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ELEKTRIKA

Voltage Sag and Mitigation Using Dynamic Voltage Restorer (DVR) System

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Abstract: This paper highlights voltage sag as one of a power quality issue and Dynamic Voltage Restorer (DVR) is using for mitigation of voltage sag. Voltage sag is short reduction voltage from nominal voltage, occurs in a short time which can cause damage and loss of production especially in industrial sector. Voltage sag always related with short circuit events and starting motor which draw very high lagging current. Since voltage sag is creating worse effects, the researchers almost keen to find the solutions for this problem. Nowadays, a lot of devices have been developed to mitigate voltage sag such as Dynamic Voltage Restorer (DVR), Distribution Static Compensator (D-Statcom) and Uninterruptible Power Supply (UPS). In this paper, focus is given only on DVR system which will be simulated by using PSCAD software in order to mitigate voltage sag. Mathematics model for calculation of voltage sag and voltage injection by DVR System also described.

Keywords: Dynamic voltage restorer, PSCAD software, Voltage sag.

1. INTRODUCTION

In many recent years, power quality disturbances become most issue which makes many researchers interested to find the best solutions to solve it. There are various types of power quality which are transients, short duration voltage variation, long duration voltage variation, voltage imbalance, waveform distortion and voltage flicker. Under short duration voltage variation, there're voltage sag, voltage swell and interruption. Based on records by Tenaga Nasional Berhad (TNB), 80% of power quality complaints in Malaysia were traced to be related to voltage sag [1]. Due to the increasing of new technology, a lot of devices had been created and developed for mitigation of voltage sag.

This paper concerns two objectives of this project which are study on voltage sag phenomenon in power system and mitigation this phenomenon by using Dynamic Voltage Restorer (DVR) system. A scope of project is DVR system will be simulate by using power system software, PSCAD/EMTDC V4.

In order to carry out these objectives successfully, voltage sag characteristics and DVR system will be discussing theoretically in details. Simulations are divided to three parts which are performance of DVR system, the effects of voltage sag caused by fault in power system connected with DVR system, and finally increasing performance of DVR system.

2. VOLTAGE SAG

Voltage sag is widely recognized as one of the most important power quality disturbances [1]. Voltage sag (Figure 1) is a short reduction in rms voltage from nominal voltage, happened in a short duration, about 10ms to seconds. The IEC 61000-4-30 defines the voltage sag (dip) as a temporary reduction of the voltage at a point of the electrical system below a threshold [2]. 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 0.5cycles and one minute[5].

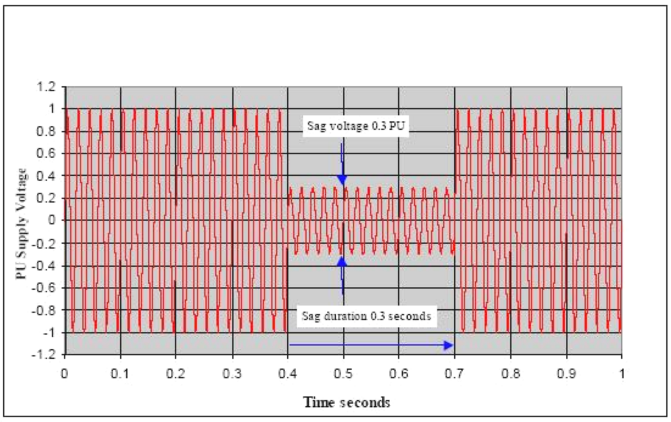

Figure 1. Voltage sag waveform

Voltage sag is happened at the adjacent feeder with unhealthy feeder (Figure 2). This unhealthy feeder always caused by two factors which are short circuits due to faults in power system networks and starting motor which draw very high lagging current. Both of these factors are the main factor creating voltage sag as power quality problem in power system.

Voltage sags are the most common power disturbance which certainly gives affecting especially in industrial and large commercial customers such as the damage of the sensitivity equipments and loss of daily productions and finances. An example of the sensitivity equipments are programmable logic controller (PLC), adjustable speed drive (ASD) and chiller control.

