Mitigation Techniques for Voltage Sag in Power Distribution Systems by Using Dynamic Voltage Restorer (DVR)

Muhammad Salman bin Sahak

Faculty of Electrical Engineering
Universiti Teknologi MARA,
40450 Shah Alam,Selangor Malaysia
E-mail: eyeshield_man86@yahoo.com

Abstract **- This paper describes the mitigation techniques for voltage sags in the distribution systems. The Dynamic Voltage Restorer (DVR) is the proposed method used to compare the effective scheme control methods to mitigate the sags problems. Simulation results carried out by Matlab/Simulink verify the performance of the proposed method.**

Keywords- ***Dynamic Voltage Restorer (DVR), voltage sag, Total Harmonic Distortion (THD)***

1. INTRODUCTION

Power quality problems like voltage sag, voltage swell and harmonic are major concern of the industrial and commercial electrical consumers due to enormous loss in terms of time and money. This is due to the advent of a large numbers of sophisticated electrical and electronic equipment, such as computers, programmable logic controllers, variable speed drives, and so forth[1].

The use of this equipment often requires very high quality power supplies[1]. Some special equipment is sensitive to voltage disturbances, especially if these take up to several periods, the circuit does not work. Therefore, these adverse effects of voltage changes necessitate the existence of effective mitigating devices.

There are various solutions to these problems. One of the most effective solutions is the installation of a Dynamic Voltage Restorer (DVR). DVR is a series custom power device, which has excellent dynamic capabilities. It is well suited to protect sensitive loads from duration voltage sag or swell. A DVR is basically a controlled voltage source installed between the supply and a sensitive load. It injects a voltage on the system in order to compensate any disturbance affecting the load voltage[1].

Voltage sag/swell that occurs more frequently than any other power quality phenomenon is known as the most important power quality problems in the power distribution systems. IEEE 519-1992 and IEEE 1159-1995 describe the voltage sags /swells as shown in Fig.1[2-4].

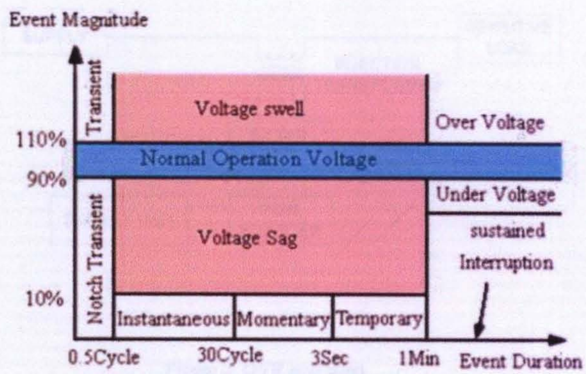


Figure 1: Voltage Reduction Standard of IEEE Std. 1159-1995

Voltage sag is defined as a sudden reduction of supply voltage down from 90% to 10% of nominal[1, 2, 5]. According to the standard, a typical duration of sag is 10 ms to 1 minute[1].

Voltage sag often caused by faults such as single line-to-ground fault, double line-to-ground fault on the power distribution system or due to starting of large induction motors or energizing a large capacitor bank[1, 6]. Voltage sag can interrupt or lead to malfunction of any electric equipment that is sensitive to voltage variations. To understand the different ways to mitigate voltage sags, various factors contributing to the problem have to be understood. The interest in voltage sags are increasing because they cause the detrimental effects on several sensitive equipments such as adjustable speed drives, process control equipments, and computers[6, 7]. Some of the equipments trip when RMS voltage below 90% for longer than one or two cycles. Although voltage sag is not damaging to customers as an interruption, the total damage due to sags is still larger than that of interruptions because these are far more voltage sags than interruptions. Moreover, voltage sags at equipment terminal can happen due to the short circuit faults hundreds of kilometers away in the distribution systems. Therefore it is important to assess the effect of the voltage sag correct.

2. CONVENTIONAL SYSTEM CONFIGURATIONS OF DVR

A mitigation technique is very important to compensate the power quality problems. In this project, the systematic device has been design in order to mitigate the voltage sag problem. The technique that will be used to mitigate the voltage sag is Dynamic voltage Restorer (DVR). The main stages of the control system of a DVR include: detection of the start and finish of the sag, voltage reference generation, injection voltage generation, and protection of sensitive load.

