Mitigation of Voltage Sag Using Dynamic Voltage Restorer With PI Controller

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Abstract - *Power quality has been an issue that is becoming progressively pivotal in modern industrial and commercial applications. Particularly the voltage sag and swell are most well-known voltage disturbance. To overcome this problem, Dynamic Voltage Restorer (DVR), which is the most productive and successful modern custom power device used in power distribution networks. In this paper, configuration of DVR is designed based on synchronous reference frame (SRFT) control method, which is capable of compensating power quality issues associated with three phase voltage sags, SLG voltage sag and three phase faults. The proposed DVR is simulated using MATLAB/SIMULINK, to test the performance of the outlined model.*

***Key Words*: Power Quality, DVR, SRFT, VSI, Voltage Sags/Swells.**

1. INTRODUCTION

Power quality and reliability in distribution systems has been attracting an increasing interest in modern times. The advanced manufacturing systems, industrial drives, accurate electronic equipment in present day times, require significant quality and reliability of power supply in distribution systems. Mainly Power quality in terms of Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE1100 defines power quality as "the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment." As appropriate as this description might seem, the limitation of power quality to "sensitive electronic equipment" might be subject to disagreement. Electrical equipment susceptible to power quality or more appropriately to lack of power quality would fall within a seemingly boundless domain. All electrical devices are prone to failure or malfunction when exposed to one or more power quality problems. The electrical device might be an electric motor, a transformer, a generator, a computer, a printer, communication equipment or a household appliance. All of these devices and others react adversely to power quality issues, depending on the severity of problems. A simpler and perhaps more concise definition might states that "Power quality is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy" [1]. This definition embraces two things that we demand from an electrical device are performance and life expectancy.

Power quality problems covers a broad range of phenomena, in which voltage sag/swell, flicker, harmonics distortion, impulse transients and interruptions are predominant. These disturbances are sensible for power quality and that leads to shut down of the plant and loss of manufacturing capacity. Voltage sags/swells can occur more often than any other power quality phenomenon. Subsequently these sags/swells are the most vital power quality issues in the power distribution system [2].

Voltage Sag or Voltage Dip is defined by the IEEE 1159 as the decrease in the rms voltage level to 10%-90% of nominal value, at the power frequency for duration of ½ cycle to one minute [3]. The International Electro-technical Commission (IEC) terminology for voltage sag is dip. The IEC defines voltage dip as a sudden decrease of the voltage at a point in the electrical system, followed by voltage recovery after a short period, from ½ a cycle to a few seconds. Voltage sags are usually associated with system faults but they can also be generated by energization of heavy loads or starting of large motors which can draw 6 to 10 times its full load current during starting. Sag durations are subdivided into three categories, instantaneous, momentary and temporary, all of which coincide with utility device operation times.

Voltage Swell is defined by IEEE 1159 as the increase in the rms voltage level to 110%-180% of nominal value, at the power frequency for duration of ½ cycles to one minute [3]. It is classified as a short duration voltage variation phenomena, which is one of the general categories of power quality problems. The term "momentary overvoltage" is used as a synonym for the term swell. Swells can occur from the temporary voltage rise on the healthy phases during a single line to ground (SLG) fault. Swells can also be caused by switching off a large load or energizing a large capacitor bank and are characterized by their magnitude (rms value) and duration. The severity of a voltage swell is a function of the fault location, system impedance and grounding. As the quality of power is stringently related to the economic

consequences, associated with the equipment and therefore it has to be assessed by considering the customers point of view. So the need for solutions dedicated to single customers with profoundly sensitive loads is vital, since a fast response of voltage regulation is required. Further it needs to synthesize the characteristics of voltage sags/swells both in domestic and industrial distributions. Together the variation in magnitudes, voltage sags/swells can also be accompanied by a change in phase angle. This phenomenon is well known as phase angle jump (i.e. the variation of phase angle before onset and during the voltage sag/swell events and is calculated as a value of complex voltage).