There are many ways in order to mitigate voltage sag problem. One of them is minimizing short circuits caused by utility directly which can be done such as with avoid feeder or cable overloading by correct configuration planning. Another alternative is using the flexible ac technology (FACTS) devices which have been used widely in power system nowadays because of the reliability to maintain power quality condition includes for voltage sag mitigation.. There are many devices have been created with purpose to enhance power quality such as Dynamic Voltage Restorer (DVR), Distribution Static Compensator (D-STATCOM) and Uninterruptible Power Supply (UPS). All of these devices are also known as custom power devices.

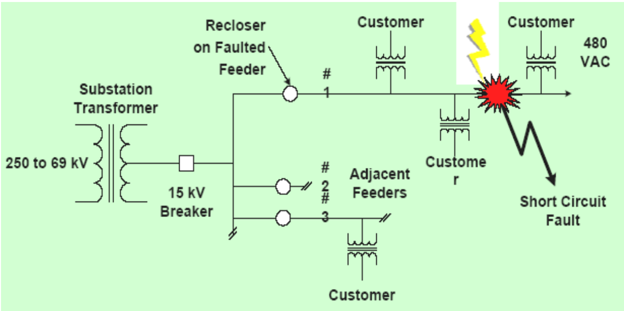

Figure 2. Voltage sag phenomenon

3. DVR SYSTEM

Dynamic voltage restorer (DVR) is a series compensator which is able to protect a sensitive load from the distortion in the supply side during fault or overloaded in power system. The basic principle of a series compensator is simple, by inserting a voltage of required magnitude and frequency, the series compensator can restore the load side voltage to the desired amplitude and waveform even when the source voltage is unbalanced or distorted [3].This DVR device employs gate turn off thyristor (GTO) solid state power electronic switches in a pulse width modulated (PWM) inverter structure. The DVR can generate or absorb independently controllable real and reactive power at the load side. The DVR also is made of a solid state dc to ac switching power converter that injects a set of three phase ac output voltages in series and synchronism with the distribution feeder voltages [3]. The amplitude and phase angle of the injected voltages are variable thereby allowing control of the real and reactive power exchange between the DVR and the distribution system [3]. The dc input terminal of a DVR is connected to an energy source or an energy storage device of appropriate capacity. The reactive power exchange between the DVR and the distribution system is internally generated by the DVR without ac passive reactive components. The real power exchanged at the DVR output ac terminals is provided by the DVR input dc terminal by an external energy source or energy storage system.

DVR structure comprises rectifier, inverter, filter and coupling transformer (Figure 3). Besides, pulse width modulated (PWM) technique is using to control variable voltage. Filter is using for elimination harmonic generated from high switching frequency in PWM technique. In power system network, DVR system is connected in series with the distribution feeder that supplies a sensitive load (Figure 4).

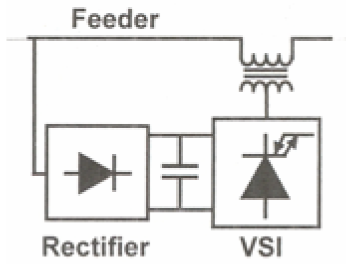

Figure 3. DVR Structure

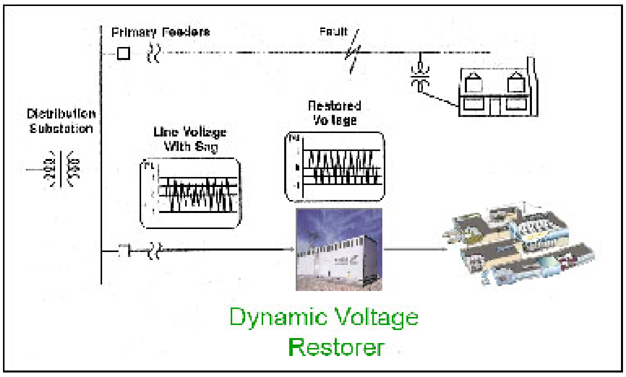

Figure 4. DVR system in power system

4. THE PRINCIPLE OPERATION OF DVR SYSTEM

In normal situation without short circuit in power system, a capacitor between rectifier and inverter (Figure 3) will be charging. When voltage sag happened, this capacitor will discharge to maintain load voltage supply. Nominal voltage will be compared with voltage sag in order to get a difference voltage that will be injected by DVR system to maintain load voltage supply. PWM technique is using to control this variable voltage. In order to maintain load voltage supply, reactive power must be injected by DVR system. Practically, the capability of injection voltage by DVR system is 50% of nominal voltage. It is sufficient for mitigation voltage sag because from statistic shown that many voltage sag cases in power system involving less than 0.5 p.u. voltage drop.

