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Mitigation of voltage sag using D-STATCOM for a test system

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During earlier days, due to conventional loads power quality did not cause any problem as there was no effect on majority of the loads connected to the electrical distribution system. But in modern power systems, power quality is certainly a major concern. With the use of sophisticated devices, the performance is very sensitive to the quality of power supply. The most common type of power quality disturbance in the present days are voltage sags and swells. Among various devices proposed for this purpose for mitigation, VSC technology was considered as it has fast responses. This paper is intended to mitigate voltage sag using Distribution Static Compensator (D-STATCOM) for a test system. The simulation is carried out for a 9 bus test system using PSCAD™/EMTDC™ to illustrate the use of D-STATCOM in mitigating the voltage sag in a distribution system.

Keywords: *D-STATCOM, voltage sag, power quality, PSCAD™/EMTDC™*

1.0 INTRODUCTION

The wide-spread applications of Power electronics based equipments are becoming more important at different voltage levels in electric energy systems, because of the advancement in power electronic technology. One of the apparatus is static synchronous compensator (STATCOM) which is generally used in Flexible AC Transmission Systems (FACTS) at transmission level and custom power devices at distribution levels. These are used for voltage regulation, power factor correction, load balancing and harmonic filtering etc.

Voltage sags and swell [1] are one of the various power quality problems in recent days. Different methods have been applied to mitigate voltage sags. The conventional methods are by using capacitor banks, introduction of new parallel feeders and by using uninterruptible power supplies. However, the power quality problems are not solved completely because of uncontrollable reactive power compensation.

The use of STATCOM has become one of the viable solutions to mitigate not only for voltage sag but a host of other power quality issues. The STATCOM has the capability to sustain reactive current at low voltage, minimize land use and can be used as a voltage and frequency support by replacing capacitors with batteries as energy storage.

2.0 POWER QUALITY ISSUES

In modern power systems, power quality is certainly a major concern. With the use of sophisticated devices, the performance is very sensitive to the quality of power supply. Modern industries use sophisticated electronic devices such as PLC's, power electronic devices,

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drives etc. Their controls are very sensitive to disturbances such as voltage sag, swell and harmonics. It is a more concerned problems faced by many utilities and industries. Voltage sag can be defined as an rms reduction in AC voltage at the power frequency, for duration from a half-cycle to a few seconds. Generally, in most of the industries voltage sags are not tolerated by sensitive equipments. Different methods have been applied to mitigate voltage sags. In this paper the D-STATCOM is used to regulate the voltage at the Point of Common Coupling (PCC).

3.0 DISTRIBUTION STATIC COMPENSATOR (D-STATCOM)

When used in low-voltage distribution systems the STATCOM is normally identified as Distribution STATCOM (D-STATCOM) [2-6]. It is a three phase shunt connected device and is connected near the load at the distribution systems. The major components of D-STATCOM are three phase IGBT based inverter, DC capacitor, coupling transformer and a control strategy [8]. It operates in a similar manner as the STATCOM with the active power flow controlled by the angle between the AC system and VSC voltages and the reactive power flow controlled by the difference between the magnitudes of these voltage [12]-[15]. As with the STATCOM, the capacitor acts as the energy storage device and its size is chosen based on the power ratings, control and harmonic considerations. If the output of the VSC is equal to the AC terminal voltage, no reactive power is delivered to the system. If the output voltage is greater than the AC terminal voltage, the D-STATCOM is in the capacitive mode of operation and vice versa. The D-STATCOM controller continuously monitors the load voltages and currents and determines the amount of compensation required by the AC system for a variety of disturbances. It is used to regulate system voltage, improve voltage profile and voltage harmonics. However, the D-STATCOM can also mitigate voltage dips by injecting reactive power to the point of connection with the grid. Normally, pulse width modulation (PWM) [8] is used to control the D-STATCOM converter. The objective of the controller is to ensure that a constant voltage is maintained at the load point where D-STATCOM is connected [7-11].

4.0 TEST CASES

As with many of the references, the system size considered to study the behavior of D-STATCOM is normally small with one source and a load. In this paper, a nine bus test system was considered for the simulation case in which Bus 5 is extended down further to form a distribution network with the assumption of lumped load at Bus 10 which is considered as point of common coupling (PCC). To enhance the performance of the system, D-STATCOM is connected at this bus. The main idea of choosing this system is to see how the reactive power requirement from the network is minimized with the inclusion of D-STATCOM and hence to improve the quality of power supply. The entire system is modeled in PSCAD^{TM}/EMTDC^{TM} version 4.1. The test system considered is shown in Figure 1. System parameters are as given [15] except for T4 (100 MVA, 230 kV / 33 kV, 6.25% reactance) and T5 (100 MVA, 33 kV / 25 kV, 10% reactance). A D-STATCOM is connected to the 25 kV secondary winding to provide instantaneous voltage support at the load point. A 300 μF capacitor on the DC side provides the D-STATCOM energy storage capabilities. Breaker is used to control the period of operation of the D-STATCOM.

The generic control strategy available in PSCAD^{TM}/EMTDC^{TM} library [16] was used in this study which is as shown in Figure 2, in which gain was further fine-tuned. An error signal is obtained by comparing the reference voltage with the rms voltage measured at the load point. The PI controller processes the error signal and generates the required angle δ to drive the error to zero so that the load rms voltage is brought back to the reference voltage [7]-[8].

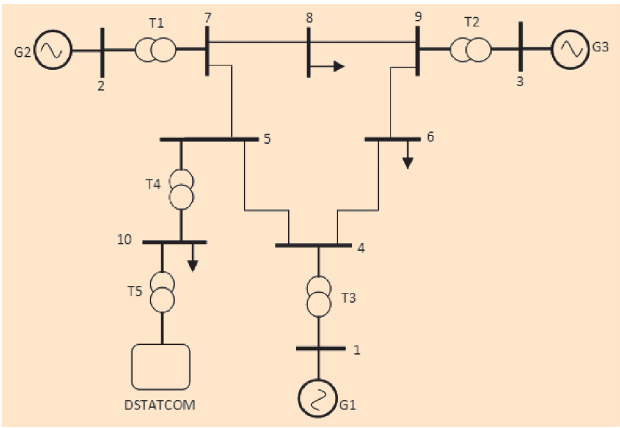

FIG. 1 SINGLE LINE DIAGRAM OF THE SYSTEM WITH D-STATCOM

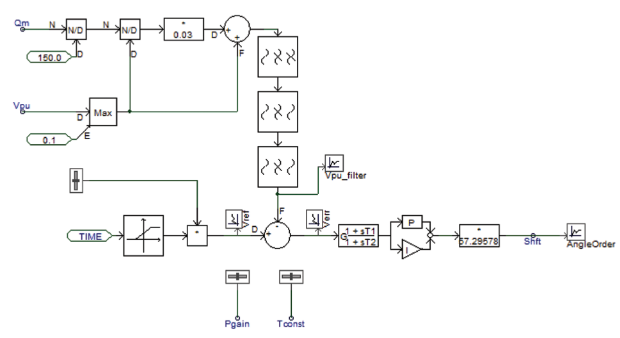

FIG. 2 CONTROL SCHEME FOR D-STATCOM

5.0 SIMULATION RESULTS

A set of simulations were carried out for the test system shown in Figure 1. The simulations pertain to 3 conditions viz,

(i) 3 Phase-to-ground fault at Bus 10, with and without D-STATCOM.

(ii) 2 Phase-to-ground fault at Bus 10, with and without D-STATCOM.

(iii) Single Phase-to-ground fault at Bus 10, with and without D-STATCOM.

5.1 3 Phase-to-Ground fault at Bus 10

5.1.1 Without D-STATCOM

In this case, simulation is carried out by creating a 3 phase-to-ground fault at Bus 10 without D-STATCOM. The ground fault is with a fault impedance to ensure that there is voltage sag phenomenon during the fault duration which is similar to that of a remote fault.

The system is simulated for 3 seconds with a 3 phase-to-ground fault occurring at time 1.5 sec for duration of 0.1 sec. In this case the voltage at Bus 10 is dropped to 15% with respect to the reference voltage.

From Figure 3, it can be seen that due to the fault, voltage sag has occurred. The depth of sag is changed by changing the fault impedance. During the fault when the D-STATCOM is not in the circuit, the bus voltage at BUS 10 is dropped to 0.744 pu and recovers back to 0.896 pu after removal of fault.

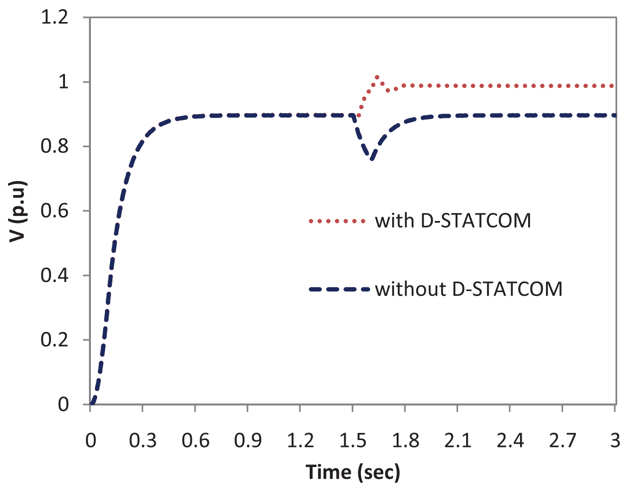

FIG. 3 3PHASE-TO-GROUND FAULT

5.1.2 With D-STATCOM

In this case, simulation is carried out by creating a 3 phase-to-ground fault with D-STATCOM connected at Bus 10. During the simulation, a 3 phase-to-ground fault is applied at Bus 10 at time 1.5 sec for a duration of 0.1 sec. This duration was considered to simulate the voltage sag condition. And at time 1.5 sec D-STATCOM is connected and remains in the system throughout the rest of simulation.

From Figure 3, it is observed that the bus voltage at BUS 10 is 0.99 pu which is close to 1.0 pu. The spikes at the beginning and end of sag are due to capacitor charging and discharging. During the period of voltage sag, D-STATCOM responds well to give the system better fault ride through capability.

Similarly, referring to Figure 4, it is observed that the reactive power generated by generator #1 gets reduced from 68.62 MVAr to 41.9 MVAr and similarly, with other generators as the voltage is improved through D-STATCOM.

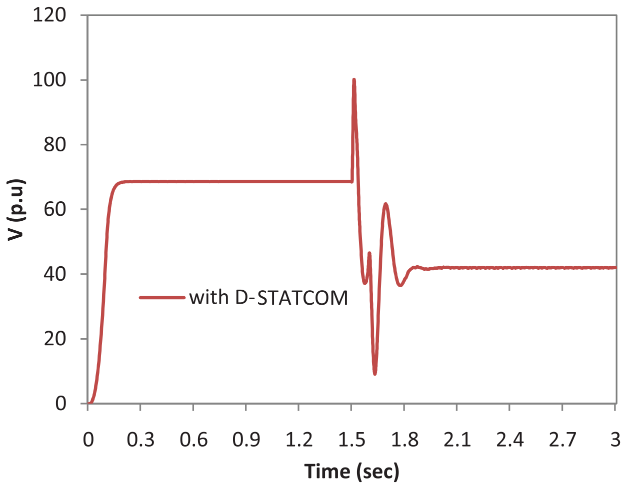

FIG. 4 GEN. #1 REACTIVE POWER

5.2 2 Phase-to-Ground fault at Bus 10

5.2.1 Without D-STATCOM

In this case, simulation is carried out by creating a 2 phase-to-ground fault at Bus 10 without connecting D-STATCOM.

