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DVR AND ITS VARIOUS CONTROL SCHEMES: A SURVEY

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Abstract - *One of the major concerns in industries is the quality of the power in main line. This has become more important with the inclusion of new advanced power quality devices which are sensitive for small changes in the quality. Main cause of the power quality problem is poor standard voltage, current or frequency which may cause the failure of the hardware. Power sagging and power swellings are the two main issues which are most prevalent in industries. Custom power devices are one of the solutions of this problem. Dynamic voltage restorer (DVR) is one of such custom power device which is used most frequently in the power distribution. This paper is an attempt to present a review work on the DVR technology along with the various applications proposed in the past.*

Key Words: **DVR, Voltage Sag, Voltage Swell, Filter, Power Quality, VSC.**

1. INTRODUCTION

The performance of many industrial applications like in advanced control, automation, precise manufacturing application, power quality play very important role. Most of the above application requires precise shape of the sine wave constant frequency and symmetrical voltage along with the constant root mean square value (RMS). It is therefore essential to eliminate such type of disturbances.

Some of the common power quality degradations are voltage sag, voltage swell, phase shift, harmonics and transients [1] [2].

Among all type of power quality problems, voltage sag is considered as the most severe problem. It is due to the facts that the sensitive loads are very susceptible to even smaller changes in the voltage.

Reduction in the voltage magnitude for a small interval of time is called voltage sag. The magnitude of the voltage suddenly drops to the lower value and comes back to the original value after approx. 150 mili-seconds. Though such kind of disturbance last for short duration even if it causes serious problems for a large rand of equipments [1][3]. Two very important characteristics which is related with the voltage sag-

i. Duration of the sag.
ii. Magnitude of the voltage during the sag interval.

Practically the magnitude of the voltage during the sag interval has more influence than the duration of the sag on the system.

It was observed that the voltage sag occurs in the industries are generally within the 40% limit of the nominal voltage.

Sagging of the voltage may cause the damage of million dollar which include the breakdown, production lost etc [2] [3]. Generally the main cause of the voltage sag is fault in short circuit, starting the motor, energizing the motor via transformer. This fault generally increases the current in the line which causes voltage sag on the line.

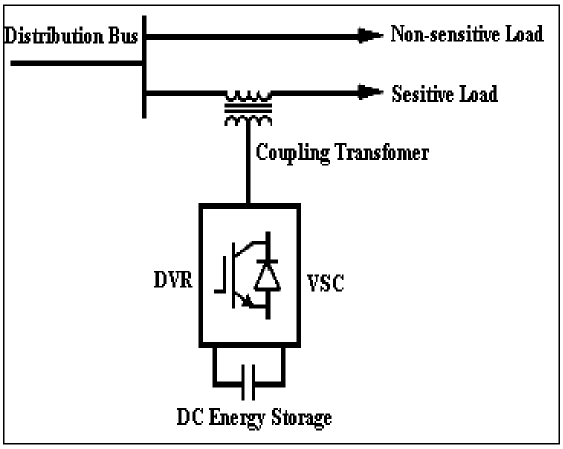

Figure 1 Basic Configuration of DVR

For most of the sensitive equipment, voltage correction device is the only cot effective solution.

Different type of approach and methods are available to fight this type of the voltage dip problem. One of the advanced approach is to apply the voltage source converter in series between the sensitive load and supply system. This type of device is generally termed as the dynamic voltage restorer (DVR).

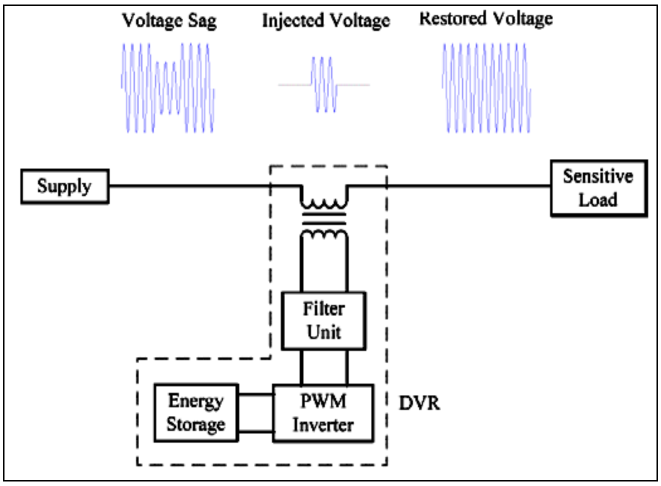

Figure 2 Application of DVR in distribution system

Uninterrupted power supply (UPS) is also one of the solutions of this type of problem but UPS are generally designed for small load. For large load ranging from few MVA to 50 MVA or higher, DVR is most suitable device [8]. Most efficient, fast and flexible solution to this problem is DVR. The DVR has the ability to restore the voltage to the original voltage within a few mili second and hence eliminate the power disturbance from the load. Main principle of the DVR is to detect the voltage sag effectively and provide the missing voltage by injecting the voltage in phase with the power line with the help of the injecting transformer.