5. MATHEMATICS MODEL FOR VOLTAGE SAG CALCULATION

Considered Figure 5, in a normal condition (no fault), current through load A and load B is equal (balance load).When there’s fault on feeder 1, a high current (short circuit current) will flow to feeder 1. So, based on Kirchhoff’s Law, currents flow to feeder 2 will be reduced. Consequently, voltage will also drop in feeder 2.This voltage drop will be 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)

$$I = \frac{V_2}{x_2 + Z_{LOAD\_B}} + \frac{V_2}{x_1 + Z_{LOAD\_A}} \quad (1)$$

When a fault happened (see Figure 5) in feeder 1, because of short circuit, a high current will flow through feeder 1 as well as source current *I*. During this time, voltage in feeder 2 decreased due to increasing of voltage drop across source reactance x_s, this makes sag happened.

$$I = \frac{V_2}{x_2 + Z_{LOAD\_B}} + \frac{V_2}{x_1} \text{ (when fault happened)} \quad (2)$$

Hence

$$V_2 = V_s - Ix_s \quad (3)$$

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

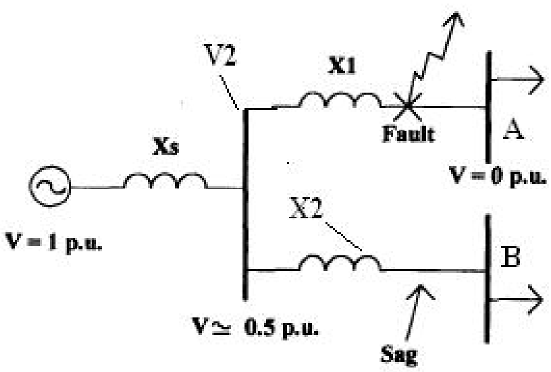

Figure 5. Calculation for voltage sag

6. MATHEMATICS MODEL FOR VOLTAGE INJECTION BY DVR SYSTEM

Consider the schematic diagram shown in Figure 6.

$$Z_{th} = R_{th} + jX_{th} \quad (4)$$

$$V_{DVR} + V_{th} = V_L + Z_{th}I_L \quad (5)$$

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

$$V_{DVR} = V_L + Z_{th}I_L - V_{th} \quad (6)$$

$$I_L = \left[\frac{P_L + jQ_L}{V_L}\right]^* \quad (7)$$

When V_L is considered as a reference, therefore;

$$V_{DVR}\angle\alpha = V_L\angle 0° + Z_{th}I_L\angle(\beta - \theta) - V_{th}\angle\delta \quad (8)$$

Here α, β and δ are the angle of V_{DVR}, Z_{th} and V_{th}, respectively and θ is the load power factor angle with $\theta = \tan^{-1}\left(\frac{Q_L}{P_L}\right)$.

The power injection of the DVR can be written as

$$S_{DVR} = V_{DVR}I_L^* \quad (9)$$

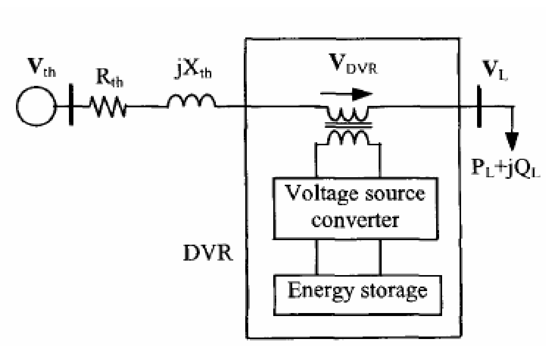

Figure 6. Calculation for DVR voltage injection

7. RESULTS AND DISCUSSION

With using PSCAD software, simulations are divided into five parts in order to study the characteristics and the performance of DVR system to mitigate voltage sag.

