Application of DSTATCOM for Improvement of Power Quality using MATLAB Simulation

Archana M. Kadam, Satyen Dhamdhere, D. S. Bankar

Abstract- ***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. This paper presents the reduction of voltage sags, using Distribution Static Compensator (D-STATCOM) with LCL Passive Filter in Distribution system. The model is based on the Voltage Source Converter (VSC) principle. D-STATCOM can use with different types of controllers. 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 simulations were performed using MATLAB SIMULINK.***

Keywords: D-Statcom, Voltage sag, Voltage source Converter (VSC), LCL Passive filter, THD.

I. INTRODUCTION

Voltage dips are one of the most occurring power quality problems. Voltage sag 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. 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. There are different ways to mitigate power quality problems in transmission and distribution systems. