Voltage Sag Mitigation on Power Distribution System
Using D-Statcom

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Abstract - This paper presents the enhancement of voltage sags, harmonic distortion and low power factor using Distribution Static Compensator (D-STATCOM) with LCL Passive Filter in distribution system. The model is based on the Voltage Source Converter (VSC) principle. The D-STATCOM injects a current into the system to mitigate the voltage sags. LCL Passive Filter was then added to D-STATCOM to improve harmonic distortion and low power factor. The performance of voltage-source converter-based shunt and series compensators used for load voltage control in electrical power distribution systems has been analyzed and compared, when a nonlinear load is connected across the load bus. A distribution static compensator (DSTATCOM) as a shunt device.

Index Terms-- D-STATCOM, Voltage Sags, Voltage Source Converter (VSC), LCL Passive Filter, Total harmonics Distortion (THD).

I. INTRODUCTION

The voltage related power-quality (PQ) problems, such as sags and swells, voltage dips, harmonic distortions due to nonlinear loads and voltage unbalancing in electrical power distribution systems, have been a major concern for the voltage-sensitive loads [1]. Load voltage regulation using VSC for different grid-connected applications has been recently attempted in [2]–[4]. With the increased use of power-electronics devices in the consumer products, the loads are becoming voltage sensitive and nonlinear in nature. Depending upon the applications, these loads are connected to the distribution system having varying voltage and power e. Also the radial feeders of the distribution system to which these loads are connected have varying length and short circuit current (SCC) levels. This depends upon the location of the load, distribution system size, and its voltage and volt-ampere (VA) ratings. This leads to the wide variations in the Thevenin’s equivalent feeder impedance looking from the load side. If the load is connected at the end of the long feeder and has small short-circuit current value, it is called a weak ac supply system (or non-stiff source) [5]. These feeders have significant line impedance depending upon their length and short-circuit current value [6]. Similarly, if the load is connected close to the feeder, it is referred to as strong ac supply system (or stiff source). The line impedance of these feeders is very small or negligible.

An increasing demand for high quality, reliable electrical power and increasing number of distorting loads may leads to an increased awareness of power quality both by customers and utilities. The most common power quality problems today are voltage sags, harmonic distortion and low power factor. Voltage sags is a short time (10 ms to 1 minute) event during which a reduction in r.m.s voltage magnitude occurs [4]. It is often set only by two parameters, depth/magnitude and duration. The voltage sags magnitude is ranged from 10% to 90% of nominal voltage and with duration from half a cycle to 1 min.

Voltage sags is caused by a fault in the utility system, a fault within the customer’s facility or a large increase of the load current, like starting a motor or transformer energizing [2,3].Voltage sags are one of the most occurring power quality problems. For an industry voltage sags occur more often and cause severe problems and economical losses. Utilities often focus on disturbances from end-user equipment as the main power quality problems [5]. Harmonic currents in distribution system can cause harmonic distortion, low power factor and additional losses as well as heating in the electrical equipment. It also can cause vibration and noise in machines and malfunction of the sensitive equipment.
The development of power electronics devices such as Flexible AC Transmission System (FACTS) and customs power devices have introduced and emerging branch of technology providing the power system with versatile new control capabilities [1]. There are different ways to enhance power quality problems in transmission and distribution systems. Among these, the D-STATCOM is one of the most effective devices. A new PWM-based control scheme has been implemented to control the electronic valves in the DSTATCOM.

The D-STATCOM has additional capability to sustain reactive current at low voltage, and can be developed as a voltage and frequency support by replacing capacitors with batteries as energy storage. In this paper, the configuration and design of the DSTATCOM with LCL Passive Filter are analyzed. It is connected in shunt or parallel to the 11 kV test distribution system. It also is design to enhance the power quality such as voltage sags, harmonic distortion and low power factor in distribution system.

II. DISTRIBUTION STATIC COMPENSATOR (D-STATCOM)

A D-STATCOM consists of a two-level VSC, a dc energy storage device, controller and a coupling transformer connected in shunt to the distribution network. Figure 2.1 shows the schematic diagram of D-STATCOM.

\[
I_{out} = I_{L} - I_{L} = \frac{V_{th} - V_{L}}{Z_{th}} (1)
\]

\[
I_{out} < \gamma = I_{L} < (-\theta) - \frac{V_{th}}{Z_{th}} < (\delta - \theta) + \frac{V_{L}}{Z_{th}} < (-\theta) (2)
\]

\[
I_{out} = \text{output current} \quad I_{L} = \text{load current} \\
I_{L} = \text{source current} \quad V_{th} = \text{Thevenin Voltage} \\
V_{L} = \text{load voltage} \quad Z_{th} = \text{impedance}
\]

Referring to the equation 2, output current, I_{out} will correct the voltage sags by adjusting the voltage drop across the system impedance, \((Z_{th} = R+jX)\). It may be mention that the effectiveness of D-STATCOM in correcting voltage sags depends on:

a) The value of Impedance, \(Z_{th} = R+jX\)

b) The fault level of the load bus

A voltage-source converter is a power electronic device that connected in shunt or parallel to the system. It can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. The VSC used to either completely replace the voltage or to inject the ‘missing voltage’. The ‘missing voltage’ is the difference between the nominal voltage and the actual. It also converts the DC voltage across storage devices into a set of three phase AC output voltages [8, 9].