The main parts consist of inverter that uses Insulated Gate Bipolar Transistor (IGBT), comparator and energy storage. The first part is to detect the difference magnitude of voltage in the system and then the signal will compare the voltage to be equal as nominal voltage. IGBT is used to inject the missing voltage reduction in the system after the comparator defines the magnitude that need to be inject.

MATLAB/SIMULINK software is a simulator designed applicable to the power simulation. The systems designed from the power supply generation system to the load. The AC system is displayed in single line diagram format. The results of simulation are plotted and displayed on the screen. Interactive controls allow the user to adjust the system conditions, very similar to what would occur in the operation that is operated the real power system from a control room. MATLAB has the solutions method that can used the function block to compare the simulation output voltage from transmission line to mitigate it by injecting signal voltage from control switch (IGBT). The DVR considered consists of:

i. an injection / series transformer
ii. a harmonic filter,
iii. a PWM inverter
iv. an energy unit as shown in Figure 2

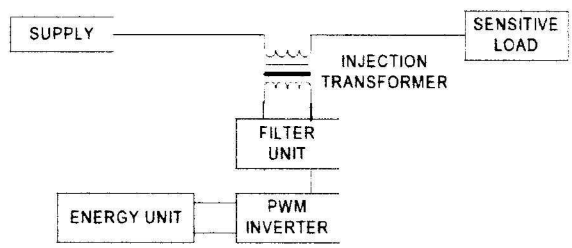


Figure 2: DVR operation.

Graphic base control allows the user to define the load conditions, system impedances for the voltages, transmission line parameters, timing and various fault configurations. The power system simulation calculates and displays the voltage and current time domain or transient waveforms. For more advanced, the cases can be customized to included simulation sequencer control, and breaker protection operation.

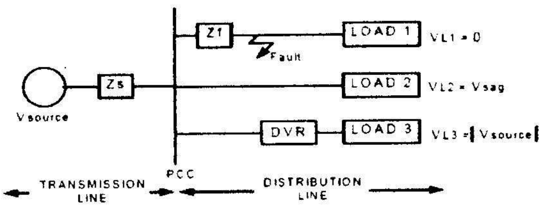


Figure 3: Location of DVR

Voltage sags are usually caused by a short circuit current flowing into a fault on a transmission or distribution line, where the magnitude and phase of faulted voltage V_{sag} during the sag at the point of common coupling (PCC) in figure 3 are determined by the fault and supply impedances using equation (1). Assume Z_f is fault impedance, Z_s is supply impedance, V_{source} is supply voltage, and V_{sag} is sag voltage[8].

$$V_{sag} = V_{source} \frac{Z_f}{Z_f + Z_s} \tag{1}$$

$$V_{injection} = V_{load} - V_{supply} \tag{2}$$

DVR installed on a critical load, restores the line voltage to its nominal value within the response time of a few millisecond thus avoiding any power disruption to the load.

