Mitigation of Single-Phase to Ground Fault Using Dynamic Voltage Restorer for Distribution System

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Abstract – Power quality is one of the major concerns in the present era. It has become important especially with the introduction of sophisticated devices, whose performance is very sensitive to the quality of power supply. Power quality problem is an occurrence manifested as a non standard voltage, current or frequency that results in failure of end use equipments. To solve this problem, custom power devices are used. Out of the several devices, Dynamic Voltage Restorer (DVR) is the most efficient and effective modern custom power device used in power distribution networks. It appeal includes lower cost, smaller size and its fast dynamic response to the disturbance. This paper presents modeling, analysis and simulation of dynamic voltage restorers (DVR) using MATLAB. Simulation shows that mitigation of single-phase to ground fault for distribution system.

Keywords– Dynamic Voltage Restorer (DVR), Voltage Source Inverter (VSI), Voltage Sags, Voltage Swells, Sensitive Load, Injection Transformer, Power Quality.

I. INTRODUCTION

DUE to increase use of large number of sophisticated electrical and electronic equipment, such as computers, programmable logic controllers, variable speed drives and so forth proliferation of highly sensitive end user device is starting to draw attention of both end user customers and suppliers to the question of power quality. Faults on either the transmission or distribution level may cause voltage sag/swell in entire system or a large part of it.

Voltage magnitude, waveform, and frequency are the major factors that dictate the quality of power supply. Voltage sag can occur at any instant of time, with amplitude ranging from 10-90% and a duration lasting for half a cycle to one minute (IEEE std. 1159-1995). Further they could be either balanced or unbalanced, depending upon the type of fault and they could have unpredicted magnitudes such as distance from the fault and the transformer connections. Voltage swell on the other hand is defined as a sudden increase in supply voltage up to 110% to 180% in r.m.s voltage at the network fundamental frequency with duration from half a cycle to one minute (IEEE std 1159-1995). However voltage swells are not as important as voltage sags because they are less common in distribution system.

The power electronic solution to the voltage regulation is the use of dynamic voltage restorer(DVR). DVRs are a class of custom power devices for providing reliable distribution power quality. They employ a series of voltage boost technology using solid state switches for compensating voltage sag/swells [1]. Out of the many custom devices like Active Power Filters (APF), Battery Energy Storage System (BESS), Distribution Series Capacitors (DSC), Surge Arrestor (SA), Superconducting Magnetic Energy System (SMES), Static VAR Compensator (SVC), Uninterruptible Power Supplies (UPS), Dynamic Voltage Restorers (DVR) is the most effective one. There are numerous reasons why DVR is preferred over others. A few of the reasons are presented as follows:

- Although, SVC predominates the DVR, but the DVR is still preferred because SVC has no ability to control active power flow.
- DVR costs less as compared to the UPS. It also have requires high level of maintenance because batteries leak and have to be replaced as often as five years.
- Other reasons include that the DVR has a high energy capacity and lower costs compared to SMES device.
- DVR is smaller in size and costs less compared to DSTATCOM.

Based on these reasons, DVR is widely considered as an effective custom power device in mitigating voltage sags [5]. In addition to voltage sags and swell compensation, DVR has an added feature of harmonics and power factor correction.

II. OPERATING PRINCIPLE OF DVR

The DVR is custom power device that is connected in series with distribution systems as shown in Fig.1. The basic function of the DVR is to inject a dynamically controlled voltage $V_{DVR}$ generated by a forced commutated inverter in series to the bus voltage by means of a booster transformer. The momentary amplitudes of the three injected phase voltages are controlled such as to eliminate any detrimental effects of a bus fault to the load voltage $V_L$. This means that any differential voltages caused by transient disturbances in the ac feeder will be compensated by an equivalent voltage generated by the converter and injected on the medium voltage level through the booster transformer.
The DVR has two modes of operation which are: standby mode and boost mode. In standby mode \((V_{DVR} = 0)\), the booster transformer’s low voltage winding is shorted through the converter. No switching of semiconductors occurs in this mode of operation, because the individual converter legs are triggered such as to establish a short-circuit path for the transformer connection. Therefore, only the comparatively low conduction losses of the semiconductors in this current loop contribute to the losses. The DVR will be most of the time in this mode. In boost mode \((V_{DVR} > 0)\), the DVR is injecting a compensation voltage through the booster transformer due to a detection of a supply voltage disturbance \([17]\).

\[
V_{DVR} = V_{load} + Z_{TH} I_{load} V_{TH}
\]

where

- \(V_{TH}\): The system voltage during fault condition
- \(V_{load}\): The desired load voltage magnitude
- \(Z_{TH}\): The load impedance.
- \(I_{load}\): The load current

The load current \(I_L\) is given by,

\[
I_{load} = \frac{P_{load} + jQ_{load}}{V}
\]

