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Mitigation Technique For Voltage Sag & Swell By Using Dynamic Voltage Restorer

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Abstract: This paper presents the application of dynamic voltage restorers (DVR) on power distribution Systems for mitigation of voltage sags/swells at critical loads. DVR is one of the compensating types of custom power devices. An adequate modeling and simulation of DVR, including controls in MATLAB, show the flexibility and easiness of the MATLAB environment in studying and Understanding such compensating devices. Simulation results are presented to illustrate and understand the performances of DVR in supporting load voltages under voltage sags/swells conditions.

Keywords: custom power, power quality, voltage sags, voltage swells, DVR.

1. INTRODUCTION

Modem power systems are complex networks, where hundreds of generating stations and thousands of load centers are interconnected through long power transmission and distribution networks . The main concern of consumers is the quality and reliability of power supplies at various load centers where they are located at. Even though the power generation in most well-developed countries is fairly reliable, the quality of the supply is not so reliable.

Power distribution systems, ideally, should provide their customers with an uninterrupted flow of energy at smooth sinusoidal voltage at the contracted magnitude level and frequency However, in practice, power systems, especially the distribution systems, have numerous nonlinear loads, which significantly affect the quality of power supplies. As a result of the nonlinear loads, the purity of the waveform of supplies is lost. This ends up producing many power quality problems. Apart from nonlinear loads, some system events, both usual (e.g. capacitor switching, motor starling) and unusual (e.g. faults) could also inflict power quality problems.

A power quality problem is defined as any Manifested problem in voltage/current leading to frequency deviations that result in failure or disoperation of customer equipment. Power quality problems are associated with an extensive number of electromagnetic phenomena in power systems with broad ranges of time frames such as long duration variations, short duration variations and other disturbances.

Short duration variations are mainly caused by either fault conditions or energization of large loads that require high starting currents. Depending on the electrical distance related to Impedance type of grounding and connection of transformers between the faulted/load location and the node, there can be a temporary loss of voltage or temporary voltage reduction (sag) or voltage rise (swell) at different nodes of the system.

Voltage sag is defined as a sudden reduction of supply voltage down 90% to 10V%of nominal, followed by a recovery after a short period of time. A typical duration of sag is, according to the standard, l0 ms to I minute.

Voltage sag can cause loss of production in Automated processes in voltage sag can trip a motor or cause its controller to malfunction. Voltage swell, on the other hand, is defined as a sudden increasing of supply voltage up l0% to 180% in rms voltage at the network fundamental frequency with duration from 10 ms to 1 minute. Switching off a large inductive load or energizing a large capacitor bank is a typical system event that causes swells .To compensate the voltage sag/swell in a power distribution system, appropriate devices need to be installed at suitable location.

The DVR is one of the custom power devices which can improve power quality, especially, voltage sags and voltage swells. As there are more and more concerns for the quality of supply as a result of more sensitive loads in the system conditions better understanding of the devices for mitigating power quality problems is important.

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This paper an attempt is made to understand the functions of DVR with the help of MATLAB

2. CUSTOM POWER TECHNOLOGY

The concept of custom Power was introduced by N.G. Hingorani in 1995. Like Flexible AC Transmission Systems (FACTS) for transmission systems, the term custom power pertains to the use of power electronics controllers in a distribution system, especially, to deal with various power quality problems. Just as FACTS improves the power transfer capabilities and stability margins, custom power makes sure customers get pre-specified quality and reliability of supply. This pre-specified quality may contain a combination of specifications of the following : low phase unbalance, no power interruptions, low harmonic distortion in load voltage, magnitude and duration of overvoltages/undervoltages within specified limits, acceptance of fluctuations, nonlinear and poor factor loads without significant effect on the terminal voltage. These can be done on the basis of an individual, large customer, industrial/ commercial parks or a supply for a high tech community on a wide area basis. Custom power technology is a general term for equipment capable of mitigating numerous power quality problems. Basic functions are fast switching, and current or voltage injection for correcting anomalies in supply voltage or load current, by injecting or absorbing reactive and active power.