Basic building block of the DVR consists of the following component block.

i. PWM based Voltage source inverter.
ii. Injection or Coupling Transformer.
iii. Energy storage device.
iv. Filter block or unit.

1.1 Appropriate Choice of DVR

DVR is preferred over the other devices due to the numerous reasons-

i. Though SVC dominates the dynamic voltage restorer but the DVR is still preferred over the SVC due to the inability of the SVC to control the active power flow.
ii. Cost wise, the dynamic voltage restorer (DVR) is less expensive.
iii. Even the UPS device require high level of maintenance as it suffer the problem of the battery leak and therefore need to be replaced after every five years.
iv. If we compare the DVR with SMES devices, the energy capacity of the DVR is high and it is less costly.
v. As far as the DSTACOM is concern, DVR is preferred over the DSTATCOM as the former is small in size and less costly.
vi. As compared to UPS, DVR is more power efficient.

2. CONVENTIONAL CONTROL STRATEGIES

Different types of approaches have been proposed in the past for compensating the voltage sag problem. Some of the noteworthy compensation are pre-sag technique, in phase technique and minimal energy control technique [2] [3].

2.1 General Compensation Approach

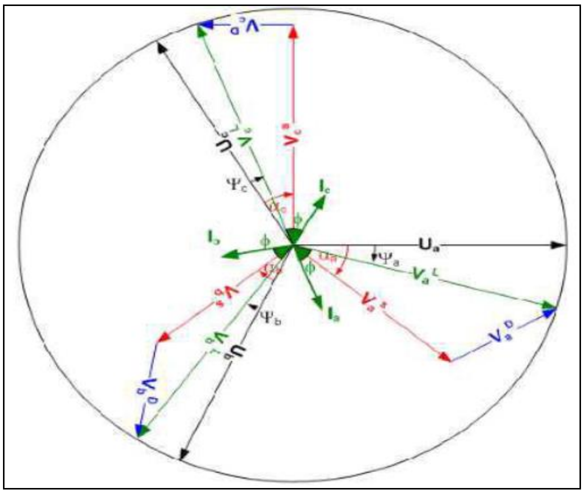

Figure 3 Phasor diagram

In this approach, the load voltage phasor along with the load current is made to rotate according to the pre-sag voltage while at the same time the supply sag voltage phasors is not altered. During the normal operation phase since no voltage sag occurs therefore DVR does not supply any voltage to the load. Under such condition, DVR is said to be in "Standby mode". During this time, DVR is also said to be in "self charging Mode" till the energy storage device is fully charged.

Under such circumstances, energy storage device is charged from the power supply itself or from a different supply source.

2.2 Pre-Sag Compensation Technique

Pre-sag compensation approach is another approach for voltage sag compensation. The main problem with this approach or technique is that it requires an energy device of much higher capacity.

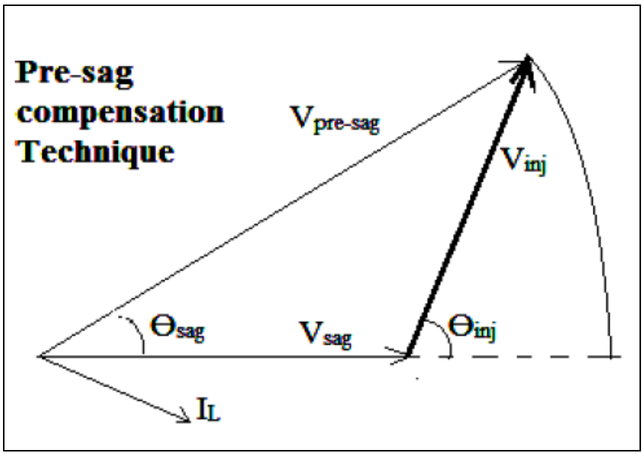

Figure 4 Pre sag compensation approach

Figure 4 above depicts the phasor diagram for the pre-sag control technique. As per the figure, Vpre-sag and Vsag represents the voltage of the common coupling points (PCC) before and during the voltage sag condition respectively. In such case Vdvr is the injected voltage by the DVR. This injected voltage is given by the following formula [9] respectively before and during the sag. In this case V_{DVR} is the voltage injected by the DVR. [9]