So as to meet all the above difficulties, it needs a device which is equipped for injecting minimum energy to regulate load voltage at its predetermined value. Dynamic Voltage Restorer (DVR) is one of the prominent strategy for compensating the power quality issues associated with voltage sags/swells. DVR can provide a stipulate solution to mitigate voltage sag/swell by establishing the suitable predetermined voltage level required by the loads. It is as of late being used as the top solution for voltage sag/swell mitigation in modern industrial applications.

2. DYNAMIC VOLTAGE RESTORER

In 1999, Woodley N.H. proposed an equipment and a method for dynamic voltage restoration for utility distribution network [8]. This technique uses real power in order to inject the faulted supply voltages and is usually known as the DVR. A typical DVR mainly consists of a voltage source converter (VSC), an injection transformer connected between the AC voltage supply and the sensitive load and a DC energy storage device. Fig. 1. shows the basic DVR topology.
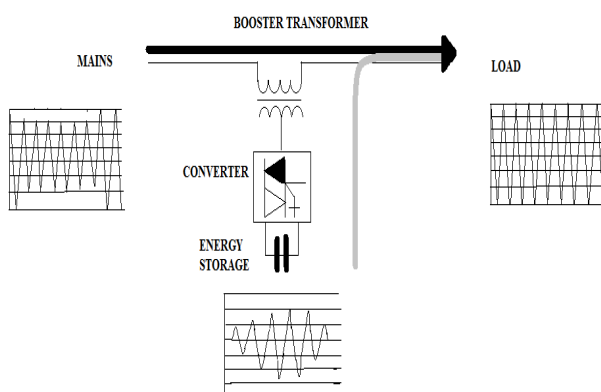

Fig.1. Basic DVR Topology

2.1 Injection Transformer

It isolates the load from rest of the system and couples the injected voltages produced by the voltage source converter to the incoming supply voltage. The transformer winding

ratio is determined according to the voltage prerequisite in its auxiliary side. Normally, winding ratio is kept equal to the supply voltage to permit the DVR to give full voltage sag compensation. The rating of the transformer is a vital factor to determine the performance of a DVR as it restrains the maximum compensation capacity of the DVR.

2.2 Passive Filter

A LC filter is connected at the output of the VSC to filter the harmonics that are present in the output voltage of VSC. It also reduces the dv/dt impact on the windings of the transformer.

2.3 Storage Devices

They satisfy the active requirement of the load. Different systems can be utilized for this reason like flywheel, SMES lead acid batteries and so on.

2.4 Voltage Source Inverter/ Converter (VSI/VSC)

A VSC is utilized to temporarily replace the supply voltage or to produce a part of the supply voltage which is lost during fault condition. The most popular three phase inverter topology is a two level inverter shown in Fig. 2.
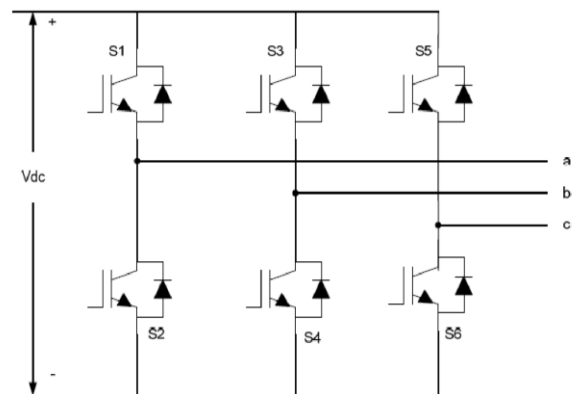

Fig. 2. Two Level Switch Mode Inverter

2.5 DC Charging Set

It performs two main tasks which are as follows, charges the dc source after a sag compensation event and 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.

2.6 Control and Protection Systems

As there exists different operating modes of DVR, so all protective functions of DVR are implemented in combination of hardware and PI controller. The control system determines the voltage that should be injected by the DVR. Transformer can be provided with differential current protection.

3. OPERATION OF DVR

The schematic diagram of DVR is shown in Fig. 3. Three phase source voltages (V_{sa}, V_{sb}, and V_{sc}) are connected to the 3-phase critical load through series impedance (Z_a, Z_b, Z_c) and an injection transformer in each phase. The terminal voltages (V_{ta}, V_{tb}, V_{tc}) have power quality problems and the DVR injects compensating voltages (V_{Ca}, V_{Cb}, V_{Cc}) through an injection transformer to get undistorted and balanced load voltages (V_{La}, V_{Lb}, V_{Lc}). The DVR is implemented using a three leg voltage source inverter with IGBTs along with a dc capacitor (C_{dc}). A ripple filter (L_r, C_r) is used to filter the switching ripple in the injected voltage. The considered load, sensitive to power quality problems is a three-phase balanced lagging power factor load.
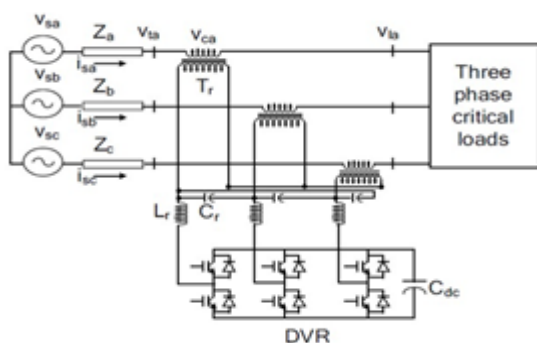
Fig. 3. Schematic Diagram of DVR

Before sag the load voltages and currents are represented as $V_{L(presag)}$ and Isa' as shown in Figure-3(a). After the sag event, the terminal voltage (V_{ta}) is gets lower in magnitude and lags the presag voltage by some angle. The DVR injects a compensating voltage (V_{Ca}) to maintain the load voltage (V_L) at the rated magnitude [11]. V_{Ca} has two components, V_{Cad} and V_{Caq}. The voltage in-phase with the current (V_{Cad}) is required to regulate the dc bus voltage and also to meet the power loss in the VSI of DVR and an injection transformer. The voltage in quadrature with the current (V_{Caq}) is required to regulate the load voltage (V_L) at constant magnitude.
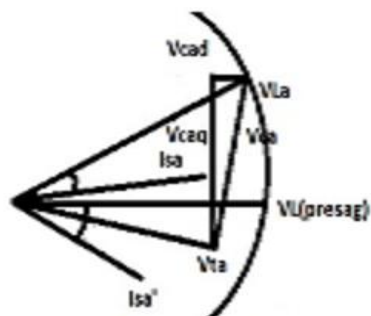

Fig. 4. Phasor Diagram for Voltage Sag

4. CONTROL STRATEGY

The principle contemplations for the control of a DVR are - identification of start and completion of the sag, reference voltage, transient and constant state control of the injected voltage and security of the system. Any control technique implemented to control the DVR should fulfill all the above aspects. The basic idea behind the control methodology is to find the amount by which the supply voltage is dropped. For this the three phase supply voltage is compared with the reference voltage Vref. If there is voltage sag (or any other voltage imbalance) then an error occurs. This error voltage is then sent to the PWM generator, which generates the firing pulses to the switches of the VSC such that obliged voltage is generated [11]. The entire control strategy can be actualized in 2-ϕ rotating (d-q) coordinate system. The flow chart of the control strategy based on dq0 transformation is shown in Fig. 5.
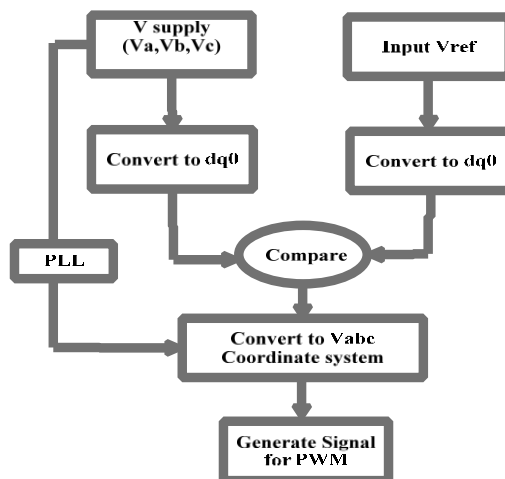

Fig. 5. Flow chart of Control Algorithm for DVR

5. MATLAB MODEL and SIMULATION RESULTS

The MATLAB Simulation model of the test system for DVR is designed using MATLAB R2013a version as shown in Fig. 6. The System is built using Sim Power System Utility tool, which comprises of three phase source of 11 kV, 50 Hz generator with specifying the impedance of the source using short circuit level. This source is feeding transmission lines through a three phase, three-winding transformer connected in Δ/Y/Y, 11000/400/400V. A three phase RL branch is connected in between three phase, three-winding transformer and load. In this test system, two comparative loads with different feeders are considered. One of the feeders is associated with DVR and the other is kept as it is. The one associated with DVR consists of DC voltage source, which acts as storage device to the DVR. The VSC here used consists of IGBT switch, which converters DC to AC and the controller pulse to gate of IGBT is given by discrete 3 phase PWM generator. This VSC isolates load from the system as show in Fig. 6. via three phase transformer. A three phase

circuit breaker is used in between VSC and the harmonic filter. The harmonic filter is used in order to filter the harmonics present in the output of VSC. This test system is analyzed under three phase voltage sag, three phase fault and SLG voltage sag condition.
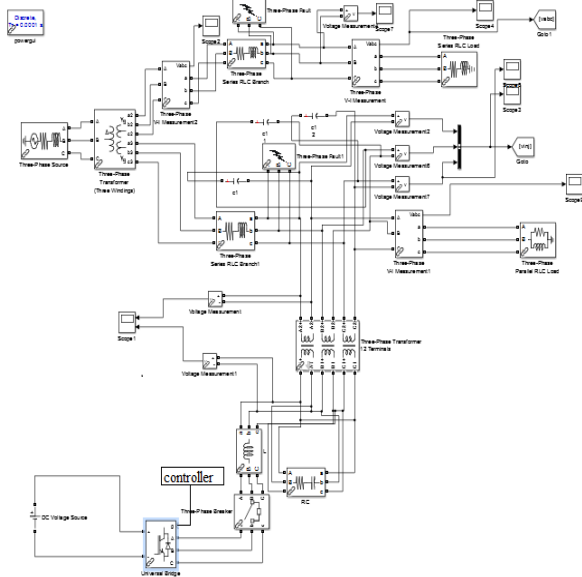
Fig. 6. MATLAB Model

The first simulation is completed without using DVR module and a three phase fault is connected to the system at point with shortcoming resistance of 0.001Ω. So fault is created between a time duration of 0.1s to 0.2s. Fig. 7. demonstrates the load side voltage with three phase fault without DVR, Fig. 8. demonstrates the injecting voltage and Fig. 9. demonstrates the load side voltage with DVR.
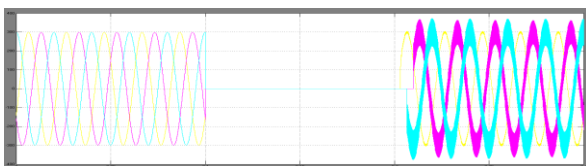
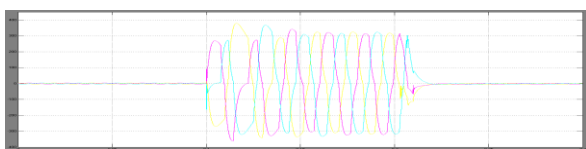Fig. 7. Load side voltage with three phase fault without DVR
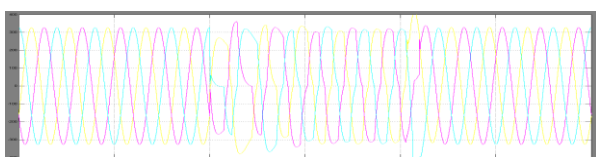