The power electronic controllers that are used in the custom power solution can be a network reconfiguring type or a compensating type. The network reconfigurating devices are usually called switchgears which include current limiting, current breaking and current transferring devices. The compensating devices either compensate a load, i.e. its power factor, unbalance conditions or improve the power quality of supplied voltage, etc. These devices are either connected in shunt or in series or a combination of both. This class of devices includes the distribution static compensator (D-STATCOM), dynamic voltage restorer (DVR), and unified power quality conditioner (UPQC) . Among compensating devices, a DVR can deal with voltage sags and swells which are considered to have a severe impact on manufacturing places such as semiconductors and plastic products, food processing places and paper

3.DYNAMIC VOLTAGE RESTORER/ REGULATOR (DVR)

3.1 **DVR**: The Dynamic Voltage Restorer (DVR) is a series connected device analogous to a SSSC. The main function of a DVR is to eliminate or reduce voltage sags seen by sensitive loads such as semiconductor manufacturing plant or IT industry. DVR that have been installed so far are modular with ratings of 2 MVA per module. They have been designed to compensate three phase voltage sags up to 35% for duration of time less than half a second (depending on the requirement). If the voltage sag occurs only in one phase (caused by SLG faults) then the DVR may be designed to provide compensation for sags exceeding 50%. The energy storage required in capacitors is typically in the range of 0.2 to 0.4 MJ per MW of load served.

A DVR is connected in series with the feeder using a transformer. The low voltage winding is connected to the converter. If the objective of a DVR is mainly to regulate the voltage at the load bus, it remains for most of the time in stand-by mode during which the converter is bypassed (no voltage is injected). Only when sag is detected, the DVR injects a series voltage of the required magnitude. It is necessary to protect a DVR against the fault currents (as in the case of a SSSC). A DVR with IGBT/IGCT devices can be controlled to act as a series active filter to isolate the load from voltage harmonics on the source side. It is also possible to balance the voltage on the load side by injecting negative and/or zero sequence voltages in addition to harmonic voltages.

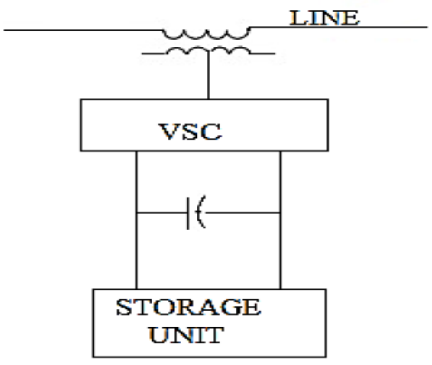

FIG 3. 1.Basic configuration of DVR

It is also known as a static voltage booster (SVB) or a static series compensator (SSC). It is generally installed in distribution systems. It is a series custom power device intended to protect the sensitive loads at the point of common coupling (PCC) from various power quality problems. DVR has the capability to deal with line voltage harmonics, reduction of transients in voltage, fault current limitations, voltage sags, voltage swells. Problems facing industries

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regarding the power quality are mainly voltage sags and swells.

3.2 CONFIGURATION OF DVR

The configuration of a DVR consists of:

1. Injection/Booster/Isolation transformer
2. Harmonic/Passive filter
3. Storage devices/Energy storage systems
4. Voltage source converter
5. DC charging set

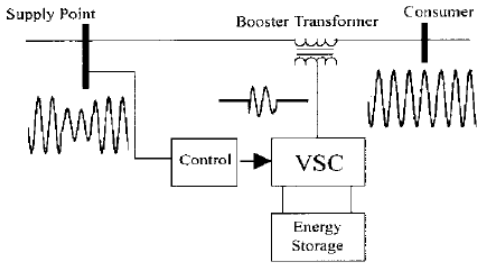

Fig.3.2 schematic representation of DVR

1. Injection Transformer

It consists of a three phase transformer or three single phase transformers which limit the coupling of noise and transient energy from primary side to the secondary side. It connects the DVR to the distribution network via high voltage windings. Transformer can be connected in star/star configuration or delta/star configuration. If the system is connected in star/star configuration then zero sequence voltage compensation is required. If a delta/star configuration is used then no zero sequence voltage compensation is required as it offers infinite impedance for zero sequence components.

