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Implementation of Dynamic Voltage Restorer in Distribution System

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Abstract: ***Power quality is one of the major concerns in the era of power system. Power quality problem occurred due to non- standard voltage, current or frequency, that result in a failure of end user equipment. To overcome this problem, Dynamic Voltage Restorer (DVR) is used, which eliminate voltage sag, swell and during fault in the distribution line, it is efficient and effective power electronic device. The size of DVR is small, cost is low and fast dynamic response to the disturbance. By injecting an appropriate voltage, the DVR restores a voltage waveform and ensures constant load voltage. The compensating signals are determined dynamically based on the difference between desired and measured values. The DVR is consisting of VSC, Booster transformer, Filter and Energy storage devices. This paper used for compensate the voltage sag, voltage swell and during three phase fault of the distribution line.***

Keywords: Dynamic Voltage Restorer, Voltage source inverter, PI controller.

1. Introduction

Modern power system is complex power network, where hundreds of generating loads and thousands of loads are interconnected through transmission or distribution networks. The main concern to the customer is to provide reliable and quality of power supply. But in develop country, the generation of power supply is fairly reliable, quality of power may poor. The ideal power supply system provides their customer uninterrupted flow of energy with smooth sinusoidal voltage at contracted voltage magnitude and frequency[1]. The power quality problem occurred due to the voltage sag, surge, flicker, voltage imbalance, interruption and harmonic problem. And it may cause problem to the industries from malfunctioning of equipment to the complete shutdown of the plant. Voltage sag/swell occurs as a result of load switching, motor starting, faults, non-linear loads, Lightning etc. It has major impact on microprocessor based loads as well as the sensitive loads.

A new control strategy has been developed for achieving maximum benefits by eliminating or mitigating voltage sag / swell and power quality problem when abnormal condition occur in the distribution system, for this purpose the dynamic voltage restorer is proposed to improve the power quality and to reduce the sag and swell and during fault problem in the system, all objectives can be accomplished either individually or simultaneously.

The DVR could be utilized as:

- Power converter to inject power at the time of fault in the system from DC source to the Grid.
- Compensating voltage unbalance, sags, and load reactive power demand.
- A supplier of the voltage at the time of heavily loaded conditions (with permissible limit).
- When system is lightly loaded, DVR can store the power or capacitor can be charges through it, which is utilize at the time of abnormal condition.

As a very less cost effective device for improving the quality of power in distribution system comparatively other methods

1.1 Objectives of thesis

The various objectives formulated and positioned for observation in the thesis are:

1) To study and analyze the complete distribution system and their problem.
2) To develop a mathematical model of various components DVR System, Voltage Sag, Three-Phase Inverter with Output.
3) To examine and analysis proposed model with and without Dynamic Voltage Restorer (DVR) system using MATLAB / SIMULINK.
4) To study the condition of developed DVR system for different case like voltage sag, swell, during fault and clearing fault.

1.2 Custom Power Device

A safe, reliable and clean power supply to industries is a pre-requisite for their profitable operation and industrial activities. The concept of custom power supply has been proposed using advanced power electronics equipment to ensure a high quality of power supply and which could better mitigate the problems associated with power quality. Custom power technology is a general term for the equipments which are capable to mitigate numerous power quality problems including voltage sags[2]. The basic three customer power applications are as follows:

- Switching the load to another supply
- Injected missing voltage from an energy storage
- Injected missing voltage by increasing the line current (booster)

Basic functions of customer power applications are fast switching and current or voltage injection for correcting anomalies in supply voltage or load current. Injecting or absorbing both active and reactive power is possible in these

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applications. Current injection is typically used for protecting the power system from a polluting load.

Dynamic Voltage Restorer, with its excellent dynamic capabilities, when installed between the supply and a critical load feeder, can compensate for voltage sags, restoring line voltage to its nominal value within a few milliseconds and hence avoiding any power disruption to that load. This device employs solid-state power electronic switches in a pulse-width modulated (PWM) inverter structure[3].

The DVR functions by injecting three single phase AC voltages in series with the three phase incoming network voltages during a dip, compensating the difference between faulty and nominal voltages. All three phases of the injected voltages are of controllable amplitude and phase. Voltage source inverter fed from the DC link supply the required active and reactive power.

1.3 Propitious choice of DVR

There are numerous reasons why DVR is preferred over other devices:

1) Although, SVC predominates the DVR but the latter is still preferred because the SVC has no ability to control active power flow.
2) DVR is less expensive compared to the UPS.
3) UPS also needs high level of maintenance because it has problem of battery leak and have to be replace as often as five years.
4) DVR has a relatively higher energy capacity and costs less compared to SMES device.
5) DVR is smaller in size and costs less compared to DSTATCOM
6) DVR is power efficient device compared to the UPS.

2. Design and Operation of DVR

Power circuit and the control circuit are the 2 main parts of the DVR. There are various critical parameters of control signals such as magnitude, phase shift, frequency etc. which are injected by DVR.

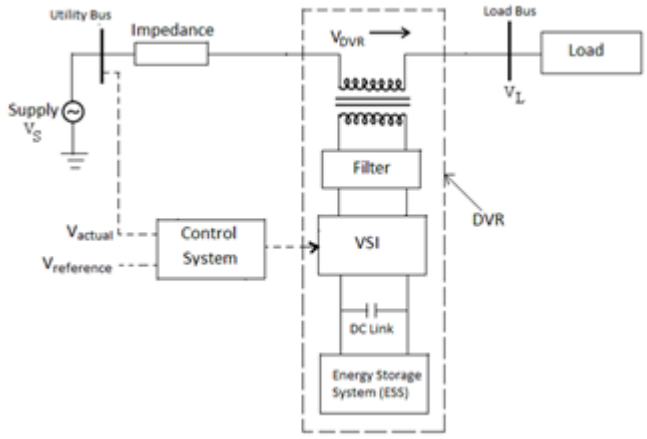


Figure 1: Basic Configuration of DVR

These parameters are derived by the control circuit. This injected voltage is generated by the switches in the power circuit based on the control signals. Furthermore the basic structure of DVR is described by the power circuit and is discussed in this section. The 5 main important parts of power circuit, their function and requirements are discussed ahead.

2.1 DVR components

A typical DVR consist of the following major components.

- Voltage Source Inverter/s (VSI)
- Injection Transformer/s
- Harmonic Filter
- Energy Storage Unit
- Control and Protection System

Voltage Source Inverter

Generally Pulse-Width Modulated Voltage Source Inverter (PWMVSI) is used. In the previous section we saw that an energy storage device generates a DC voltage. To convert this DC voltage into an AC voltage a Voltage Source Inverter is used. In order to boost the magnitude of voltage during sag, in DVR power circuit a step up voltage injection transformer is used. Thus a VSI with a low voltage rating is sufficient.

Voltage Injection Transformers

The injected voltages are introduced into the distribution system through an injection transformer connected in series with the distribution feeder. The primary side of the injection transformer is connected in series to the distribution line, while the secondary side is connected to the DVR power circuit[4][5]. Now 3 single phase transformers or 1 three phase transformer can be used for 3 phase DVR whereas 1 single phase transformer can be used for 1 phase DVR. The type of connection used for 3 phase DVR if 3 single phase transformers are used is called “Delta-Delta” type connection. If a winding is missing on primary and secondary side then such a connection is called “Open-Delta” connection which is as widely used in DVR systems. In order to carefully select a suitable injection transformer the following issues should carefully be addressed.

Harmonic Filters

To convert the PWM inverted pulse waveform into a sinusoidal waveform, low pass passive filters are used. In order to achieve this it is necessary to eliminate the higher order harmonic components during DC to AC conversion in Voltage Source Inverter which will also distort the compensated output voltage. These filters which play a vital role can be placed either on high voltage side i.e. load side or on low voltage side i.e. inverter side of the injection transformers. We can avoid higher order harmonics from passing through the voltage transformer by placing the filters in the inverter side. Thus it also reduces the stress on the injection transformer. One of the problems which arise when placing the that there might be a phase shift and voltage drop in the inverted output. So this could be resolved by placing the filter in the load side. But this would allow higher order harmonic currents to penetrate to the secondary side of the transformer, so transformer with higher rating is essential.

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Energy Storage Unit

Various devices such as Flywheels, Lead acid batteries, Superconducting Magnetic energy storage (SMES) and Super-Capacitors can be used as energy storage devices. The main function of these energy storage units is to provide the desired real power during voltage sag. The amount of active power generated by the energy storage device is a key factor, as it decides the compensation ability of DVR. Among all others, lead batteries are popular because of their high response during charging and discharging. But the discharge rate is dependent on the chemical reaction rate of the battery so that the available energy inside the battery is determined by its discharge rate.

Protection and Short Circuit Operation of DVR

The protection and short circuit operation of DVR is implemented by properly switching the semiconductors of the VSIs. By this way additional thyristor needed during short circuit operation are eliminated. Since DVR is rated to compensate for 50% voltage sags, the current rating of the semiconductor switches must be enough to handle full load current which makes them suitable for continuous operation during non-sag condition.

2.2 Basic DVR Operating principles

The DVR functions by injecting three single phase AC voltages in series with the three phase incoming network voltages during sag, compensating for the difference between faulty and nominal voltages. All three phases of the injected voltages are of controllable amplitude and phase. Three pulse-width modulated (PWM) voltage source inverters (VSI) fed from a DC link supply the active and reactive power. During undisturbed power supply condition, the DVR operates in a low loss standby mode. In the normal operation mode (no sag) the low voltage side of the booster transformer is shorted either by solid state bypass switch or by switching one of the inverter legs and it functions as a short-circuited current transformer. Since no VSI switching takes place, the DVR produces conduction losses only. These losses should be kept as low as possible so as not to cause steady state power loss.

Harmonics produced by the operation of VSI must be reduced to an acceptable limit defined by proper filtering scheme. Modulation scheme used on the VSI switches has also impact on the harmonics produced. The required energy during sags has to be supplied by an energy source. The necessary amount of energy that must be delivered by the energy source depends on load MVA requirement, control strategy applied, deepest sag to be protected. Under normal conditions, the short circuit impedance of the injection transformer determines the voltage drop across the DVR. This impedance must be low and has an impact on the fault current through the VSI on secondary side caused by a short-circuit at load side. The filter design is also affected by the impedance of the injection transformer. In case of fault or over current exceeding the rating of DVR on the load side, solid state bypass switches or electromechanical bypass switches must be added as a measure to protect DVR from getting damaged.

Control of dvr

The control of a DVR is not straight forward because of the requirements of fast response, large variation in the type of sags to be compensated and variation in the type of connected load. The DVR must also be able to distinguish between background power problems and the voltage sags to be compensated. Sags are often non symmetrical and accompanied by a phase jump. The possibility of compensation of voltage sags can be limited by a number of factors including finite DVR power rating, different load conditions, background power quality problems and different type of sags. If the DVR should be a successful device, the control may be able to handle most sags and the performance must be maximized according to the equipment inserted. Otherwise, the DVR may not be able to avoid load tripping and even cause additional disturbance to load.

A control strategy for voltage sags with phase jump should be included, to be able to compensate this particular type of sag. The control strategy can depend on the type of the load connected. Some loads are very sensitive to phase jump and the load should be protected from them. Other types of loads are more tolerant to phase jump and the main task is to maintain the nominal voltage on all three phases.

2.3 Dynamic voltage restorer system with PI controller

Voltage sag is created at load terminals via a fault. Load voltage is sensed and passed through a sequence analyser. The degree is evaluated with position voltage (Vref).