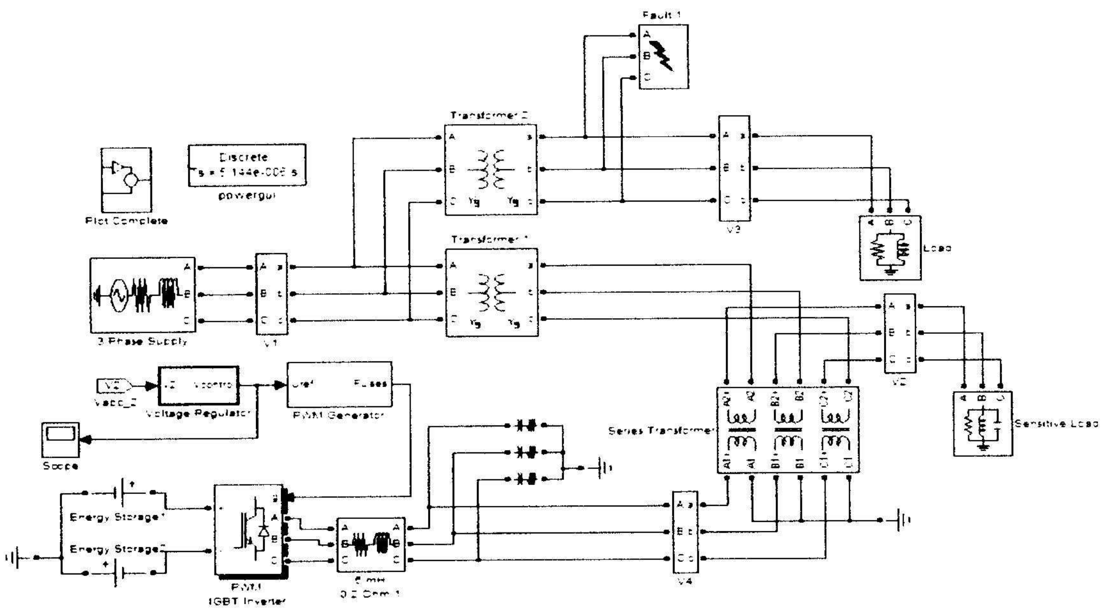


Figure 4: Proposed system configuration.

A) Control methods

In electrical engineering, direct–quadrature–zero (dq0) transformation is a mathematical transformation used to simplify the analysis of three-phase circuits. In the case of balanced three-phase circuits, application of the dq0 transform reduces the three AC quantities to two DC quantities[9].

The dq0 transformation or Park's is used to control of DVR. The dq0 method gives the sag depth and phase shift information with start and end times. In this control method, monitoring of V_d and V_q is used to return the magnitude and phase load voltage to the magnitude and phase reference load voltage[9]. The control block system is presented in figure 5. Equation (3) defines the transformation from three phase system a-b-c to d-q-0 stationary frame. The theta (θ) is defined by the angle between phase A to the d-axis[6, 10]. The two axes are called the direct (d-axis) and the quadrature (q-axis).

$$\begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \cos(\theta - \frac{2\pi}{3}) & 1 \\ -\sin(\theta) & -\sin(\theta - \frac{2\pi}{3}) & 1 \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (3)$$

After conversion, the balanced three-phase voltage V_a, V_b and V_c become two constant voltages V_d and V_q. They are easily controlled by Proportional Integral (PI) controller as shown in Fig.5[11]. The components of the load voltage vectors are compared with the reference values and they are transformed back into V_a, V_b and V_c values. The DC link error is used to get optimized controller output signal because the energy on the DC link will be changed during the sag. The method should not be affected from the harmonics, flickers, frequency variations and unbalanced voltages because the correct detection of the phase of the source voltage is very important for DVR. Using a Phase Locked Loop (PLL) algorithm satisfies these requirements. Finally the calculated signal is compared with saw tooth signal at 2 KHz carrier frequency to produce required firing signals for each leg of the PWM inverter that is known as SPWM technique.