2. Harmonic/Passive filter

Usually, a filter unit consists of inductor and capacitor. It eliminates the unwanted harmonic components produced by the voltage source converter.

3. Storage devices/Energy storage systems

They fulfill the active requirement of the load. Various systems can be used for this purpose like flywheel, super conducting magnetic energy storage systems (SMES), lead acid batteries.

4. VOLTAGE SOURCE CONVERTER

It basically consists of a storage device and switching devices. It produces sinusoidal voltage of desired phase angle and magnitude. There are four main types of storage devices: MOSFET, GTO, IGBT .

5. DC charging set

It performs two main tasks which are as follows:

- It charges the dc source after a sag compensation event.

- It maintains dc link voltage at the nominal dc link voltage.

Excess of dc link voltage will damage the dc storage capacitor and switching device.

4. PRINCIPLE & OPERATION OF DVR

4.1 LOCATION OF A DVR

If a fault occurs on the line feeding load 1 then its voltage collapses to zero. Load 2 experiences voltage sag whose magnitude is equal to the load voltage at the point of common coupling. The voltage of the sensitive load is protected by the DVR and is restored to its pre-fault value. DVR is located downstream of a delta/star distribution transformer. Hence, there is no need to provide zero sequence voltage compensation.

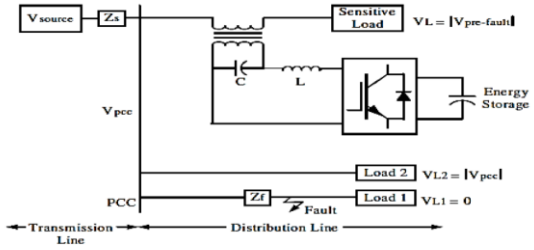

FIG.4.1 Location of DVR

4.2 OPERATION OF A DVR

It injects dynamically controlled voltages in series with the bus voltage through the booster transformer. The amplitudes of the injected phase voltages are controlled so as to eliminate the detrimental effects of a bus fault to the load voltage.

The system impedance Zth depends on the fault level of the load bus. When the system voltage (Vth) drops, the DVR injects a series voltage VDVR through the injection transformer so that the desired load voltage magnitude VL can be maintained. The series injected voltage of the DVR can be written as:

$$V_{DVR} = V_L + Z_{th}I_L - V_{th}$$

$$I_L = \left(\frac{P_L + jQ_L}{V_L}\right)$$

Where,

V_L= Desired load voltage magnitude

Z_{th}= load impedance

I_L= Load current

V_{th}= system voltage during fault condition

5. Modeling of DVR in MATLAB

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The compensation of voltage sag/swell can be limited by a number of factors, including finite DVR power rating, loading conditions, power quality problems and types of sag/swell. lf a DVR is a successful device,the control is able to handle most sags/swells and the performance must be maximized according to the equipment inserted. Otherwise, the DVR may not be able to avoid tripping and even cause additional disturbance to the loads.

5.1 Voltage Sags

First, a case of symmetrical sag is simulated by connecting a three-phase reactance to the busbar. The results are shown in Figure 6. A 30% voltage sag is initiated at 400 ms and it is kept until 550 ms, with total voltage sag duration of 150 ms. Figure show the series of voltage components injected by the DVR and compensated load voltage, respectively. As a result of DVR, the load voltage is kept at 1.00 p.u. throughout the simulation, including the voltage sag period.

Observe that during normal operation, the DVR is doing nothing. It quickly injects necessary voltage components to smooth the load voltage upon detecting a voltage sag.

In order to understand the performance of the DVR under unbalanced conditions, a single line- ground (SLG) fault at supply bus bar at 400 ms is simulated. As a result of SLG fault. An unbalanced voltage sag is created immediately after the fault as shown in Figure, the supply voltage with two of the phase voltages dropped down to 80%. The DVR injected voltage and the load voltage are shown in Figure . A s can be seen from the results, the DVR is able to produce the required voltage components for different phases rapidly and help to maintain a balanced and constant to voltage to 1.00p .u.

