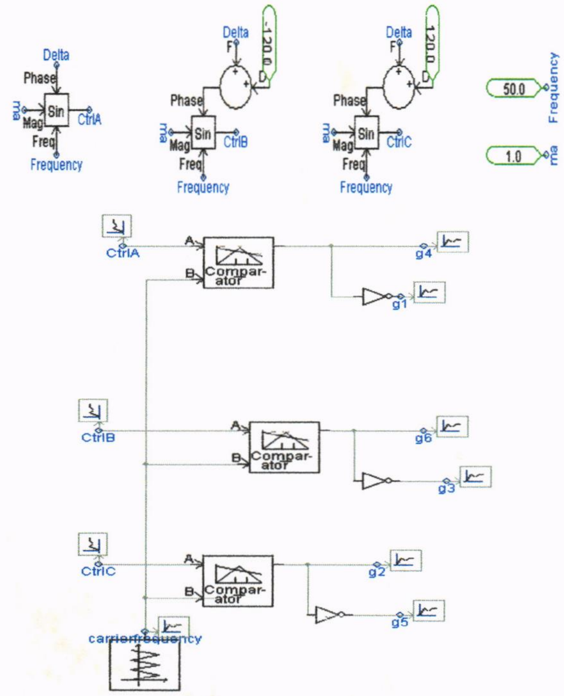

Figure 10: Sine PWM Generators

From Figure 9 and 10 show the controller scheme implemented in PSCAD. This control system exerts voltage angle control as follows: an error signal is obtained by comparing the reference voltage with the rms voltage measured at the load point. The PI controller produced the error signal and generates the required angle δ to drive the error to zero. In the PWM generators, the sinusoidal signal, $V_{control}$ is compared against a triangular carrier to generator the switching signal of the VSC valves. The main parameters of the sinusoidal PWM scheme are the amplitude modulation index, of signal $V_{control}$, and the frequency modulation index, of the triangular signal. The $V_{control}$ in figure 10 are labeled as CtrlA, CtrlB and CtrlC. The value of the modulation index is fixed at 1 pu in order to obtain the highest fundamental voltage component at the controller output [7, 8]. The modulating angle δ or delta is applied to the PWM generators in phase A, whereas the angles for phase B and C are shifted by 240° or -120° and 120° respectively.

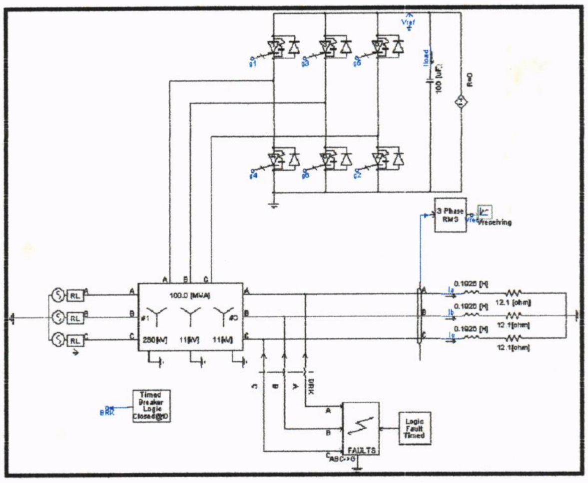

Figure 11: STATCOM circuit simulation using PSCAD

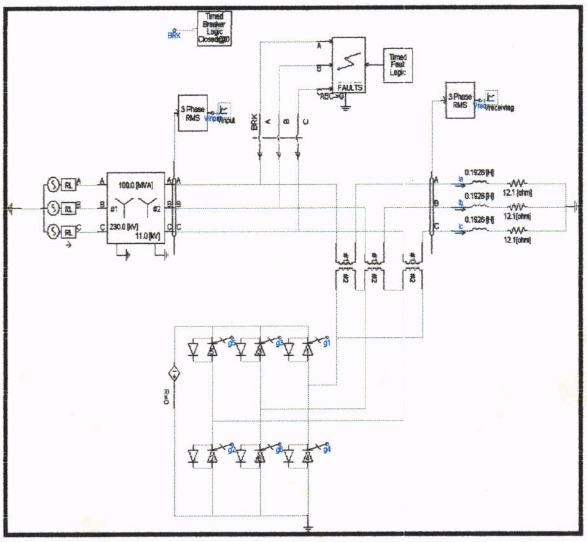

Figure 12: DVR circuit simulation using PSCAD

VII. RESULTS AND DISCUSSION

This is the result for three phase fault and double line to ground fault for with and without mitigation technique.

A. *THREE PHASE FAULT*

a) No mitigation techniques

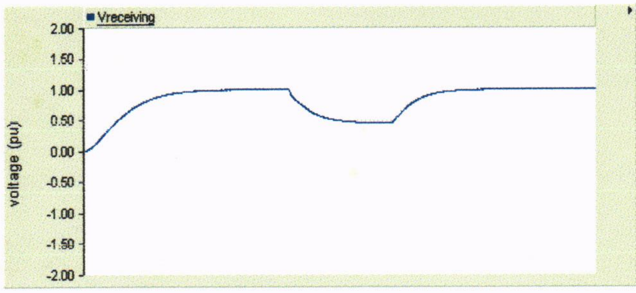

Figure 13: Voltage drops for three phase fault

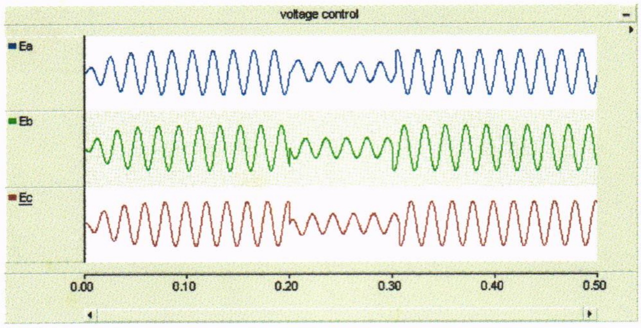

Figure 14: Waveform three phase faults

Figure 13 and 14 clearly shows the rms voltage drop to 0.4409 from the reference value when the three phase fault is occurs at the system.

b) STATCOM mitigation techniques

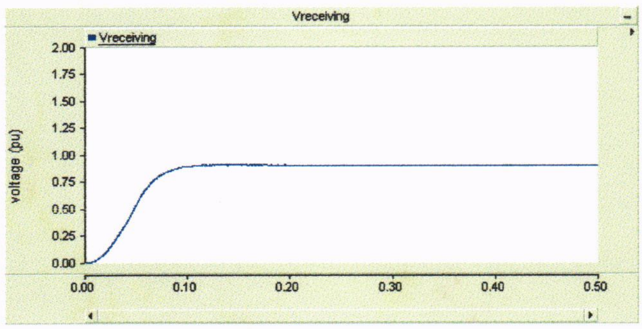

Figure 15: Compensated voltage sag with STATCOM

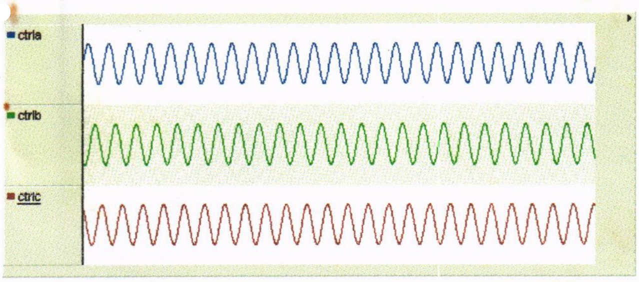

Figure 16: Waveform with STATCOM

The first technique that has been used in mitigating the voltage sags is Static Compensator (STATCOM). Figure 15 and 16 shows the recovery of the voltage sags. STATCOM manages to recover nearly 0.8322 per unit of the voltage with the respect to the reference voltage.

c) DVR mitigation techniques

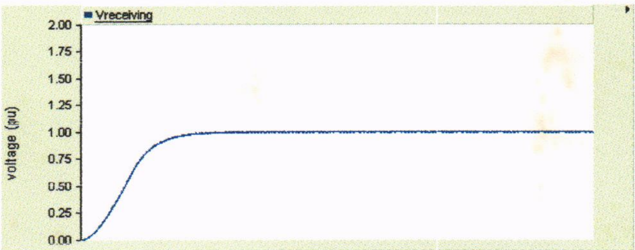

Figure 17: Compensated voltage sag with DVR

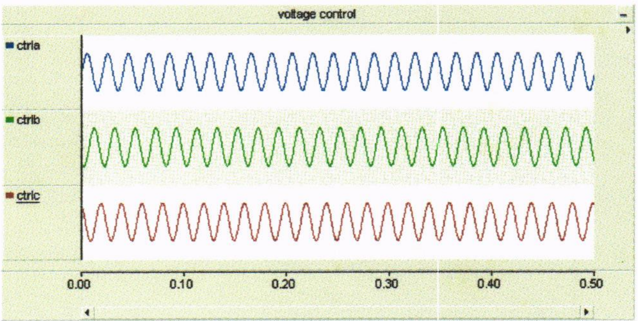

Figure 18: Waveform with DVR

The second technique that had been used is the Dynamic Voltage Restorer (DVR). Figure 17 and 18 show how the technique compensates the voltage drop. DVR recovers almost 0.9624 per unit of the reference voltage.

Table 1 show the value of the rms voltage has been recovered from used three different mitigation techniques to compare the best result to get which the best mitigation techniques for three phase fault. From the table 1, it can be seen that when three phase fault occur the rms voltage drop to 0.4409 per unit. The Static Compensator (STATCOM) only recovers minimum 0.8322 per unit and maximum 0.9042 while for the Dynamic Voltage Restorer (DVR) the value rms voltage restorer 0.9624 per unit equal 1 per unit. From the table 2, show that the best mitigation techniques used for three phase fault is DVR which is 93.214%, greater than STATCOM techniques which are 6.208% less than DVR performance.

Table 1: Recovery three phase fault

TECHNIQUES	Vrms (p.u)	
	Vmin	Vmax
FAULT	0.4409	0.9950
STATCOM	0.8322	0.9042
DVR	0.9624	1.0000

Table 2: Performance efficiency of three phase fault

TECHNIQUES	VOLTAGE PERFORMANCE
STATCOM	87.006 %
DVR	93.214%

B. DOUBLE LINE TO GROUND FAULT

a) No mitigation techniques

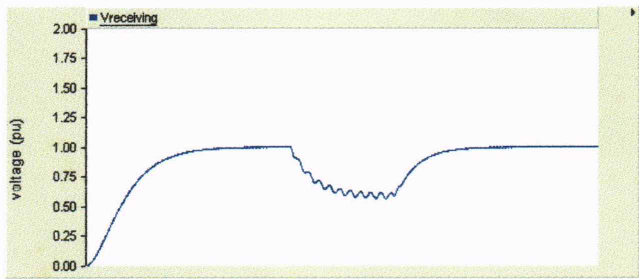

Figure 19: Voltage RMS drops for double line to ground fault

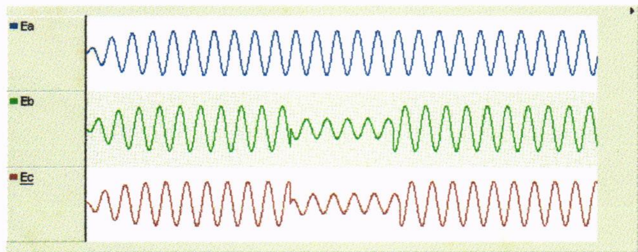

Figure 20: Waveform double line to ground fault

Figure 19 and 20 clearly shows the rms voltage drop to 0.5830 from the reference value when the double line to ground fault is occurs at the system.

b) STATCOM mitigation techniques

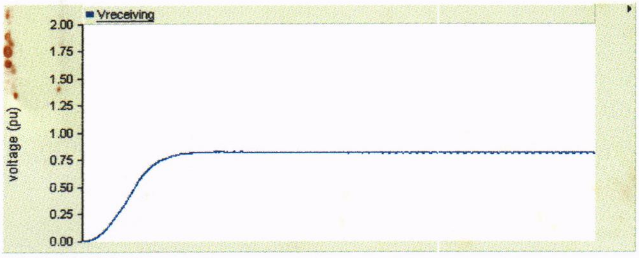

Figure 21: Compensated voltage sag with STATCOM

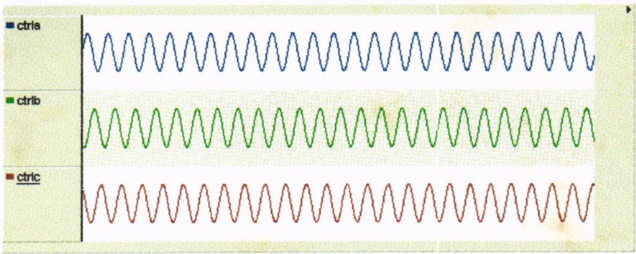

Figure 22: Waveform with STATCOM

Figure 21 and 22 shows the recovery of the voltage sags using Static Compensator (STATCOM). STATCOM manages to recover nearly 0.8077 per unit of the voltage with the respect to the reference voltage.

c) DVR mitigation techniques

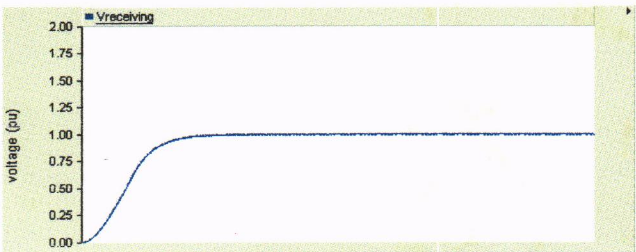

Figure 23: Compensated voltage sag with DVR

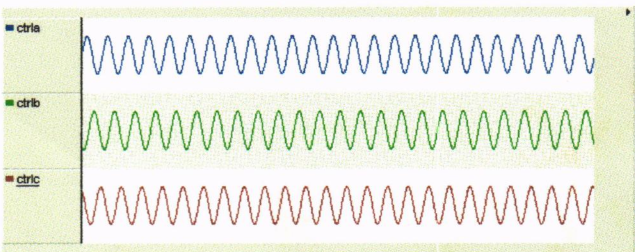

Figure 24: Waveform with DVR

Figure 23 and 24 show how the Dynamic Voltage Restorer (DVR) technique compensates the voltage drop. DVR recovers almost 0.9958 per unit of the reference voltage.

Table 3: Recovery double line to ground fault

TECHNIQUES	Vrms (p.u)	
	Vmin	Vmax
FAULT	0.5830	0.9856
STATCOM	0.8077	0.8209
DVR	0.9958	1.0000

Table 4: Performance efficiency of double line to ground fault

TECHNIQUES	VOLTAGE PERFORMANCE
STATCOM	96.721 %
DVR	98.957 %

The next line of test is double line to the ground fault. The test is for line B to C to the ground fault. From table 3, it can be seen that when double line to ground fault occur the rms voltage drop to 0.5830 per unit. The Static Compensator (STATCOM) only recovers minimum 0.8077 per unit and maximum is 0.8209 per unit. For the Dynamic Voltage Restorer (DVR) the value rms voltage recover 0.9958 per unit equal 1 per unit. From the table 4, show that the best mitigation techniques used for double line to ground fault is DVR which is 98.957%, greater than STATCOM techniques which are 96.721%.

C. EFFECT OF HARMONIC

This is the result for the Total Harmonic Distortion (THD) for Static Compensator (STATCOM) and Dynamic Voltage Restorer (DVR) mitigation technique.

a) Three Phase Fault

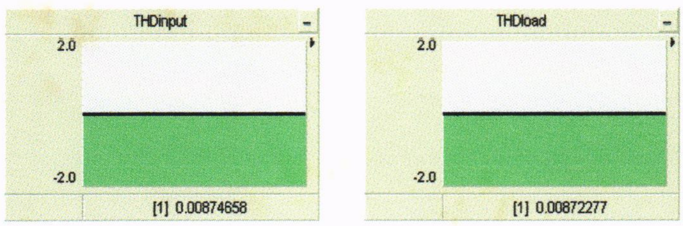

Figure 25: Total Harmonic Distortion for input current and load current of STATCOM system