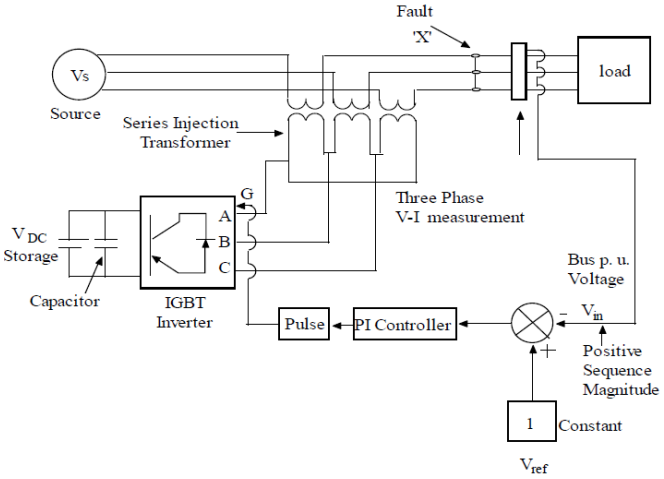


Figure 2: Circuit model of DVR

A dynamic voltage restorer (DVR) is a custom power device used to correct the voltage sag by injecting voltage as well power in to the system. The mitigation capacity of DVR is generally influenced by the maximum load; power factor and maximum voltage dip to be compensated. The DVR is to transfer the voltage which is required for the compensation from DC side of the inverter to the injected transformer after filter. Therefore, there is a maximum voltage required below which the inverter of the DVR cannot generate the required voltage thus size and rating of capacitor is very important for DVR power circuit. The DC capacitor charge in support of a three phase scheme can be consequential. The advantage of these capacitors is the potential to supply high current pulses repetitively for hundreds of thousands of cycles. Assortment

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of capacitor ranking is conferred on the fundamental of RMS charge of a capacitor current, rated electrical energy of a capacitor in addition to VA evaluation of the capacitor.

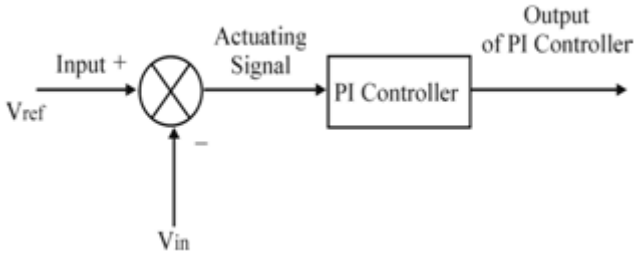


Figure 3: Schematic of a typical PI controller

A controller is used for proper operation of DVR system. DVR detects the presence of voltage sags and operates to mitigate the voltage dip. Pulse Width Modulation (PWM) control technique is applied for inverter switching so as to generate a three phase 50 Hz sinusoidal voltages at the load terminals. The magnitude of load voltage is compared with reference voltage and if any difference is there error signal will be generated. This error signal is the actuating signal which drives the PI controller and the final output signal which is obtained controls the pulses for the Inverter. PI controller is a feedback controller which controls the system depending on the error signal. In PI controller technique the proportional response can be obtained by multiplying the error with constant Kp (proportional gain). The integral response is proportional to both the magnitude of error and duration of error.

In this study, the dq0 transformation or the Park's transformation is used for voltage calculation where the three phase stationary co-ordinate system is converted to the dq rotating quantity. The dq0 transformation technique is used to give the information of the depth (d) and phase shift (q) of voltage sag with start and end time.

After conversion of the three phase voltage V a, V b and V c into two constant voltages V d and V q the three phase system is simplified for voltage calculations. And the system can be easily controlled. The input of the DVR controller is taken from the output voltage measured by three-phase V-I measurement at load. This load voltage is then transformed into the dq term. Then if there is any voltage sag then the error signal is generated from the difference between the dq voltage and the reference voltage. The d reference is set to the rated voltage while the q reference is always set to zero. The gains such as K p and Ki control the stability of the system. The output obtained from the PI controller is then again transformed back to Vabc before it is forwarded to the PWM generator. The PWM generator will generate 6 pulses to trigger the PWM inverter.

