*Impact Factor (SJIF): 4.542*

**International Journal of Advance Research in Engineering, Science & Technology**

*e-ISSN: 2393-9877, p-ISSN: 2394-2444*

***Volume 4, Issue 4, April-2017***

# Comparison of Voltage Sag and Swell Mitigation Using DVR and D-STATCOM

**Arsha S[1], Arya Rajeev[2], Gopika S Nair[3], Renjitha George[4], Sankaran Nampoothiri K[5]**

*[1, 2, 3] UG Student, Department of Electrical and Electronics, Sree Buddha College of Engineering*
*[5]Assistant Professor, Department of Electrical and Electronics, Sree Buddha College of Engineering*

***Abstract —*** ***A wide range of electrical, power electronic and electronic equipments are included in modern power systems. Thus the concern of power engineers over the quality of electrical power has increased recently. The transmission of power from the generating station to the load centers is affected by variations in loads, weather, demands etc. Various power quality issues that could arise during such transmission of power include voltage sags, swells, interruptions, flickers etc. Almost all of these power quality issues will have severe impact on consumer devices which may eventually lead to malfunctions and loss of production. In this paper we present two different methods of mitigating voltage sag and swell using two different custom paper devices – DVR and D-STATCOM. Also a comparison of these two mitigation methods is made in this paper.***

***Keywords- Power Quality, Sag, Swell, DVR, D-STATCOM***

## I. INTRODUCTION

The economy invested in the distribution system is large enough to take into account the concept of equipment protection against various disturbances that affects the reliability of not only the distribution system but the entire power system incorporating generation & transmission too. The wide acceptance of sophisticated electronic devices at the utility end deteriorates the quality of supply & utility is suffering from its bad effects on large scale. Power quality is generally defined as the grid’s ability to supply a stable and lean power throughout. Major power quality issues encountered are voltage sags, swells, flickers, interruptions, harmonics etc.

## II. VOLTAGE SAG AND SWELL

IEEE 1159 defines voltage sag as the decrease in RMS voltage to a level of 0.1 to 0 .9 p.u of nominal value. On the other hand voltage sells are defined to be the short duration increase in RMS voltage to a level of 1.1 to 1.8 p.u. of nominal value. Based on duration sag and swell are classified as instantaneous (½ cycle to 30 cycles), momentary (30 cycles to 3 seconds), and temporary (3 seconds to 1 minute). Voltage sags are caused by abrupt increase in loads such as short circuits or faults, motors starting, or electric heaters turning on, or they are caused by abrupt increases in source impedance, typically caused by a loose connection. Voltage swells are almost always caused by an abrupt reduction in load on a circuit with a poor or damaged voltage regulator, although they can also be caused by a damaged or loose neutral connection.

## III. MITIGATION TECHNIQUES

The mitigation of PQ problems may take place at different levels: transmission, distribution and the end use equipment. Thus, to minimize the occurrence of PQ problems a proper transmission and distribution grid, with adequate planning and maintenance is essential. Primarily custom power devices are used to compensate for the major voltage variations. These devices can be classified into two groups – network reconfiguring type and compensating type. The network reconfiguring type CPDs includes static transfer switch, static current limiter, solid state limiter, whose primary aim is to limit the current in the network. D-STATCOM, DVR and UPQC come under the category of compensating type CPDs which can compensate well for voltage sags and swells. Here we are concentrating our discussion to DVR and D-STATCOM.

### 3.1. Dynamic Voltage Restorer (DVR)

DVR is a static series compensator. It injects voltage in series to the distribution system and regulates the load side voltage. It can be connected in between the supply and the sensitive load to compensate for the line voltage harmonics and reduction of transients in addition to compensation of voltage sags & swells. Figure 1 shows the block diagram of a DVR system.