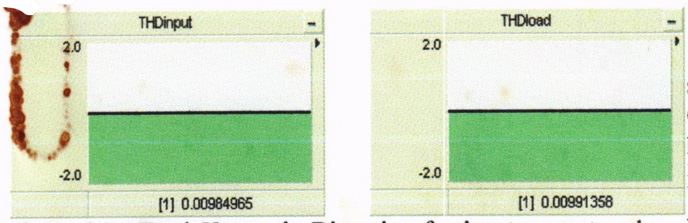

Figure 26: Total Harmonic Distortion for input current and load current of DVR system

Table 5: Simulation result for THD input and THD load

TECHNIQUE	THD input	THD load
STATCOM	0.00874658	0.00872277
DVR	0.00984965	0.00991358

From table 5 shows that STATCOM have lower THD input and THD load than DVR mitigation technique.

b) Double Line to Ground Fault

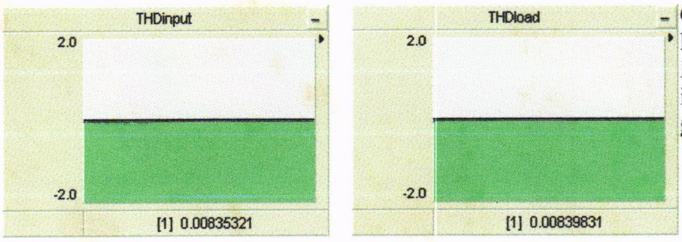

Figure 27: Total Harmonic Distortion for input current and load current of STATCOM system

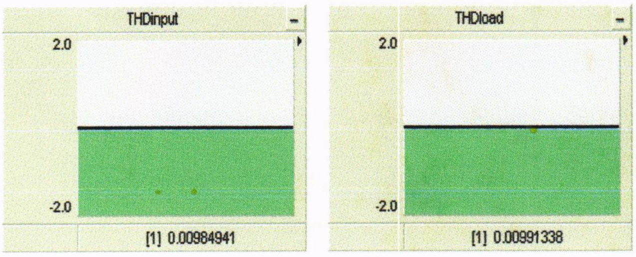

Figure 28: Total Harmonic Distortion for input current and load current of DVR system

Table 6: Simulation result for THD input and THD load

TECHNIQUE	THD input	THD load
STATCOM	0.00835321	0.00839831
DVR	0.00984941	0.00991338

From table 6 shows that STATCOM have lower THD input and THD load than DVR mitigation technique. The lower of total harmonic in per unit value, the better performance of the system. The systems have the harmonic because used the example of harmonic from nonlinear load like adjustable speed drive (ASD). Harmonic caused by nonlinear devices in the power system.

VIII. CONCLUSION

In this paper, a complete simulated STATCOM and DVR system has been developed by using the PSCAD software. It's characteristic and performance when applied to a simulated power system has been studied. It is shown that when mitigate for three phase fault and double line to ground fault, Dynamic Voltage Restorer (DVR) system is the best mitigation technique rather than Static Compensator (STATCOM) system. When DVR is in operation the voltage sag is mitigated almost completely, and the performance efficiency for three phase fault is 93.241% and for double line to ground fault is 98.957%. And STATCOM have lower THD input and THD load than DVR mitigation technique. By introducing DVR in the power system network, it can help to improve power quality. It is important to have a good delivery power quality in electrical power system especially to the critical areas, such as in the industrial sectors in order to ensure the smoothness of daily operations.

IX. FUTURE RECOMMENDATION

For this project is simulated using 6 pulses Static Compensator (STATCOM) and 6 pulses Dynamic Voltage Restorer (DVR) in order to investigate voltage sag mitigation. In future hope a further investigation of a simulated 6 pulse improved to 12 pulse STATCOM and DVR system in order to get better result for voltage sag problem.

X. ACKNOWLEDGEMENT

In the name of Allah The Most Gracious and Merciful with the Selawat and Salam to Prophet Muhammad S.A.W. First and foremost, I would like to thank God, for without His strength and encouragement this project would never materialize. I would like to thank my supervisor, Assoc. Prof. Dr. Hjh Noraliza Hamzah, for the guidance and support that has been given to me for my final year project. In addition, I would like to acknowledgement my colleagues for their constructive comments and support. And also to my beloved family for the contribution and sacrifice they have made.

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