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Research Article

Enhancement of Voltage Quality using D-STATCOM

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Abstract

This paper presents the mitigation of voltage sags and harmonic distortion using Distribution Static Compensator (D-STATCOM) in existing 11kV/440v distribution system. The D-STATCOM is controlled using decoupled theory using the PI controller. This model is based on voltage source converter (VSC) principle. The D-STATCOM injects a current into the system to improve the voltage profile and also to reduce the harmonic distortion in the system. The simulations are carried out using Matlab/simulink. The results are presented.

Keywords: *Distribution system, voltage sag, D-STATCOM, optimal allocation, total harmonic distortion (THD).*

1. Introduction

Power quality is one of the most important topics that electrical engineers have been noticed in recent years. Voltage sag is one of the problems related to power quality. This phenomenon happens continuously in transmission and distribution systems. During a voltage sag event, amplitude of the effective load voltage decrease from 0.9 of the nominal load voltage to 0.1 in very short time (less than one minute).

Short circuit, transformer energizing, capacitor bank charging etc are causes of voltage sag (H. Nasiraghdam *et al*, 2007).

Various methods have been applied to reduce or mitigate voltage sags. The conventional methods are by using capacitor banks, introduction of new parallel feeders and by installing uninterruptible power supplies (UPS). However, the PQ problems are not solved completely due to uncontrollable reactive power compensation and high costs of new feeders and UPS. The D-STATCOM has emerged as a promising device to provide not only for voltage sag mitigation but also for a host of other power quality solutions such as voltage stabilization, flicker suppression, power factor correction, and harmonic control (G. F. Reed *et al*, 1999). D-STATCOM is a shunt device that generates a balanced three-phase voltage or current with ability to control the magnitude and the phase angle (S. Aizam *et al*, 2006).

Among the vast literature about the D-STATCOM, only a few of them explore its performance when connected to a realistic and complex distribution system.

The aim of this work is to contribute in the assessment of the D-STATCOM performance in realistic distribution system. A 11kV/440V distribution system is considered for analysis. The role of D-STATCOM in voltage sag mitigation has been analyzed through computer simulation in Matlab/Simulink.

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2. Distribution Static Compensator (D-STATCOM)

A D-STATCOM (Distribution Static Compensator), which is schematically depicted in Figure1, consists of a two-level Voltage Source Converter (VSC), a dc energy storage device, a coupling transformer connected in shunt to the distribution network through a coupling transformer. The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages. These voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. Suitable adjustment of the phase and magnitude of the D-STATCOM output voltages allows effective control of active and reactive power exchanges between the D-STATCOM and the ac system. Such configuration allows the device to absorb or generate controllable active and reactive power.

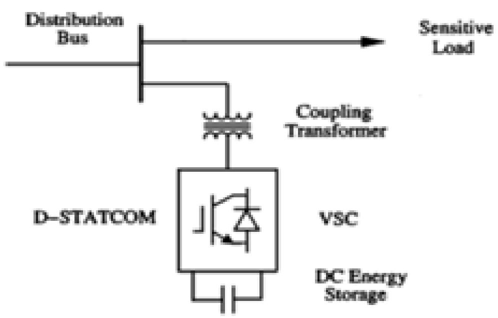


Fig.1 Schematic representation of D-STATCOM as a custom power controller

The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes:

1. Voltage regulation;
2. Compensation of reactive power; and
3. Elimination of current harmonics.

Here, such device is employed to provide continuous voltage regulation using an indirectly controlled converter.

2.1 Voltage Source Converter (VSC)

A voltage source converter is a power electronic device that is 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.

In addition, D-STATCOM is also capable to generate or absorb reactive power. If the output voltage of the VSC is greater than AC bus terminal voltages then 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 D-STATCOM output voltages allows effectives control of active and reactive power exchanges between D-STATCOM and AC system. In addition, the converter is normally based on some kind of energy storage which will supply the converter with a DC voltage.

2.2 Voltage Controller

This section describes the PWM-based control scheme for the D-STATCOM. The aim of the control scheme is to maintain constant voltage magnitude at the point where a sensitive load is connected, under system disturbances. The voltage controller analyzed in this work is exhibited in the figure below, which employs the dq0 rotating reference frames because it offers higher accuracy than stationary frame based techniques.

