VOLTAGE SAG MITIGATION BY DYNAMIC VOLTAGE RESTORER

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***ABSTRACT*:** *The most noticeable topic for electrical engineering is power quality in recent years. Power quality problem is an occurrence manifested as a non-standard voltage, current or frequency. Utility distribution networks, sensitive industrial load and critical commercial operation suffer from various types of outages and service interruptions that can cost significant financial losses. One of the major problems dealt here is the voltage sag. Dynamic Voltage Restorer provides a cost effective solution for protection of sensitive loads from voltage sags. Implementation of DVR has been proposed both at a low voltage level as well as medium voltage level. This paper presents modeling and analysis of a dynamic voltage restorer with sinusoidal pulse width modulation based controller by using MATLAB SIMULINK.*

KEYWORDS— DVR, voltage dips, swells, interruption, power quality, VSC.

1. INTRODUCTION

Power quality is one of the major issues in the power system. It becomes very important with use of the sophisticated devices whose performance is very sensitive to the quality of power supply. There are many of the power quality problems such as voltage sag, voltage swell, harmonics, flickers, interruption etc. Among these, voltage sag is most important and affects many of the equipments [1].Voltage sag occurs on utility system both at distribution voltages and transmission voltages. Voltage sag which occur at higher voltages will normally spread through a utility system and will be transmitted to lower voltage systems, via transformers. Voltage sag can cause serious problem to sensitive loads that use voltage-sensitive components such as adjustable speed drives, process control equipment, and computers. Many of the devices are available to mitigate the voltage sag such as tap changing transformer, UPS, STATCOM or DVR.

Tap changing transformer is a conventional device to mitigate voltage sag, but due to its bulky construction and slow operation it is rarely used for this purpose. UPS (Uninterrupted Power Supply) takes the entire load without any energy contribution from the grid so it is not applicable for the high power application. Operation of the STATCOM depends on load condition whether it is inductive or it capacitive. If the load is inductive then it absorbs the reactive power or if it is capacitive then it supplies the reactive power. Dynamic Voltage Restorer is a cost effective and efficient solution for voltage sag [5].

The wide area solution is required to mitigate voltage sag and improve power quality. Nowadays the new approach is to use a DVR. The basic operating principle of DVR is to detect the voltage sag and inject the missing voltage in series as shown in Fig. 1, [3].

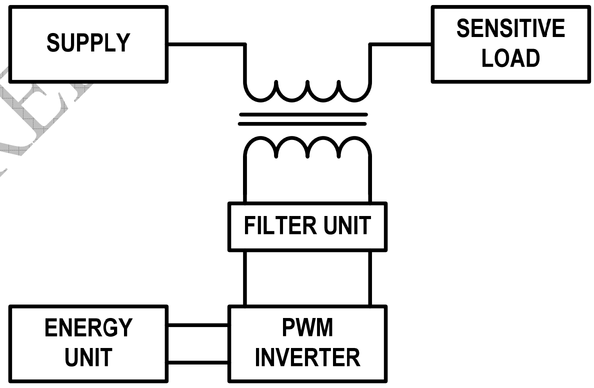

Fig.1Typical application of DVR and its output

DVR becomes a cost effective solution for protection of sensitive loads from voltage sag. DVR is connected in the utility primary distribution feeder. This location of DVR helps to mitigate voltage sag in a feeder caused by fault on the adjacent feeder to certain group of consumers is as shown in Fig. 2, [3].

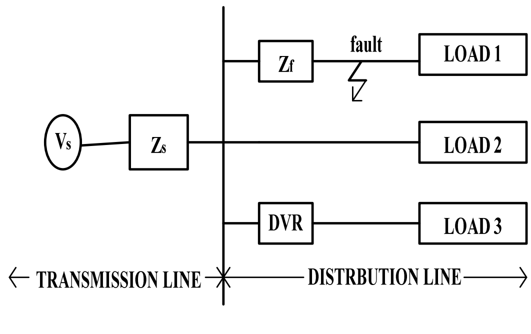

Fig 2. Location of DVR

2 CONFIGURATION OF DVR

Converter: The converter is most likely a voltage source converter (VSC) which pulse width modulates the DC from dc link/ storage to ac voltage injected in to the system. VSC is a power electronics system consisting of a storage device and switching devices, which can generate a sinusoidal voltage at any required frequency, magnitude and phase angle. In DVR application the VSC is used to temporarily replace the supply voltage or to generate the part of the supply voltage which is missing.