2.3 In-Phase Compensation Approach or Method

In this approach, only the magnitude of the voltage is compensated here V_{DVR} is the in phase voltage of the DVR. In this technique, DVR injected voltage is minimized which make it different from the pre-sag compensation technique. Figure below represent the phase diagram of the in phase compensation technique. [9]

$V_{DVR}=V_{inj}$

$| V_{inj} | = | V_{pre\text{-}sag} | - | V_{sag} |$

$V_{pre\text{-}sag} = V_L$, $V_{sag} = V_s$, $V_{DVR} = V_{inj}$

$| V_{inj} | = | V_{pre\text{-}sag} | - | V_{sag} |$ ……. (1)

In this technique, only the voltage magnitude is compensated. V_{DVR} is in-phase with the left hand side voltage of DVR.

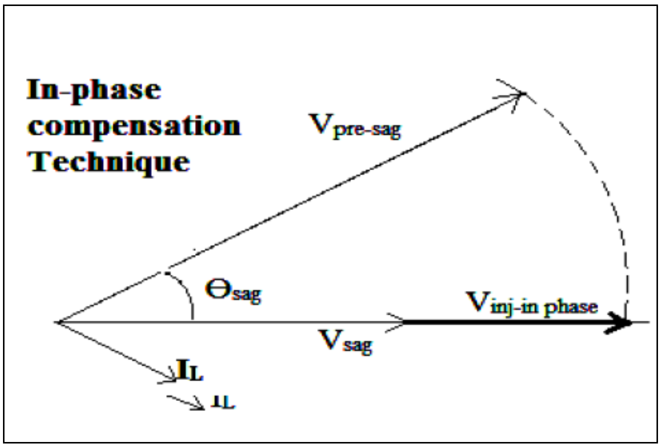

Figure5 In phase compensation approach

This method minimizes the voltage injected by the DVR, unlike in the pre-sag compensation. Fig.2 shows phase diagram for the in-phase compensation technique [9].

$V_{DVR}=V_{inj}$

$| V_{inj} | = | V_{pre\text{-}sag} | - | V_{sag} |$

2.4 Energy Optimized compensation Approach or method

One of the drawbacks of the pre-sag compensation approach and the in-phase compensation approach is that in both the method, almost all the time active power need to be injected to the load. Since there are some limitation of the energy storage capacity of the DC link, the performance as well as the restoration time of the DVR is very limited. The basic principle of the energy optimized compensation approach is somehow to make the active power zero. So for minimizing the use of the real power of the injected voltage, voltages are injected at the angle of 90° to the supply current. Figure below depicts the description of the energy optimized compensation approach.

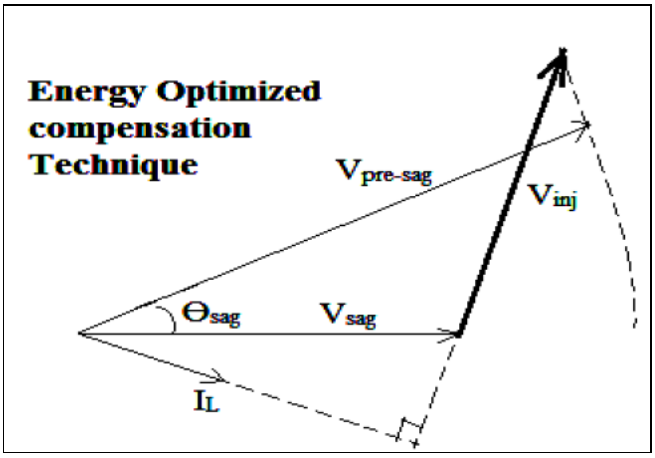

Figure 6 Energy Optimized Compensation Approach

The design parameter of the DVR depends upon the selection of the above mentioned approaches. In this paper, the compensation approach of pre-sag compensation is adopted for maintain the load voltage to the pre-fault value [9].

3. MATHEMATICAL MODEL

Under the duration of the "standby mode", DVR does nothing and therefore it is ensured that during this time, the load should not be disturbed by the DVR. If under any circumstances the line voltage drops or dip, DVR must be able to inject the voltage in proper magnitude to compensate the fault.