In addition, D-STATCOM is also capable to generate or absorbs reactive power. If the output voltage of the VSC is greater than AC bus terminal voltages, D-STATCOM is said to be in capacitive mode. So, it will compensate the reactive power through AC system and regulates missing voltages. These voltages are in phase and coupled with the AC system through the reactance of coupling transformers. Suitable adjustment of the phase and magnitude of the DSTATCOM output voltages allows effective control of active and reactive power exchanges between D-STATCOM and AC system [9].

B. Controller

Figure 2 shows the block diagram of Controller system.
The controller system is partially part of distribution system. Figure 2. Block Diagram of Controller System

Proportional-integral controller (PI Controller) is a feedback controller which drives the system to be controlled with a weighted sum of the error signal (difference between the output and desired set point) and the integral of that value. In this case, PI controller will process the error signal to zero. The load r.m.s voltage is brought back to the reference voltage by comparing the reference voltage with the r.m.s voltages that had been measured at the load point. It also is used to control the flow of reactive power from the DC capacitor storage circuit.

PWM generator is the device that generates the Sinusoidal PWM waveform or signal. To operate PWM generator, the angle is summed with the phase angle of the balance supply voltages equally at 120 degrees. Therefore, it can produce the desired synchronizing signal that required. PWM generator also received the error signal angle from PI controller. The modulated signal is compared against a triangle signal in order to generate the switching signals for VSC valves.

C. Energy Storage Circuit

DC source is connected in parallel with the DC capacitor.

It carries the input ripple current of the converter and it is the main reactive energy storage element. This DC capacitor could be charged by a battery source or could be recharged by the converter itself.

D. LCL Passive Filter

LCL Passive filter is more effective on reducing harmonic distortion. To design it, equation (3), (4) and (5) are used.

\[ L_s = \frac{E_s}{2 \sqrt{6} i_{p_{rms}}/f_{sw}} \]  
\[ L_c = \frac{L_s}{2} \]  
\[ L_f = \frac{L_s + L_g}{L_s + L_f} \]  

To design an efficient LCL Passive filters make sure that,

\[ 10 f_s \leq s_{res} \leq 0.5 f_{sw} \]

![Figure 3. circuit diagram of DC storage](image)

![Figure 4. circuit diagram for single phase LCL Passive Filter](image)

### TABLE 2.1. LIST AND VALUE OF PARAMETERS USE IN SIMULATION

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Quantity Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( E_s )</td>
<td>RMS value of grid voltage</td>
<td>19kV (rms)</td>
</tr>
<tr>
<td>( i_{p_{rms}} )</td>
<td>13% of peak value fundamental Harmonic current</td>
<td>793.1mA (rms)</td>
</tr>
<tr>
<td>( L_g )</td>
<td>Grid-side filter inductance</td>
<td>1630 mH</td>
</tr>
<tr>
<td>( L_c )</td>
<td>Converter-side filter inductance</td>
<td>815 mH</td>
</tr>
<tr>
<td>( C_f )</td>
<td>Filter capacitance</td>
<td>0.0017 uF</td>
</tr>
<tr>
<td>( R_f )</td>
<td>Resistance of converter-side filter</td>
<td>15 Ω</td>
</tr>
<tr>
<td>( f_{sw} )</td>
<td>Switching frequency</td>
<td>20kHz</td>
</tr>
<tr>
<td>( f_{res} )</td>
<td>Resonance frequency</td>
<td>5.25 kHz</td>
</tr>
</tbody>
</table>

![Figure 5. shows the input current harmonic spectrum with respect to the IEEE STD 519-1992 harmonic limits](image)

III. METHODOLOGY

To enhance the performance of distribution system, DSTATCOM was connected to the distribution system. DSTATCOM was designed using MATLAB simulink. Figure 6 below shows the flowchart for the methodology:
B. Simulink Model for the test system

The test system was design using MATLAB simulink is shown in figure 8 below.

IV. RESULTS AND CONCLUSION

To create distortion in the distribution system, different types of fault such as Three Phase to Ground (TPG), Double Line to Ground (DLG), Line to Line (LL), and Single Line to Ground (SLG) are injected.

Figure 9. Input Line Voltage.

Figure 10. Line Voltage RMSE Response.
V. CONCLUSION

The simulation results show that the voltage sags can be mitigate by inserting D-STATCOM to the distribution system. By adding LCL Passive filter to D-STATCOM, the THD reduced within the IEEE STD 519-1992. The power factors also increase close to unity. Thus, it can be concluded that by adding D-STATCOM with LCL filter the power quality is improved.

VI. REFERENCES