Filter unit: Line filter is inserted to reduce the switching harmonics generated by PWM VSC.

Injection transformer: In most of the DVR applications the DVR is equipped with injection transformer to ensure galvanic isolation and simplify the converter topology and protection equipment. There are two main purposes of isolation transformer. First, it connects the DVR to the distribution network and couples the injected compensating voltage generated by the voltage source converter to the incoming supply voltage and second, it serves the purpose of isolating the load from the system.

Energy storage & DC link voltage: A DC link voltage is used by the VSC to synthesize an ac voltage into the grid and during the majority of voltage dips, active power injection is necessary to restore the supply voltage. The DC charging circuit has two main tasks, first is to charge the energy source after compensation events, and second is to maintain dc link voltage.

Bypass Equipment: During fault, overload and service a bypass path for the load current has to be ensured, which is illustrated in Fig. 3 as a mechanical bypass and a thyristors bypass [1].

3. DIFFERENT TOPOLOGIES FOR DVR

DVR topologies without energy storage use the fact that a significant part of the supply voltage remains present during the sag and this residual supply can be used to provide the boost energy required to maintain full load power at rated voltage. A passive shunt converter is used because only unidirectional power flow is assumed necessary and it is cheap solution for voltage sag.

Two basic topologies can be used, which are categorized here according to the location of shunt converter. First is supply side connected shunt converter and second is load side connected shunt converter.

Topology with energy storage: Storing of electrical energy is expensive but for certain types of voltage sag the performance of the DVR can be improved and the strain on the grid connection is lower. Two methods are considered here and in both the current flow from the grid is unchanged during voltage sag.

Experimental tests using 10 kVA DVR shows that no energy storage concept is feasible, but an improved performance can be achieved for certain voltage sag using stored energy topology. [4]

4. OPERATING MODES

Generally, the DVR operation is categorized into three different modes, such as protection mode, standby mode (during steady state) and injection mode (during sag)

Protection Mode: The DVR is protected from over current due to short circuit on the load side or large inrush currents. The bypass switches remove the DVR from system by providing another path for current as shown in Fig. 3.

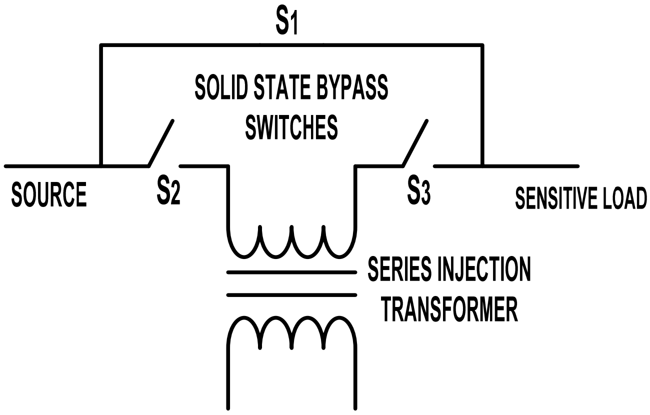

Fig 3. The view of protection mode.

Standby Mode: In standby mode (normal steady state conditions), the DVR may either go into short circuit operation or may inject small voltage to compensate the voltage drop on transformer reactance or losses as shown in Fig. 4.

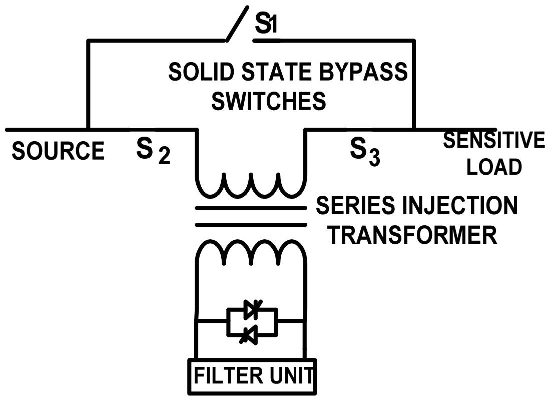

Fig 4. The view of standby mode.

Injection Mode: The DVR goes into injection mode as soon as the sag is detected. Three single phase ac voltages are injected in series with required magnitude; phase and wave shape for compensation. The types of voltage sag, load conditions and power rating of DVR will determine the probability of successful compensation of voltage sag. The DVR should ensure fairly constant load voltage with minimum energy dissipation for injection considering high cost of energy storage capacitors. The available voltage injection strategies are pre-sag, phase advance, voltage tolerance and in phase method [3].

5. VOLTAGE INJECTION METHODS

Pre-sag compensation method: This method injects the voltage difference between sag and pre-fault voltages to the system. It is the best solution to obtain the same load voltage as the pre-fault voltage but there is no control on injected active power so high capacity energy storage is required.

Phase advance method: The real power spent by DVR is minimized by decreasing the power angle between the sag voltage and load current. The values of load current and voltage are fixed in the system so we can change only the phase of the sag voltage.

***Voltage tolerance method with minimum energy injection*:** Generally the voltage magnitude between 90%- 110% of nominal voltage and phase angle variation between 5%-10% of normal state do not disturb the operation characteristics of loads. This method can maintain load voltage in the tolerance area with small change of voltage magnitude.

In phase voltage injection method: The injected voltage is in phase with supply voltage. The phase angles of the pre-sag and load voltage are different but the most important criteria for power quality that is the constant magnitude of load voltage are satisfied. $V_L = V_{Lprefault}$

6. WORKING OF DVR

The main operation principles of DVR can be summarized as shown in Fig. 5.

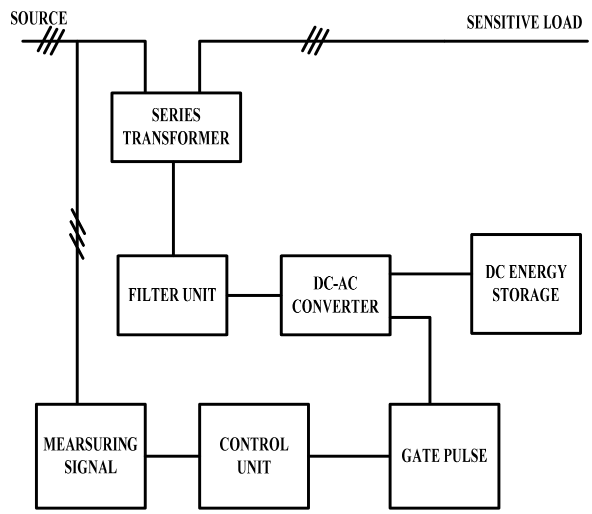

Fig 5. Function blocks of designed DVR.

This kind of control model is used to minimize the response time and maximize the dynamic performance. Voltage regulation, low harmonic distortions and no interruptions are realized with this type of control architecture. In this study the measurement is provided for continuous monitoring of the voltage in the line, when the fault occurs in the system which causes the voltage sag then reference signal is obtained from the measured parameters by using the Instantaneous Reactive Power Theory method (d-q theory) which is the most popular waveform correction method based on the time domain analysis. In this method the quantities are expressed as the instantaneous space vectors.

Firstly voltages are converted from *a-b-c* reference frame to *d-q* reference frame. For simplicity zero phase sequence component is ignored. Conversion of these parameters from *a-b-c* to *d-q-0* is done according to the following equations.

$$V_0 = \frac{1}{3}(V_a + V_b + V_c)$$

$$V_d = \frac{2}{3}[V_a \sin \omega t + V_b \sin\left(\omega t - \frac{2\pi}{3}\right) + +V_c \sin\left(\omega t + \frac{2\pi}{3}\right)]$$

$$V_q = \frac{2}{3}[V_a \cos \omega t + V_b \cos(\omega t - \frac{2\pi}{3}) + V_c \cos\left(\omega t + \frac{2\pi}{3}\right)]$$

After conversion, the balanced three-phase voltage V_a, V_b and V_c become two constant voltages V_d, V_q. now these two components are compared with the reference voltage signal which is also in *dq0* form. By comparing these two signals error signal is generated and this error signal is applied to the PI controller. Then output of the PI controller is transformed to the V_a, V_b and V_c value using following equations.

$$V_a = V_d \sin \omega t + V_q \cos \omega t + V_0$$

$$V_b = V_d \sin(\omega t - \frac{2\pi}{3}) + V_q \cos\left(\omega t - \frac{2\pi}{3}\right) + V_0$$

$$V_c = V_d \sin(\omega t + \frac{2\pi}{3}) + V_q \cos\left(\omega t + \frac{2\pi}{3}\right) + V_0$$

Now signal is in sinusoidal form which is compared with triangular wave of 1.5 KHz carrier frequency to produce required firing signals for each leg of the PWM inverter that is known as SPWM technique.