The main aim of DVR is to regulate the voltage at the load terminals irrespective of sag, distortion or unbalance in the supply voltage. The basic operating principle is that it injects a voltage of required magnitude & frequency to restore the load voltage under voltage sag or distortion and absorbs voltage in case of swells. The basic components of DVR system are a voltage source converter, an injection transformer, DC storage device and a harmonic filter. It employs solid state power electronic switches like GTO, IGBT or IGCT in the voltage source converter, which can be operated with various pulse width modulation techniques

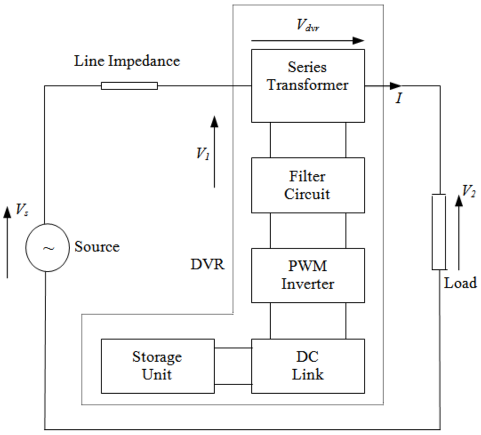


***Figure 1: Block Diagram of DVR***

**3.2. Distribution Static Compensator (D-STATCOM)**

Basically D-STATCOM is a shunt connected solid state device that can be installed at the Distribution level so as to mitigate the load side disturbances. The basic components of D-STATCOM system are same as that of DVR, except that the coupling transformet is connected in shunt with the distribution network. The synchronous machine supplies lagging current when under excited and leading current when over excited. Similarly, DSTATCOM can produce and absorb reactive power depending upon the compensation required i.e. the fundamental working principle of a DSATCOM is same as that of synchronous machine.

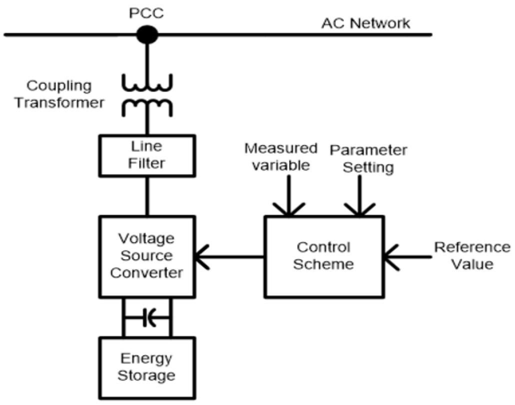


***Figure 2: Block Diagram of D-STATCOM***

## IV. CONTROL STRATEGY

The purpose of control scheme is to generate an appropriate control signal prior to the unbalanced condition prevailing in the system and thereby control the system output. It generates the gate signals to power semiconductor devices of the voltage source inverter.

Here the proportional integral (PI) controller has be employed with both DVR and D-STATCOM systems.

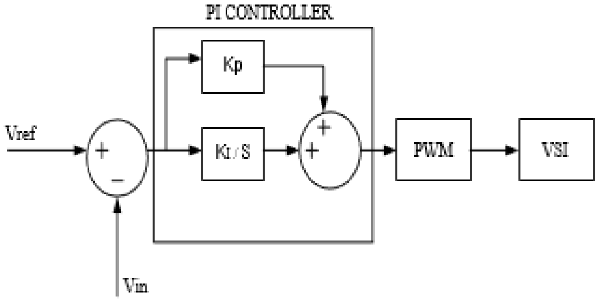


Figure 3: PI Controller

PI is a feedback controller that uses the weighted sum of error & its integral value to perform the control operation. The proportional response can be adjusted by multiplying the error by constant Kp, called proportional gain. The contribution from integral term is proportional to both the magnitude of error and duration of error. The error is first multiplied by the integral gain, Ki and then was integrated to give an accumulated offset that have been corrected previously. The input to the PI controller is difference between the reference value & error value of voltage. As per the comparison of reference value & error value of voltage, linear PI adjusts its proportional & integral gains Kp & Ki in order to reduce the steady state error to zero for a step input.

## V. SIMULATION MODEL

### 5.1. DVR Test System

The test system for DVR is composed by a 13 kV, 50 Hz generation system, feeding two transmission lines through a 3- winding transformer connected in Y/Δ/Δ, 13/115/115 kV. Such transmission lines feed two distribution networks through two transformers connected in Δ/Y, 115/11 kV. The DVR is simulated to be in operation only for the duration of the fault. Simulink model of test system is shown in figure 3.

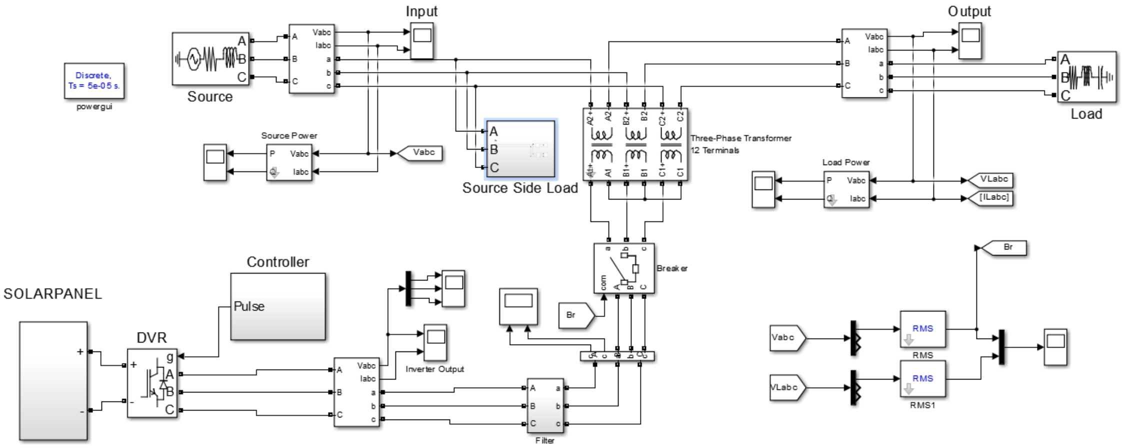


*Figure 3: SIMULINK model of DVR system*

Table 1 gives a brief of the simulation parameters of DVR system.

***Table 1: Simulink parameter for DVR model***

| Sl. No | System Quantities | Standards |
|---|---|---|
| 1 | Source | 3-phase, 208 V, 60 Hz |
| 2 | Inverter Parameters | IGBT based, 3 arms, 6 Pulse |
| 3 | PI Controller | $K_p$ = 0.5, $K_i$ = 0.001 Sample time=50 μsec |
| 4 | LC Filter | Inductance = 10 mH Capacitance = 600 μF |

The first simulation was done with no DVR and a three phase fault is applied to the system at point with fault resistance of 0.1 Ω for time duration of 200 ms. The simulation waveform of this scenario is shown in figure 3.

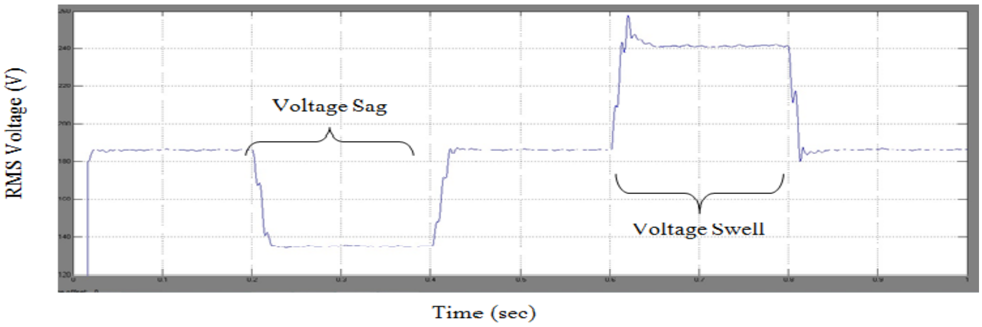


*Figure 4: RMS Voltage at load point, with 3-Ø fault, without DVR*

The second simulation is carried out with the DVR connected by closing all the bypass switches. Sequel to this, the system voltage is restored to its reference level. Figure 5 shows the simulation waveforms in case of introducing DVR into the distribution system.