7.1 Performance of DVR System-Variable Voltage of Supply

This part of simulation was done in order to study the performance of DVR system in boosting the drop voltage caused by sag voltage. Refer to IEC standard, the voltage range is +5% to -10%. Practically, DVR has a limitation in boosting the drop voltage. Modeling for simulation in this part can be seeing in Figure 7. Figure 8 shows DVR structure and Figure 9 shows firing pulses for controlling DVR system. The voltage is varied from 5kV to nominal voltage, 11kV. From Table 1, we can see DVR can provide sufficient voltage (within the power quality requirement) for the drop voltage as low as 0.62p.u. While for the drop voltage below 0.62p.u, DVR system still can boost the voltage drop but not enough to achieve to 0.9p.u of nominal voltage as the minimum power quality requirement. It means for a high severity of dropped voltage, DVR still can boost that dropped voltage but insufficient to achieve the desired output voltage.

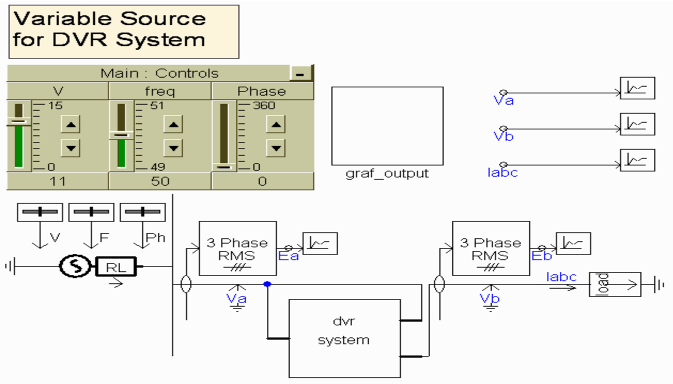

Figure 7. Modelling for variable voltage of supply

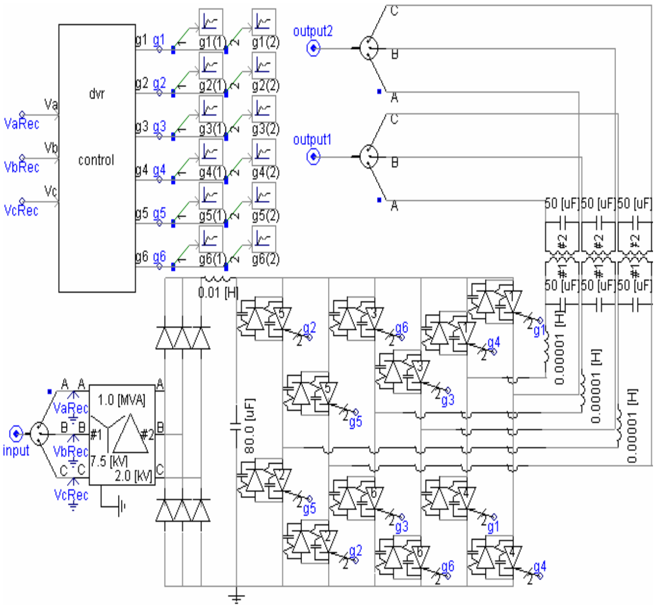

Figure 8. DVR structure

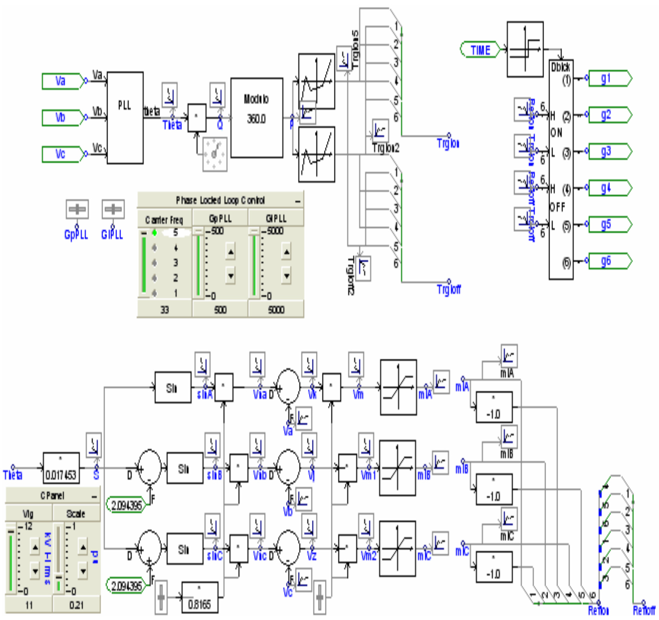

Figure 9. Firing pulses for PWM technique

Table 1: Data for variable voltage of supply

Voltage (kV)	E_a (p.u)	E_b (p.u)
11	0.987247	0.990688
10	0.899512	0.994037