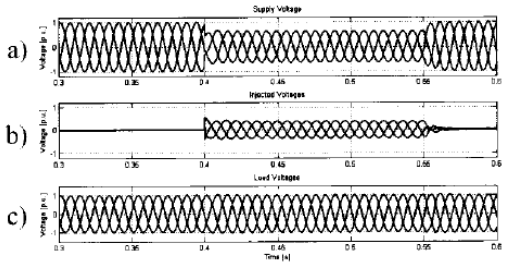


FIG.5.1.1Simulation result response to dvr for voltage balanced sag

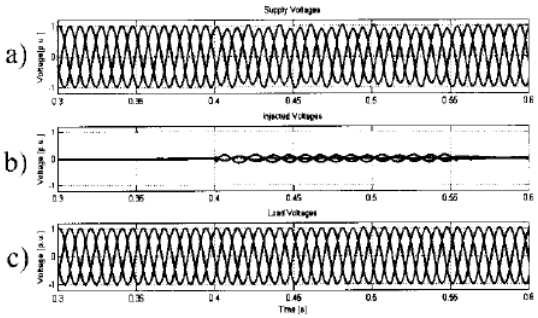


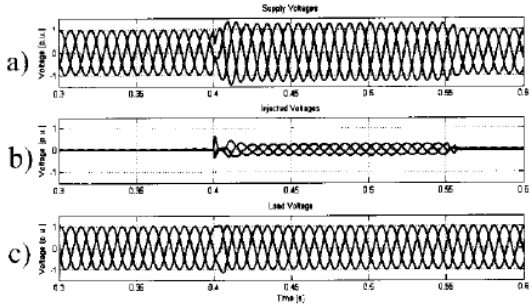
FIG.5.1.2Simulation result response to dvr for voltage unbalanced sag

5.2 Voltage Swells

Next, the performance of DVR for a voltage swell condition is investigated. Here, voltage swell is generated by energizing of a large capacitor bank and the corresponding supply voltage is shown in Figure. The voltage amplitude is increased about l25% of nominal voltage. The injected voltage that is produced by DVR in order to confects the load voltage and the load voltage, are shown in Figure . As can be seen from the results, the load voltage is kept at the nominal value with the help of the DVR. Similar to the case of voltage sag, the DVR reacts quickly to inject the appropriate voltage component anti phase with the supply voltage or negative voltage magnitude)to correct the supply voltage.

The performance of the DVR with an Unbalanced voltage swell is shown in Figure .

In this case, the unbalanced voltage swell is created by partly rejecting the load. This results in an unbalanced voltages.



5.2.1Simulation result response to dvr for voltage balanced swell

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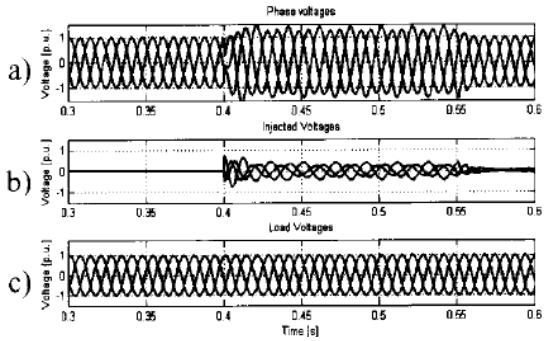

5.2.2 Simulation result response to dvr for voltage unbalanced swell

6. CONCLUSION

In this paper, performance of a DVR in mitigating voltage sags/swells is demonstrated with the help of MATLAB. The DVR handles both balanced and unbalanced Situations without any difficulties and injects the appropriate voltage component to correct any anomaly in the supply voltage to keep the load voltage balanced and constant at the nominal value. In the case of a voltage sag, which is a condition of a temporary reduction in supply voltage, the DVR injects an equal positive voltage component in all three phases which are in phase with the supply voltage to correct it. On the other hand, for a voltage swell case, which is a condition of a temporary increase in supply voltage, the DVR injects an equal negative voltage in all three phases which are anti-phase with the supply voltage. For unbalanced conditions, the DVR injects an appropriate unbalanced three-phase voltage component positive or negative depending on whether the condition is an unbalanced voltage sag or unbalanced voltages well.

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