During the "Standby Mode", Only conduction losses take place in the DVR because of no switching of the PWM inverter or no production of the voltage from the inverter. When the fault occur at the load side of the DVR, the injection transformer produce fast rising current surge and the switching of the PWM inverter start functioning.

The inbuilt protection system ensures that the switching of the power semiconductor occurs when the current magnitude exceeds the switching capacity of the power semiconductor. If at any time critical current level is detected or sensed, control mechanism bypassed the DVR. This bypassed control strategy protects the DVR component from the harmful very high load current or fault current. It is very important to mention here that the DVR must possess a very effective and efficient by-pass scheme in order to produce zero disturbances during this time which may affect the load.

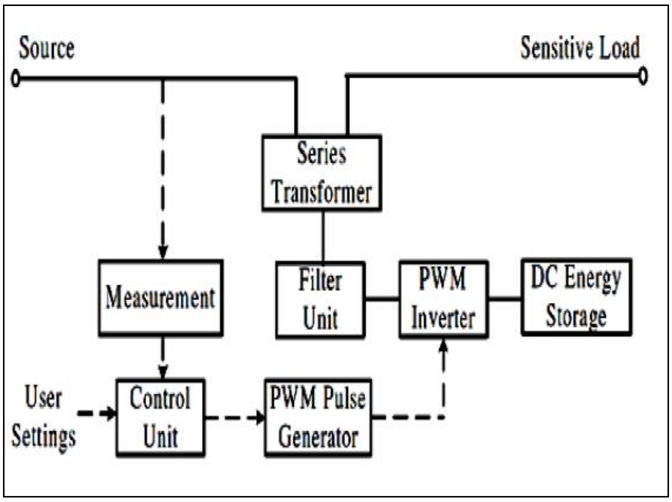

Figure 7 Simple Block Diagram of DVR

When the depth of the voltage sag or voltage dip is under the DVR rating, DVR activate to generate or produce the missing voltage and start injecting it to the main line through the injection transformer. DVR keeps on injecting the missing voltage until the bus voltage comes back to its original pre-fault value.

DVR is capable of injecting the three single phase AC voltage with controllable phase and amplitude.

The voltage sag or voltage dip caused due to the fault can be effectively corrected or compensated in the distribution system or transmission system.

DVR is capable of compensating or correcting the small disturbances by injection of the reactive power. DVR is also capable of the correcting or compensating the large disturbances by injection of the real power to the system.
In order to guess the amplitude of the missing voltage, DVR keeps on comparing the source voltage with the pre-fault value of the voltage and accordingly generate the control signal to the PWM inverter which later on generates the voltage of the appropriate amplitude for compensation.

The control unit of the DVR play very important role to provide the information of required voltage required to be inserted along with the duration of the voltage sag. Sinusoidal pulse width modulation technique is used for controlling the DVR. IN Pulse Width Modulation (PWM), solid state power switching devices are used as it requires less power and more efficient [10]. Harmonics filter is used on the inverter side in order to filter out the harmonics produced in PWM inverter which smooth the signal waveform. The filtering operation keeps the total harmonics distortion (THD) of the generated voltage as well as the line voltage under the determined standard.

The main aim of the DVR is to inject the energy from the DVR to the Distribution system during the time of voltage sag. The required energy for injection during the voltage sag fault must be supplied by the some energy storage device. For this, generally DVR is equipped with some batteries or in some cases it is equipped with the super conducting magnetic energy storage system (SMES). Some time, capacitor are also used in DVR for the same purpose but the the capability of the capacitor for providing the energy is very limited.

Therefore it is necessary to consider how to provide the energy during the deep voltage sag so that the load voltage can be made very close to the pre-fault value. This approach is known as the DVR with minimum energy injection [5][7][10].

DVR is basically connected in series fashion to the system and it just act like emergency energy source with the capability to provide the energy dynamically.

The DVR is a series connected device onto the system and it acts as an additional energy source. Therefore carefully design of the system is required to integrate the DVR to the system. Figure 4 represent the operation of the DVR.

4. CONCLUSIONS

Main aim of this paper is to summarize the DVR and its various control technique along with the discussion of various pros and cons of the implementation of the DVR.

Section 1 present the basic review of the DVR technique while in section 2 the advantage of the DVR over other techniques or method is discussed. Section 3 discuss about the various schemes of the DVR implementation. Section 3 also covers the mathematical model of the basic structure of the DVR. It is clear from the above discussion that there are several ways of implementing the DVR for reducing the harmonics in a very complex power system.

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