9	0.810032	0.976532
8	0.719321	0.954032
7	0.628609	0.905341
6	0.538808	0.866222
5	0.449598	0.810467

7.2 Applying Voltage Sags in Power System with DVR

Three phase fault is created on the network system (Figure 10). Time duration for fault is (0.3-0.5)s and breaker will isolate the unhealthy feeder at 0.5s. The length between the feeders will determine the severity of dropped voltage. For short distance between these feeders, if fault occurred at one feeder, the other feeder will face high severity for dropped voltage. For long distance between these feeders, the severity for dropped voltage is not too high. So, a variable length is set in this simulation to show the severity of dropped voltage during voltage sag phenomenon. Table 2 shows the data taken from the simulation.

From previous section that has been discussed (Variable Voltage of Supply), DVR can only provide sufficient voltage for the 48% severity from nominal voltage. As the conclusion for this simulation, the lengths between these feeders determine the severity of drop voltage and DVR will mitigate voltage sag phenomenon. Mitigation voltage sag for this simulation can be observed in Figure 11 and Figure 12.

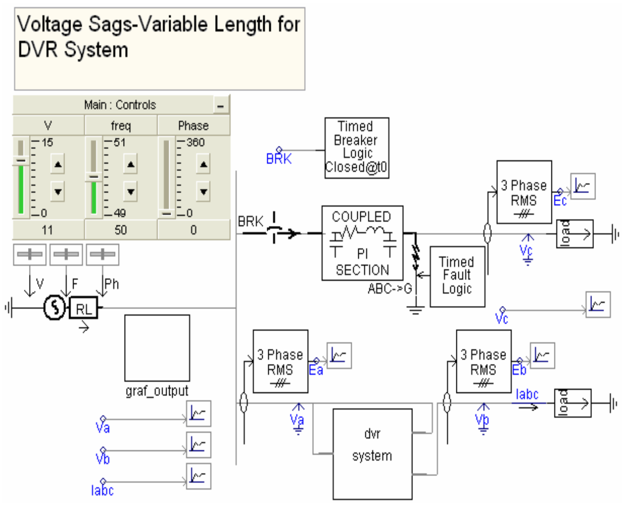

Figure 10. Variable length for voltage sag

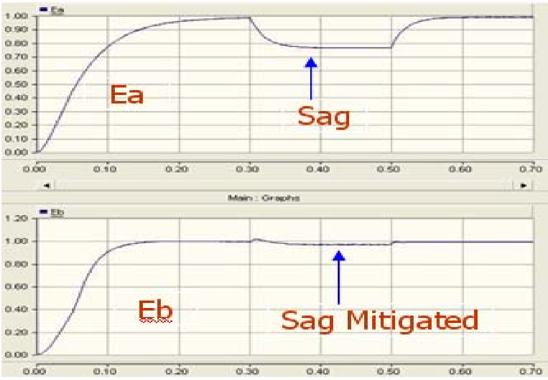

Figure 11. Waveform of mitigation voltage sag (p.u.)