Referring to Figure 5, it is observed that during the fault when the D-STATCOM is not in the circuit, the bus voltage at BUS 10 is dropped to 0.8 pu and recovers back to 0.896 pu after removal of fault.

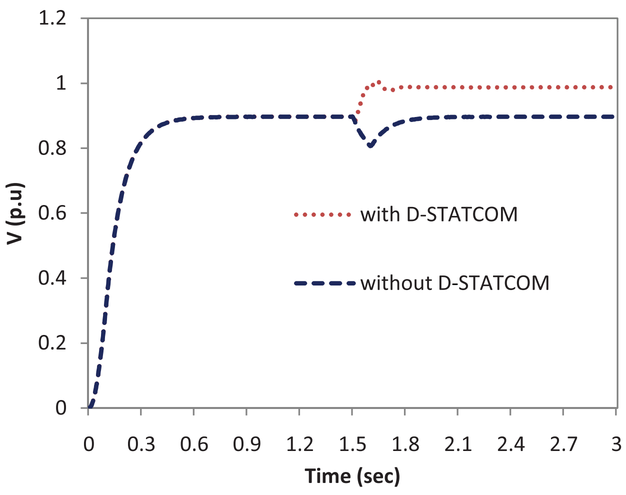

FIG 5. 2 PHASE-TO-GROUND FAULT

5.2.2 With D-STATCOM

In this case, simulation is carried out by creating a 2 phase-to-ground fault and with D-STATCOM connected at Bus 10. Referring to Figure 5, it is observed that the bus voltage at BUS 10 is 0.99 pu which is close to 1.0 pu.

5.3 Single Phase-to-Ground fault at Bus 10

5.3.1 Without D-STATCOM

In this case, simulation is carried out by creating a Single phase-to-ground fault at Bus 10 without connecting D-STATCOM. Referring to Figure 6, it is observed that during the fault when the D-STATCOM is not in the circuit, the bus voltage at BUS 10 is dropped to 0.853 pu and recovers back to 0.896 pu after removal of fault.

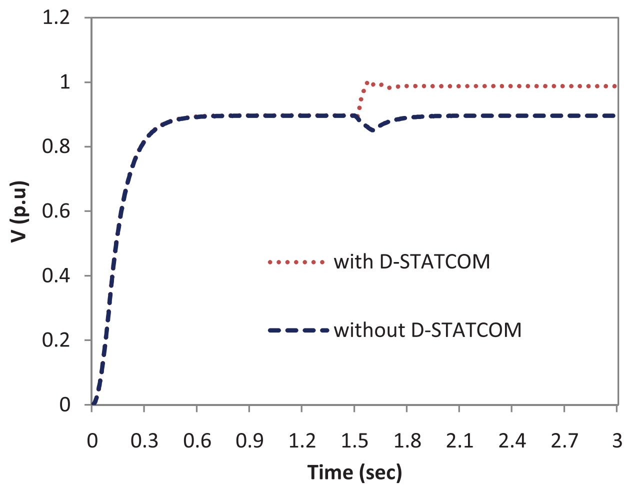

FIG. 6 SINGLE PHASE-TO-GROUND FAULT

5.3.2 With D-STATCOM

In this case, simulation is carried out by creating a Single phase-to-ground fault and with D-STATCOM connected at Bus 10. Referring to Figure 6, it is observed that the bus voltage at BUS 10 is 0.99 pu which is close to 1.0 pu.

6.0 CONCLUSION

In this study modeling and simulation of standard 9 bus system with D-STATCOM and necessary control strategy is implemented. The simulation results showed clearly the performance of the D-STATCOM in mitigating the voltage sag and providing reactive power requirement at Bus 10. The load has been maintained at constant voltage magnitude. Thus it is observed that the voltage magnitude at Bus 10 where D-STATCOM is connected is improved from 0.74 pu to 0.99 pu during the fault condition. This proves that the D-STATCOM works very well in compensating the voltage sag caused by the balanced and unbalanced fault.

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