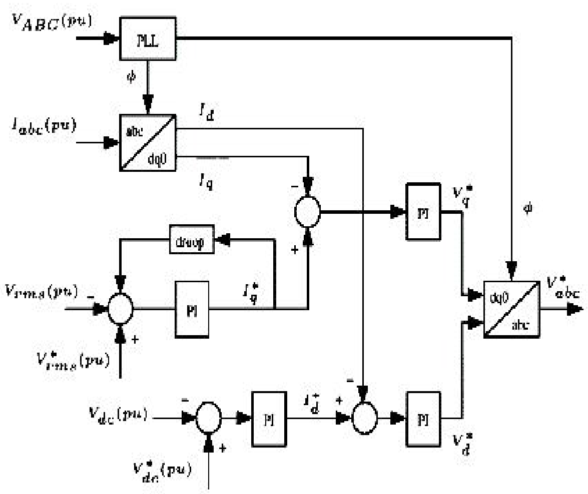


Fig.2 Voltage controller of D-STATCOM

In this figure 2, V_{ABC} are the three-phase terminal voltages, I_{abc} are the three phase currents injected by the devices into the network, V_{rms} is the rms terminal voltage, V_{dc} is the DC voltage measured in the capacitor and the superscripts * indicate reference values. Such controller employs a PLL (Phase Lock Loop) to synchronize the three-phase voltages at the converter output with the zero crossings of the fundamental component of the phase-A terminal voltage. Therefore, the PLL provides the angle ϕ to the abc-to-dq0 (and dq0-to-abc) transformation.

There are four PI regulators. The first one is responsible for controlling the terminal voltage through the reactive power exchange with the AC network. This PI regulator provides the reactive current reference Iq*, which is limited between +1 pu capacitive and -1 pu inductive. This regulator has one droop characteristics, usually ±5%, which allows the terminal voltage to suffer only small variations. Another PI regulator is responsible for keeping the DC voltage constant through a small active power exchange with the AC network, compensating the active power losses in the transformer and inverter. This PI regulator provides the active current reference Id*. The other two PI regulators determine voltage reference Vd* and Vq*, which are sent to the PWM signal generator of the converter, after the dq0-to-abc transformation. Finally V_{abc}* are the three-phase voltages desired at the converter output.

3. Mathematical Procedure To Determine The Optimal Allocation of D-STATCOM

Load flow studies are important in planning and designing future expansion. Load flow studies give steady state solution of the voltage at all the buses, for a particular load condition. Different steady state solution can be obtained for different operating conditions to help in planning, design and operation of the power system.

Run the load flow program and find the value of
(i) Voltages at all nodes (ii) Total real power loss
(iii) Total reactive power loss.

To reduce the total power loss by allocating the capacitor, following equation is used.

PU power loss reduction

$$\Delta P = \frac{3cx}{1+\lambda+\lambda^2}\left[(2-x)c + x\lambda c - c^2\right]$$

where,

x = Distance of the line segment where the the capacitor is to be allocated in pu.

$$\lambda = \frac{\text{Reactive current at the end of the line segment}}{\text{Reactive current at the beginning of he line segment}}$$

$$c = \frac{\text{ckva of capacitor installed}}{\textit{total reactive load}}$$

Based on the different values of x and c, the graph for loss reduction as a function of the capacitor bank location and capacitor compensation for a line segment is obtained as follows.

From the graph, it can be seen that the optimal location is at the end of the line segment for the capacitor rating of 1pu of the total kva load. But from economic point of view

1pu of the total kva load is not suitable. Hence, 0.8pu of the total kva load is considered as economical.

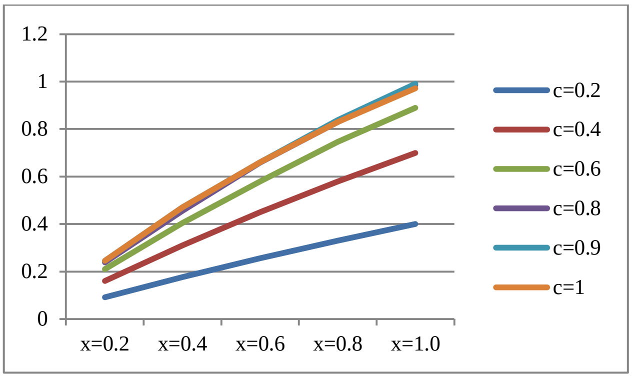


Fig.3 Graph for optimal allocation of capacitor

4. Case Study

An 11kV/440V low voltage (LV) side Distribution network of Dharwad district, India, has been considered for analysis. The network consists of a 250KVA power transformer. There are two sub-networks connected to the transformer. Load receives a voltage level of 440V at 0.85 pf. Supply frequency is 50Hz. The single line diagram of the network under case study is shown in figure 4.