Fig. 8. Injecting three phase voltage

Fig. 9. Load side voltage after mitigating the three phase fault with DVR

The second simulation is completed without using DVR module and a three phase fault is connected to the system at point with shortcoming resistance of 2.6 Ω, which creates a three phase voltage sag between a time duration of 0.1s to 0.2s. Fig. 10. demonstrates the load side voltage with three phase voltage sag without DVR, Fig. 11. demonstrates the injecting voltage and Fig. 12. demonstrates the load side voltage after mitigating the three phase voltage sag with DVR.
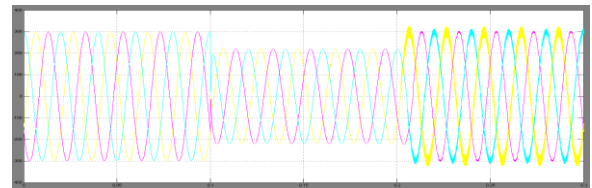

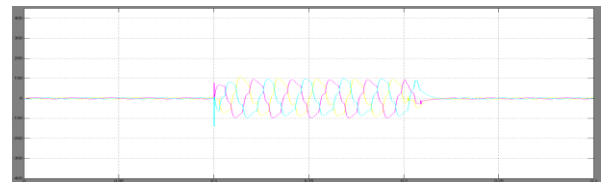Fig. 10. Load side voltage with three phase voltage sag without DVR
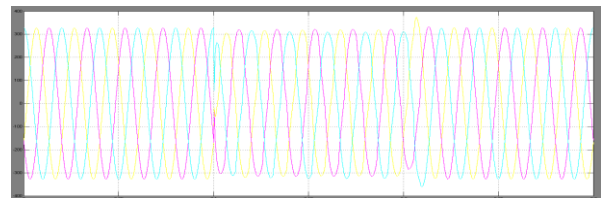

Fig. 11. Injecting three phase voltage

Fig. 12. Load side voltage after mitigating the three phase voltage sag with DVR

The third simulation is carried out without using DVR module and a SLG fault is connected to the system at point with shortcoming resistance of 2.6 Ω, which creates a SLG voltage sag between a time duration of 0.1s to 0.2s. Fig. 13. demonstrates the load side voltage with SLG voltage sag without DVR, Fig. 14. demonstrates the injecting voltage and Fig. 15. demonstrates the load side voltage after mitigating the SLG voltage sag with DVR.
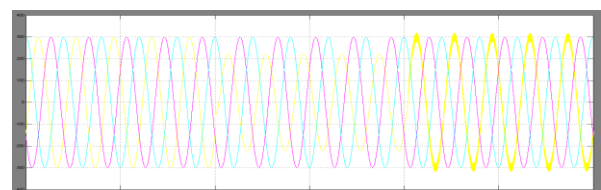

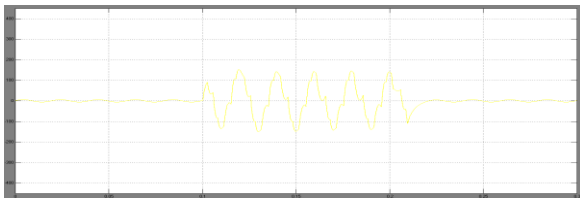Fig. 13. Load side voltage with SLG voltage sag without DVR
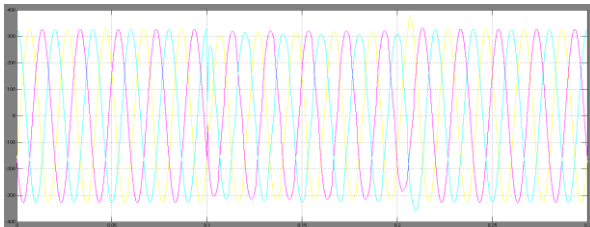
Fig. 14. Injecting SLG voltage

Fig. 15. Load side voltage after mitigating the SLG voltage sag with DVR

6. CONCLUSION

There are many techniques to mitigate the voltage sag. Among them the best way is to use a DVR to regulate the voltage. The control strategy used to control DVR here is PI controller. With the help of PI controller, the designed DVR by connecting to the distribution system is simulated using MATLAB/SIMULINK software. This paper presents the simulation results for three phase voltage sag, three phase fault and SLG voltage sag and performance of DVR using SRFT algorithm is studied. Further this work can be expanded by using adaptive fuzzy controller, SVPWM Technique can be employed with DVR to increase the effectiveness of DVR in distribution networks and also dynamic loads can be considered in future work and then the effect of DVR can be studied.

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