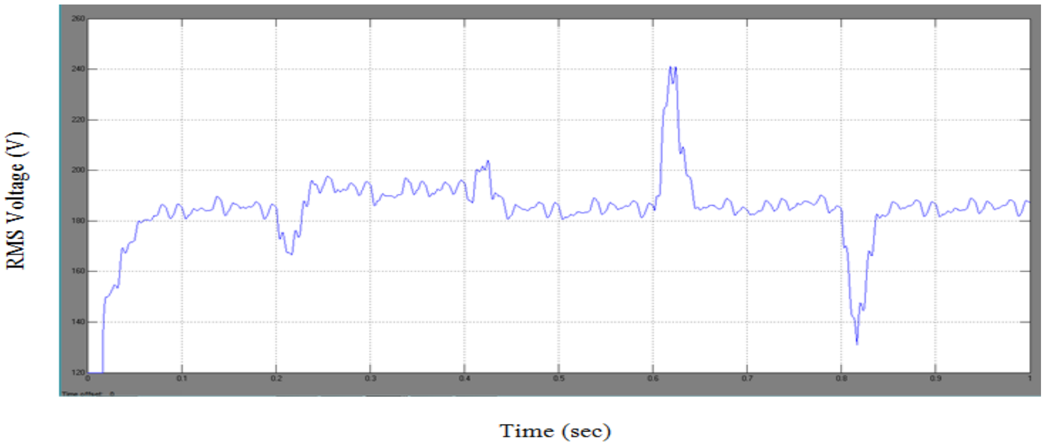


***Figure 5: RMS Voltage at load point, with 3-Ø fault, with DVR***

**5.2. D-STATCOM Test System**

It consist of 2-bus, 11kV distribution system with a balanced three phase fault to create a voltage dip and a sensitive capacitive load for creating a voltage swell. These scenarios could be as a result of short-circuits, energizing capacitor banks or switching-off large sensitive loads (like industrial induction motors) respectively. Subsequently, a 6-pulse D-STATCOM is connected via a 2- winding Y-o coupling transformer to stabilize the voltage. It comprises of an 800ȝF capacitor serving as DC link component, a 5.5kV/11kV coupling transformer and a 6-pulse VSC to provide an instantaneous voltage support at the PCC. Figure 6 shows the simulink model of D-STATCOM test system.

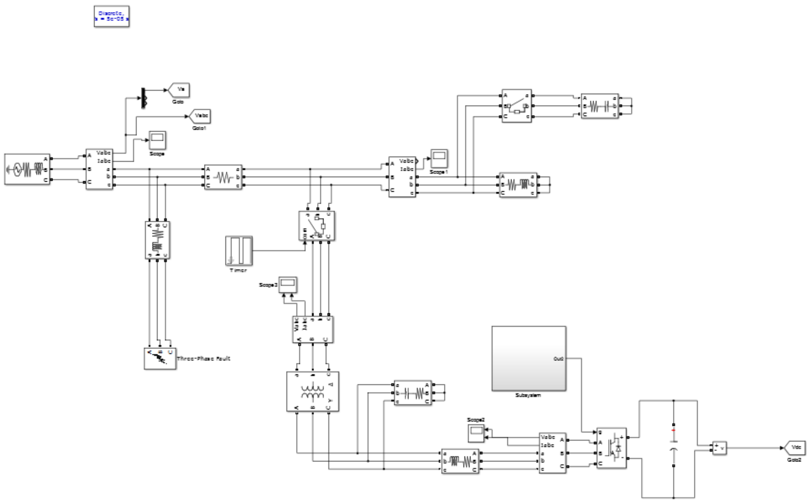

***Figure 6: SIMULINK model of D-STATCOM system***

A balanced three-phase fault was introduced at 0.05 sec which lasted for additional 0.10 sec. This caused the voltage to drop by 21% with respect to the reference voltage magnitude (sag). A capacitive load also introduced at $0.2 \leq ts \leq 0.3$ sec, by closing Switch B. Sequel to this, the voltage increased by almost 14% of the reference (swell).The waveform thus obtained is shown in figure 7.

The subsequent simulation is carried out with the D- STATCOM by closing switch A to ascertain its effectiveness. The voltage has been restored to the nominal voltage level by clearing the sagging and swelling. The voltage waveforms after coupling the D-STATCOM is shown in figure 8.

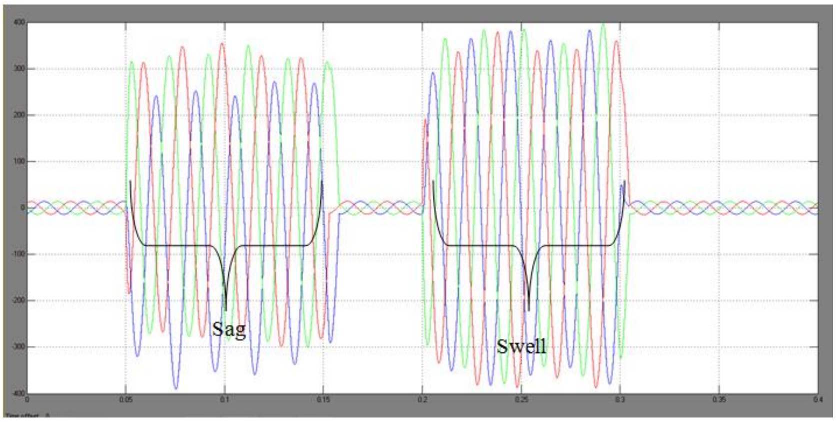


***Figure 7: Variation in current waveform at Load Point before applying the D-STATCOM***

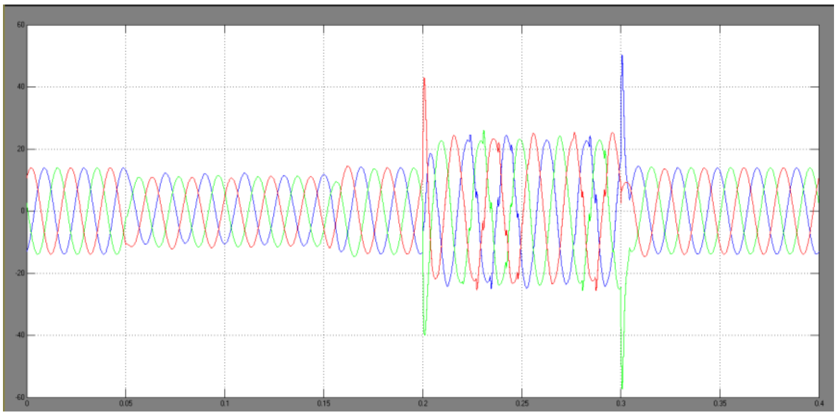

***Figure 8: Variation in current waveform at Load Point after applying the D-STATCOM***

## VI. CONCLUSION

Comparison of D-STATCOM & DVR system in mitigating sags and swells is done by comparing the simulation results i.e. by comparing load voltage and load current waveforms. Simulation is done by using MATLAB SIMULINK software. The controlling of D-STATCOM & DVR is done with the help of PI controller. From the simulation result it is seen that compensated load voltage and load current waveforms by using DVR is much better than the compensated load voltage and load current waveforms by using D-STATCOM. The simulation results clearly showed the more efficient performance of the DVR than D-STATCOM in mitigating the voltage sag and swell due to different faults on distribution systems. DVR has shown the efficiency and effectiveness on voltage and current quality improvement hence it makes DVR to be an interesting power quality improvement device. This has been proved through simulation. the following are the major possible future extensions of this project are as follows. The control circuit used here is PI controller. However this can be changed. The other controllers like fuzzy and adaptive PI fuzzy controller can be employed in the compensation scheme. Also the simulation results can be improved by considering the operation with multi-level inverter.

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