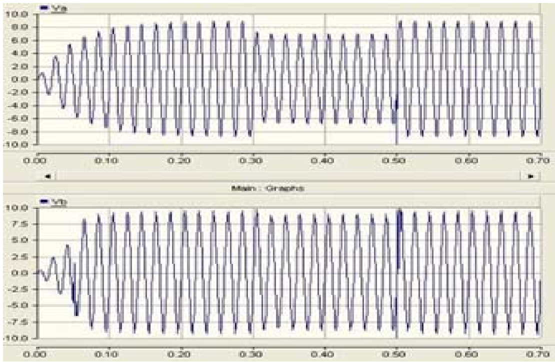

Figure 12. Waveform of mitigation voltage sag

Table 2. Variable length for voltage sag

Length (km)	Ea (p.u)	Eb (p.u)
10	0.95812	0.998482
3	0.896826	0.993272
1	0.763966	0.966975
0.75	0.71729	0.95369
0.5	0.651827	0.920331
0.1	0.547569	0.870387

7.3 Increasing Performance of DVR System

There are two main factors relating to the capability and performance of DVR working against voltage sags in a certain power system: the sag severity level and the Total Harmonic Distortion (THD). Both of these in turn are mainly decided by the DC source [4].

Based on previous discussion (Variable Voltage of Supply), the DC voltage is coming from the transformer that the setting parameter is 1MVA and secondary voltage is 2kV.Besides that, the secondary filter at coupling transformer is 50uF. The result shows DVR only can compensate voltage for severity 48% from nominal value. It means DVR can inject sufficient voltage when the drop voltage is at least 0.62 p.u.

There are two ways for increasing DC voltage in DVR system. One of them is increasing secondary voltage value and another one is increasing rating MVA transformer. Increasing rating MVA transformer will draw small dropped voltage from primary to secondary voltage. For better and higher DC result for this simulation, both of this parameter is increased.

In this simulation, the DC voltage is increased with setting the transformer 1.5MVA and secondary voltage is 3kV. In doing so, changing the filter to 100uF will produce a better filtration (doubled the value before this) (Refer Figure 8). The result from Table 3 shows that DVR can compensate drop voltage as low as 42% of nominal voltage. Compared to the previous DVR system (2KV DC voltage), it enable compensate drop voltage to as low as 62% of nominal voltage only.

As the conclusion, with increasing DC voltage, DVR performance for compensating the dropped voltage can be increased.

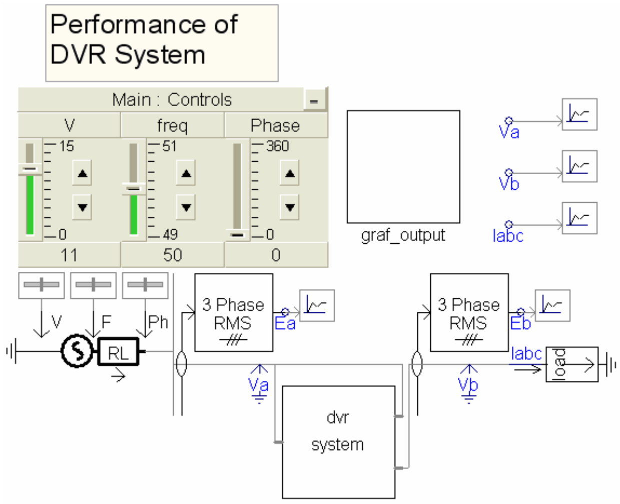

Figure 13. Increasing performance of DVR system

Table 3: Data for increasing performance of DVR

Voltage(kV)	Ea(p.u)	Eb(p.u)
11	0.97835	0.993059
5	0.445864	0.936014
4.8	0.428068	0.910269
4.7	0.419155	0.896031
4	0.35688	0.788454

8. CONCLUSION

In this paper, a complete simulated DVR system has been developed by using the PSCAD software. Its characteristic and performance when applied to a simulated power system has been studied. It is shown that the simulated DVR developed, works successfully without lacks in its performance when applied to a simulated power system network. By introducing DVR in the power network, it can help to improve power quality. It is important to have a good delivery power quality in electrical power systems especially to the critical areas, such as in the industrial sectors, in order to ensure the smoothness of the daily operations. Hopefully this paper could be a beneficial reference to others who are keen on voltage sag study.

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