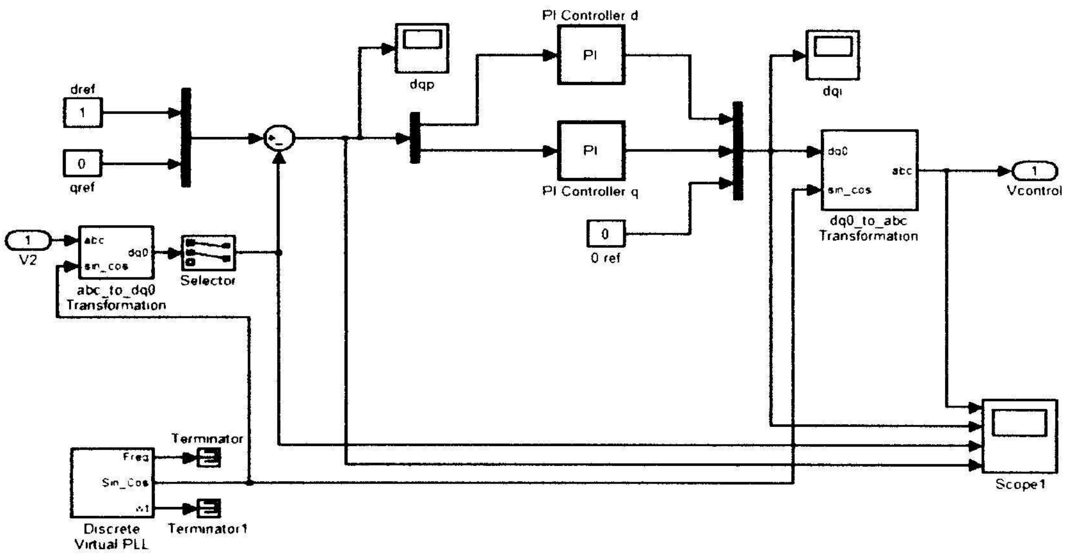


Figure 5: Voltage regulator of DVR

3. Results And Discussions

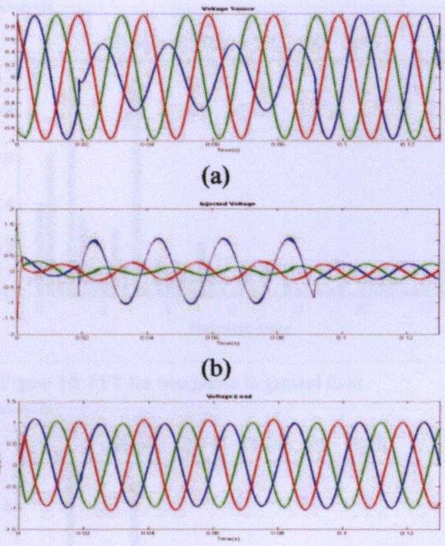
TABLE I

System Parameters And Constant Values

Main supply voltage	22.5kV
Series transformer turn ratio	1:10
Filter inductance	6mH
Filter capacitance	20μF
Filter resistance	0.2Ω
Line frequency	50Hz

The system parameters and constant value are listed in Table I to study the efficiency of suggested control strategy modeled by MATLAB/SIMULINK. The first simulation shows the effectiveness of the DVR under unbalanced conditions is shown in figure 6. The single phase voltage dropped down to 50% shown in figure 6(a). The injected voltage of DVR and the load voltage are shown in figure 6(b) and (c) respectively. The compensations method maintained the value of load voltages constant at 1p.u. The same as figure 7, the unbalanced condition for two phases to ground fault shows 50% voltage sag initiated at 0.019s until 0.0914s.

The three phase voltage sag is simulated as shown in figure 8. Figure 8(a) shows a 50% voltage with total duration 0.0724s. Figure 8(b) and (c) show the voltage injected by DVR and the corresponding load voltage with compensation. As a result of DVR, the load voltage maintain constant at 1p.u.

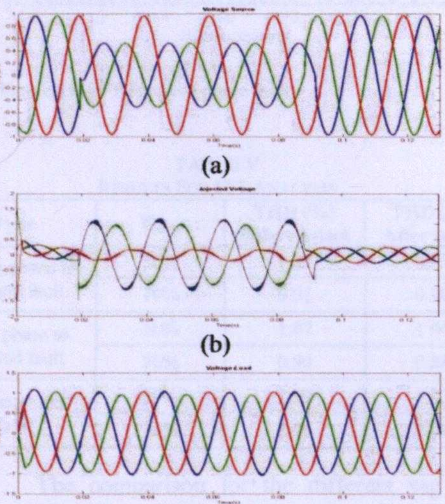


(a)

(b)

(c)

Figure 6: Single phase to ground fault. (a) Voltage source; (b) Injected voltage; (c) Load voltage

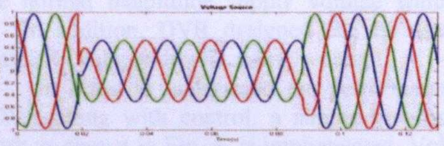


(a)

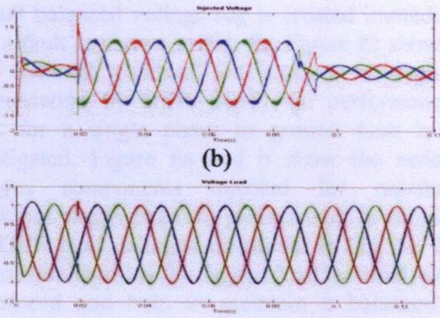
(b)