3. DVR Test Model

Using MATLAB, the model of DVR is established, and the simulation tests are performed to evaluate the system performance. A fault is given for a period of 0.3-0.7s. At 0.4s the circuit breaker gets opened and closes on 0.8s. Without using DVR, from it is clear that, when a fault is applied voltage gets reduced. With DVR when the circuit breaker gets opened, DVR is automatically connected and injects appropriate voltage in proportion to the reduction in voltage and hence get compensated.

System Parameters:
Source Voltage – 11kv
Transformer – 11kv/ 415 V
Frequency – 50 Hz
Converter – IGBT (3arm- 6Pulse)
Sample time- 1sec
$K_p = 5$
$k_i = 10$
Load – RL
Resistance-10 ohm
Inductance – 40e-4 Henry
Load terminal voltage- 587 V

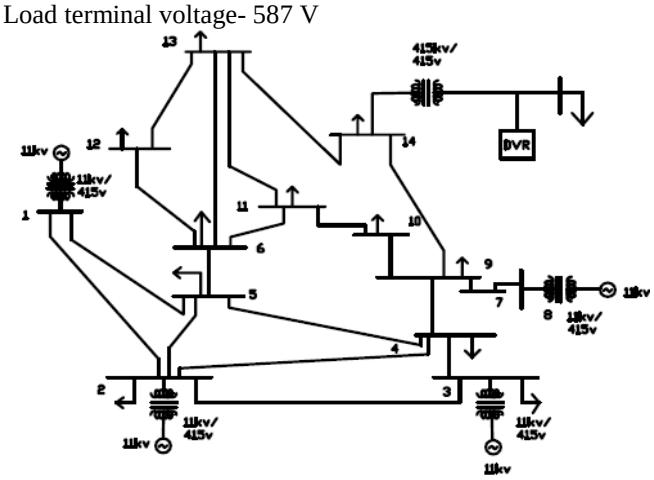


Figure 4: IEEE 14 bus system with DVR

In this section the various results obtained after simulation are analysed and discussed. The simulink test model of DVR. The test system comprises of 11KV distribution network and the system has been examined under different fault conditions such as three phase to ground fault and line to line fault. A systematic presentation of the simulation results for the developed Dynamic Voltage Restorer system connected to the distribution system is presented for both the with and without DVR system conditions. Several different conditions i.e. voltage rise, voltage dip, during fault. simulation result are presented to validate the developed models and control for the proposed DVR system.

3.1 Simulation results

- Voltage sag – 0.3 to 0.7
- Voltage swell – 0.3 to 0.7
- During three phase fault – 0.3 to 0.35
- Voltage sag

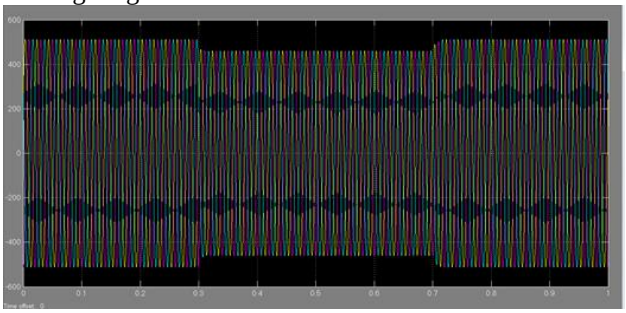


Figure 5a: Load voltage without DVR – Sag

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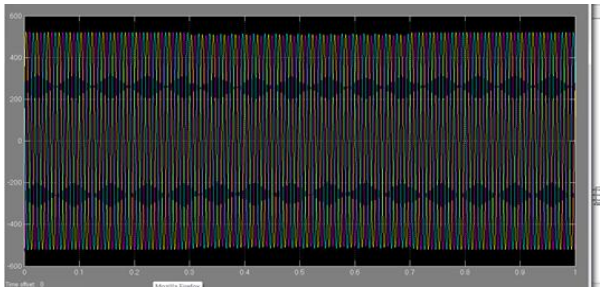