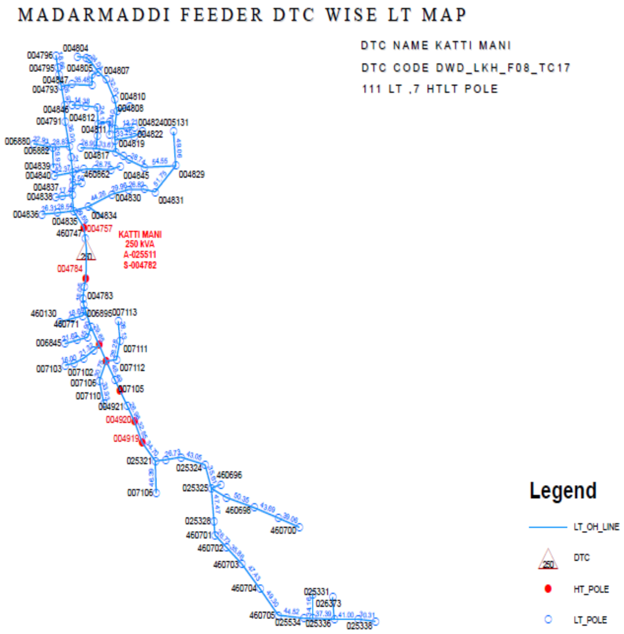


Fig.4 Single diagram of 11kV/440V LV side Distribution network

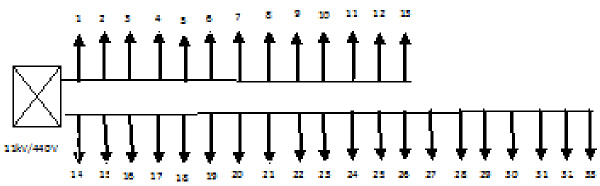


Fig.5 Simplified diagram of the network

As shown in figure 5, network has total 33 load points. Two tappings are taken from the 11kV/440V transformer. Load 1 to load 13 are connected to first tapping of total length 0.23121 km and load 14 to load 33 are connected to second tapping of total length 0.506 km. Rabbit conductor of resistance 05449 ohms per km and inductance 0.301 ohms per km is used for connection.

Recorded data from substation for connected load and length between the loads is reported in Table 1.

Table 1 Distribution network parameters

Load Points	Distance (km)	Connected Load	
		P (kW)	Q (kVAr)
1	0.0296	22.371	11.7846
2	0.01748	18.6425	9.820
3	0.0155	11.1855	5.892
4	0.0217	7.457	3.928
5	0.018	3.7285	1.964
6	0.018	11.1855	5.892
7	0.0138	13.4226	7.071
8	0.01347	8.9484	4.714
9	0.01866	16.4054	8.642
10	0.020	14.914	7.856
11	0.015	11.1855	5.892
12	0.018	7.457	3.982
13	0.012	18.6425	9.821
14	0.018	7.457	3.928
15	0.02	11.1855	5.892
16	0.02	3.7285	1.964
17	0.015	13.4226	7.071
18	0.015	11.1855	5.892
19	0.012	7.457	3.928
20	0.022	7.457	3.928
21	0.017	3.7285	1.964
22	0.011	26.0995	13.748
23	0.019	7.457	3.928
24	0.014	14.914	7.8567
25	0.01	11.1855	5.892
26	0.009	13.4226	7.071
27	0.012	7.457	3.928
28	0.011	22.371	11.784
29	0.01	18.6425	9.821
30	0.012	12.6769	6.6779
31	0.013	14.917	7.8567
32	0.009	14.917	7.8567
33	0.02	22.371	11.785

5. Experimental Result

Matlab/Simulink model of the system under consideration is shown in figure 6.

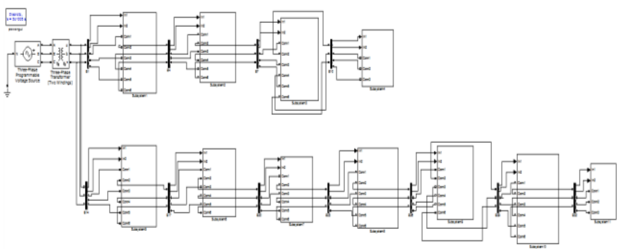


Fig.6 Matlab/Simulink model of the Distribution network

From mathematical procedure it is found that end point is the optimal allocation. Hence D-STATCOM is connected near load 33. Matlab/Simulink model of the D-STATCOM is shown in the figure 7.

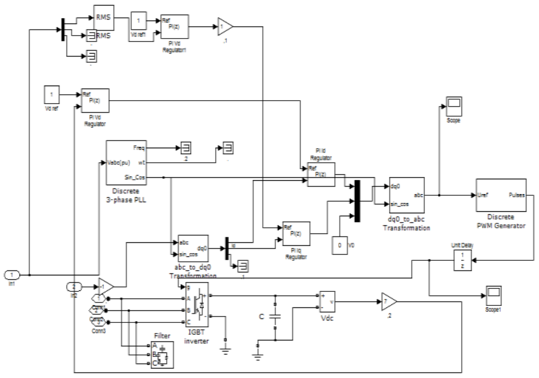


Fig.7 Matlab/Simulink model of the D-STATCOM

Simulation Results:

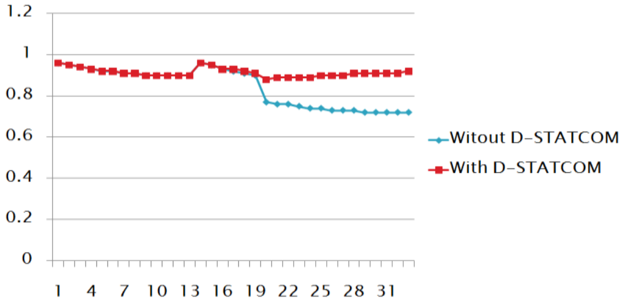
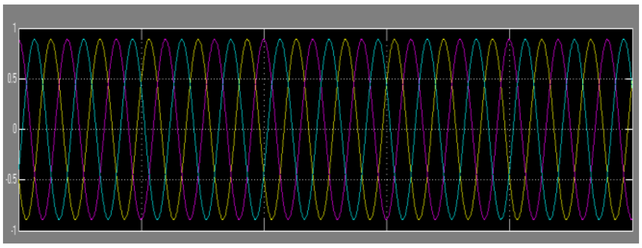


Fig.8 Graph showing Voltage profile without and with insertion of D-STATCOM

Output Waveforms:

a.Voltage waveform



b. Current Waveform

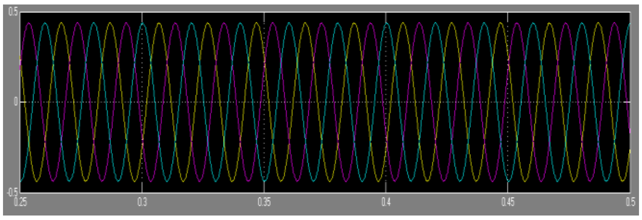
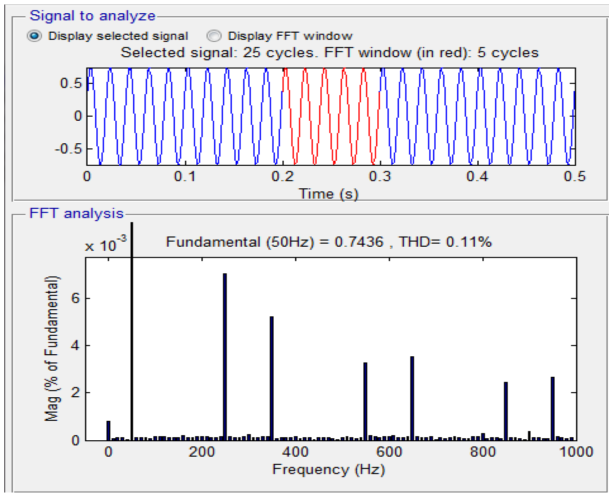


Table 2 Power Loss calculation

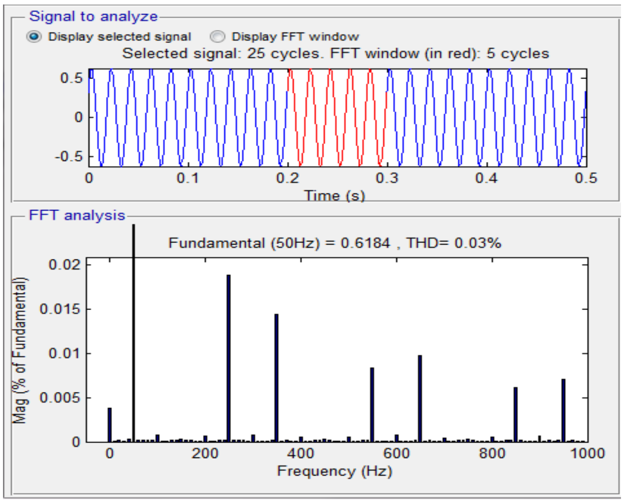
Power Loss	Without D-STATCOM	With D-STATCOM
Real power Loss	62.07 KW	49.95 KVar
Reactive Power Loss	46.27 KVar	36.01 KVar

Harmonic Analysis:

a. Without D-STATCOM



b. With D-STATCOM:



Conclusion

Figure 8 shows the bus voltages with and without D-STATCOM insertion at load 33. It is observed there was an improvement in voltage profile. With the improvement in bus voltages, the overall system losses were reduced with KVAR compensation at various locations. Before D-STATCOM insertion the voltages at loads 22 to 33 is between 0.77-0.72 pu. The losses were 62.07 kW and 49.95 KVAR. After placing the D-STATCOM at load 33 the voltages were improved to 0.88-0.92 p.u and the losses were reduced to 46.27kW and 36.01KVAR Total harmonic distortion (THD) witout D-STATCOM was 0.11% of fundamental and when D-STATCOM THD reduced to 0.11% of the fundamental. Finally, simulation results for Dharwad distribution network are presented.

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