(c)

Figure 7: Two phase to ground fault. (a) Voltage source; (b) Injected voltage; (c) Load voltage



(a)



(b)

(c)

Figure 8: 3 phase fault. (a) Voltage source; (b) Injected voltage; (c) Load voltage

TABLE II
RESULTS FOR INJECTION VOLTAGE TO SINGLE PHASE TO GROUND FAULT

V_{sag}	Before inject (p.u.)			After Inject (p.u.)		
	A	B	C	A	B	C
50%	0.524	0.970	0.970	0.970	0.980	1.065
70%	0.704	0.971	0.971	0.960	0.990	1.030

TABLE III
RESULTS FOR INJECTION VOLTAGE FOR TWO PHASE TO GROUND FAULT

V_{sag}	Before inject (p.u.)			After Inject (p.u.)		
	A	B	C	A	B	C
50%	0.524	0.520	0.970	0.970	0.980	1.065
70%	0.704	0.700	0.971	0.960	0.990	1.030

TABLE IV
RESULTS FOR INJECTION VOLTAGE FOR 3 PHASE FAULT

V_{sag}	Before inject (p.u.)			After Inject (p.u.)		
	A	B	C	A	B	C
50%	0.524	0.520	0.519	0.970	0.980	1.065
70%	0.704	0.700	0.698	0.960	0.990	1.030

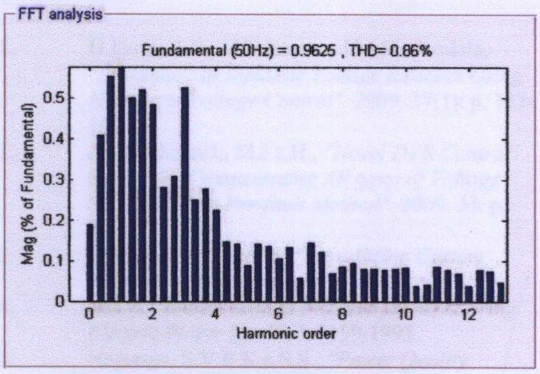


Figure 9: FFT for single phase to ground fault

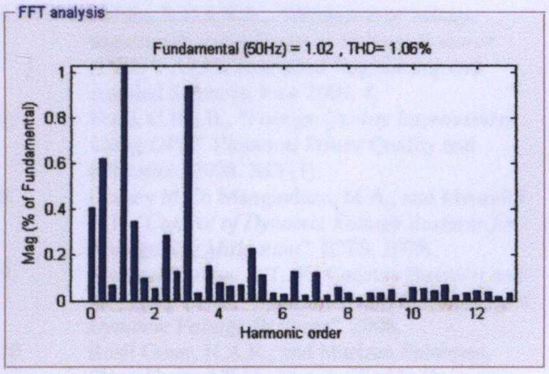


Figure 10: FFT for two phase to ground fault

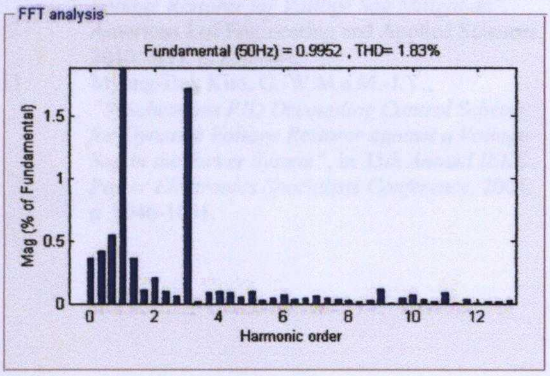


Figure 11: FFT for three phase fault

TABLE V
RESULTS FOR FFT ANALYSIS

Type	V_{sag}	THD (%) Before inject	THD (%) After inject
Single phase to ground fault	50%	1.87	0.86
	70%	0.91	0.70
Two phase to ground fault	50%	1.87	1.06
	70%	0.90	0.88
Three phase fault	50%	2.09	1.83
	70%	1.06	0.91

The comparison for the different sag has been simulated as shown in Table II until IV. The magnitudes of supply voltage sag used are 50% and 70%. The results from both percentage sags condition after compensation have similar values. The values after inject shows the all phases has been recovered to the normal magnitude supply voltage which is 1p.u. In addition, DVR designed can be used to mitigate any voltage drop at supply voltage.