Figure 5b: Compensated voltage with DVR

- Voltage swell

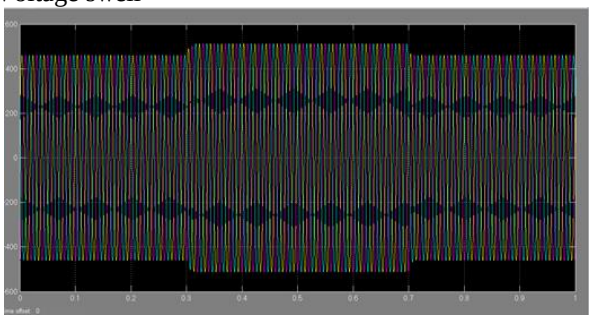


Figure 6a: Load terminal voltage without DVR - Swell

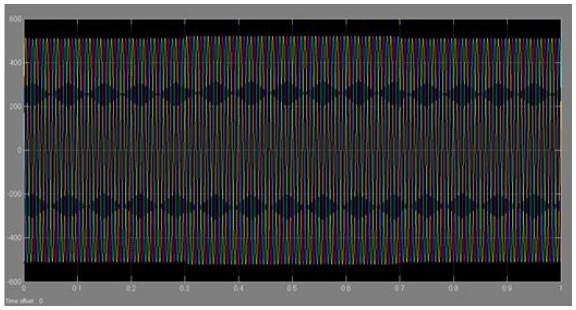


Figure 6b: Compensated voltage with DVR

- During fault

A fault is given for a period of 0.3-0.35s. At 0.4s the circuit breaker gets opened and closes on 0.36s. Without using DVR, from it is clear that, when a fault is applied voltage gets reduced. With DVR when the circuit breaker gets opened, DVR is automatically connected and injects appropriate voltage in proportion to the reduction in voltage and hence get compensated.

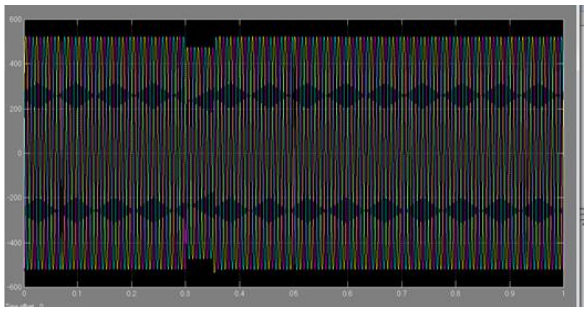


Figure 7a: During fault

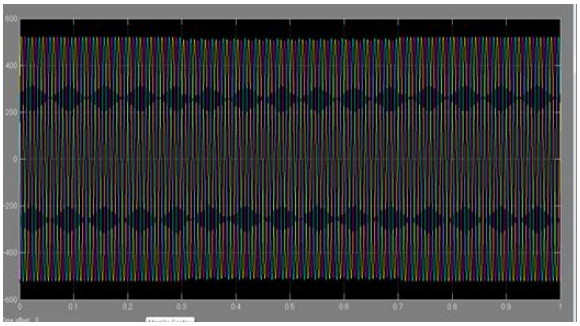


Figure7b: Fault cleared with DVR

4. Conclusion

This paper represents simulation of DVR in MATLAB. In order to show the performance of DVR in mitigation of voltage sags, s simple distribution network is simulated using MATLAB. A DVR is connected to a system through a series transformer with a capability to insert a maximum voltage of 50% of phase to ground system voltage. In-phase compensation method is used. DVR injects the appropriate voltage component to correct rapidly any deviation in the supply voltage to keep the load voltage constant at the nominal value and handles both balanced and unbalanced situations without any difficulties. The main advantages of the proposed DVR are simple control, fast response and low cost. The proposed PWM control scheme using PI controller is efficient in providing the voltage sag compensation. As opposed to fundamental frequency switching schemes already available in the MATLAB/SIMULINK, this PWM control scheme only requires voltage measurements. This characteristic makes it ideally suitable for low-voltage custom power applications. The main shortcoming of the DVR, being a series device, is its inability to mitigate complete interruptions.

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