Then the output of the inverter is applied to the line through injection transformer of ratio1:1 such that the sag is compensated and the voltage across the load remains fairly constant. [3].

7. RESULTS

Single line diagram of the test system shown in the Fig. 6 for DVR is composed of 11 kV, 50 Hz generation system. To verify the working of DVR for voltage compensation a fault is applied at point X. The first simulation was done without DVR and a three phase fault was applied to the system at point with fault resistance of 0.004 Ω for time duration of 200 mS.

Fig. 7 shows there is a voltage drop for 200 mS. Now DVR has to inject the voltage for the duration of the fault. Fig. 8 shows the voltage that is to be injected by the DVR through series injection transformer. The second simulation is carried out at the same scenario as above but a DVR is now introduced on the load side to compensate the voltage sag occurred due to the three phase fault. When the DVR is in operation the voltage interruption is compensated almost completely and the RMS voltage at the sensitive load point is maintained at nominal value even during the fault as shown in Fig. 9.

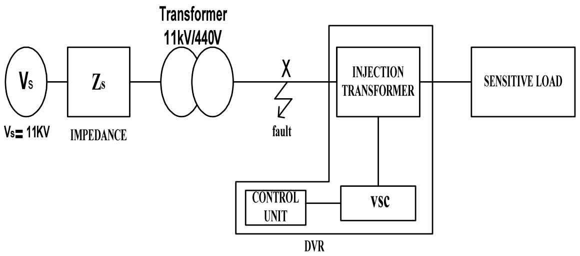

Fig 6. Test System.

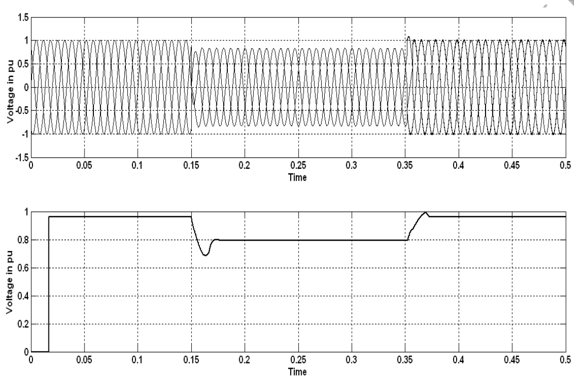

Fig 7. Three phase voltage without DVR.

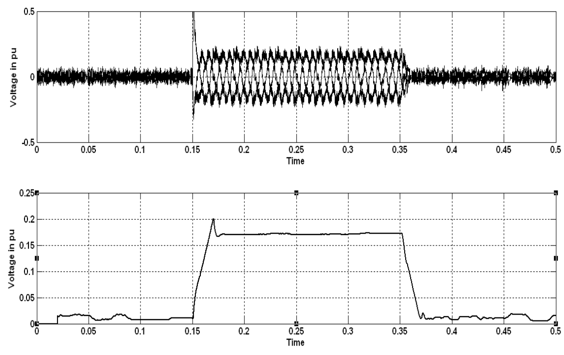

Fig 8 RMS voltage injected by DVR.

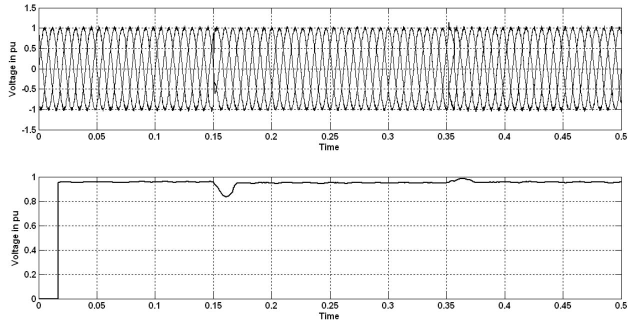

Fig 9. Three phase voltage with DVR.

8. Conclusion

In this paper, the simulation of a DVR using MATLAB SIMULINK has been presented. The simulation results show the performance of the DVR. The DVR handles the situation without any difficulties and rapidly injects the appropriate voltage component to correct rapidly any changes in supply voltage thereby keeping the load voltage balanced and constant at the nominal value. In this study, the DVR has shown the ability to compensate for voltage sag. The performance showed by the DVR makes it an interesting power quality device compared to other devices.

9. REFERENCES

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