In order to understand the performance of the DVR along with control, a simple distribution network as shown in Fig. 4, is implemented. Voltage sags are simulated using MATLAB software. First a case of three phase balanced sag is simulated by connecting a three phase reactance to the bus bar. As a result balanced voltage sag is created immediately after a fault as shown in Fig. 8a. Figure 8c shows the load terminal voltages are restored through the compensation by DVR. Next, the performance of DVR for a single phase to ground fault is also investigated. Figure 6a and b show the series of voltages components injected for unbalanced conditions single phase to ground fault is simulated. The DVR load voltages are shown in Fig. 6c. From the results show that the sagged load terminal voltage is restored and help to maintain a balanced and constant load voltage.

When compensate at the voltage sag at critical load, DVR produce a harmonics distortion fed from series transformer as an injection voltage to the critical load. Table V shows the results using FFT analysis to analyze the Total Harmonic Distortion (THD) for the voltage signal. The THD improved after the voltage sag compensated (THD<5%).

4. CONCLUSIONS

The modeling and simulation of a DVR using MATLAB/SIMULINK has been presented. The simulation results showed clearly the performance of the DVR in mitigating voltage sags. The DVR handled both balanced and unbalanced situations without any difficulties and injected the appropriate voltage component to correct rapidly any anomaly in the supply voltage to keep the load voltage balanced and constant at the nominal value. In this study, the DVR has shown the ability to compensate for voltage sags at the grid side; this can be proved through simulation. The results of the MATLAB/SIMULINK simulation also verify the proposed control algorithm based on Space Vector Pulse Width Modulation (SVPWM) technique to generate the pulses for mitigating voltage sags.

REFERENCES

1. H.Ezoji, A.S., M.Tabasi, and M.M. Seednia, *"Simulation of Dynamic Voltage Restorer Using Hysteresis Voltage Control"*. 2009. **27**(1): p. 152-166.
2. Abdollahzadeh, M.J.a.H., *"Novel DVR Control System for Compensating All types of Voltage Sags Based on Pre-fault Method"*. 2009. **33**: p. 70-85.
3. Higorani, N.G. (1995) *"Introducing Custom Power in IEEE Spectrum"*. 41-48.
4. Std, I., *"Recommended Practice for Monitoring Electric Power Quality"*. 1159-1995.
5. Nagaraju, S.V.R.K.a.S.S., *"Power Quality Improvement Using D-Statcom and DVR"*. International Journal of Electrical and Power Engineering 2007. **1(3)**: p. 368-376.

6. Rahim, R.O.a.N.A., *"Mitigation of voltage sags/swells using Dynamic Voltage Restorer (DVR)"*. ARPN Journal of Engineering and Applied Sciences, June 2009. 4.
7. Ferdi, C.B.a.B., *"Voltage Quality Improvement Using DVR"*. Electrical Power Quality and utilization, 2008. XIV(1).
8. Glanny M Ch Mangindaan, M.A., and Mauridhi H P, *"Control of Dynamic Voltage Restorer for Voltage Sag Mitigation"*. ICTS, 2008.
9. Mehmet Tumay, A.T., K. Çağatay Bayındır and M. Uğraş Cuma, *"Simulation and Modeling of A Dynamic Voltage Restorer"*. 2006.
10. Rosli Omar, N.A.R., and Marizan Sulaiman, *"New Control Technique Applied in Dynamic Voltage Restorer for Voltage Sag Mitigation"*. American J.of Engineering and Applied Sciences, 2010. 3(1): p. 858-864.
11. Myung-Bok Kim, G.-W.M.a.M.-J.Y., *"Synchronous PID Decoupling Control Scheme for Dynamic Voltage Restorer against a Voltage Sag in the Power System"*, in *35th Annual IEEE Power Electronics Specialists Conference*. 2004. p. 1046-1051.