When VL is considered as a reference equation can be rewritten as,

\[
V_{DVR} < \alpha = V_{load} < 0 + Z_{TH} I_{load} < (\beta - \theta) - V_{TH} < \delta
\]

Where \(\alpha, \beta,\) and \(\delta\) are angles of \(V_{DVR}, Z_{TH}\) and \(V_{TH}\) respectively and \(\theta\) is Load power angle

\[
\theta = \tan^{-1}\left(\frac{\theta_1}{\theta_2}\right)
\]

The complex power injection of the DVR can be written as,

\[
S_{DVR} = V_{DVR} I_L^* \]

It requires the injection of only reactive power and the DVR itself is capable of generating the reactive power.

### III. CONTROL TECHNIQUE FOR DVR BASED ON dq0 TRANSFORMATION

The dq0 transformation or Park’s transformation is used to control of DVR. The dq0 method gives the sag depth and phase shift information with start and end times. The quantities are expressed as the instantaneous space vectors. Firstly convert the voltage from abc reference frame to d-q-0 reference. For simplicity zero phase sequence components is ignored. Figure 3 illustrates a flow chart of the feed forward dq0 transformation for voltage sags/swells detection. The detection is carried out in each of the three phases.

The control scheme for the proposed system is based on the comparison of a voltage reference and the measured terminal voltage \((V_a, V_b, V_c)\). The voltage sags is detected when the supply drops below 90% of the reference value whereas voltage swells is detected when supply voltage increases up to 25% of the reference value. The error signal is used as a modulation signal that allows generating a commutation pattern for the power switches (IGBT’s) constituting the voltage source converter. The commutation pattern is generated by means of the sinusoidal pulse width modulation technique (SPWM); voltages are controlled through the modulation. The PLL circuit is used to generate a unit sinusoidal wave in phase with mains voltage.
Equation (3.10) defines the transformation from three phase system a, b, c to \(dqo\) stationary frame. In this transformation, phase A is aligned to the d axis that is in quadrature with the q-axis. The \(\theta\) is defined by the angle between phase A to the d-axis [18].

IV. SIMULINK MODEL OF DVR
The DVR uses self-commutating IGBT solid-state power electronic switches to mitigate voltage sags in the system. The voltage controlled three phase full bridge inverters are used to produce compensating voltage. The switching frequency of the inverters is 1080 kHz. Three-phase inverters are connected to the common DC voltage source. The DC voltage source is an external source supplying DC voltage to the inverter for AC voltage generation.

A proposed DVR built in MATLAB/SIMULINK and installed into a simple power system to protect a sensitive load in a distribution system is presented in Fig. 4.1. 11 kV (r.m.s) main feeders is energizing for proposed system. Main feeder is connected with static linear loads. Three sensitive loads are rated at 6 kVA, 2.5 kVA and 4.5 kVA at 98%, 78% and 89% power factor lagging and receive power from the grid at 11 kV. The grid voltage is reduced to 400 V (r.m.s) to allow the utilization of low voltage sensitive load.

There are two numbers of 10 MVA power transformers are used to step-up and step-down of voltage. The ratings of both transformers are 11 kV/120 kV (Star/Delta) and 120 kV/400 V (Delta/Star). The DC link voltage is 250 V. The system runs 50 Hz frequency. The DVR is designed to mitigate single phase to ground fault occurs in power distribution system.

To verify the working of a DVR employed to avoid voltage sags during short-circuit as shown in Fig. 4.12. In simulation model voltage sag created in the distribution system for the duration 0.05s to 0.25s using 1-phase to ground fault with fault resistance is 0.66 ohms and the ground resistance is 0.001 ohms.

The following results are obtained.

Figure 4. Simulink model of DVR.

Figure 5. Load voltage without DVR in case of single phase to ground fault.

Figure 6. Load voltage with DVR in case of single phase to ground fault. Figure 5 and Figure 6 show that the load voltage of the distribution system is compensated by DVR, when single phase to ground fault occurs in power distribution system.

FFT analysis of the voltage waveform at load side of the distribution system with and without DVR illustrates the increment in the level of total harmonic distortion in Fig.7 and Fig.8 respectively.
The THD of the system without DVR is about 0.08% and for the system with DVR, the THD is 0.07%.

V. CONCLUSION

The modeling and simulation of a DVR using MATLAB/SIMULINK has been presented. The simulation shows that the DVR performance is satisfactory in mitigating voltage sags/swells.

The DVR handles both balanced and unbalanced situations without any difficulties and injects the appropriate voltage component to correct rapidly any anomaly in the supply voltage to keep the load voltage balanced and constant at the nominal value[6][7]. From simulation results also show that the DVR compensates the sags quickly and provides excellent voltage regulation.

VI. REFERENCES


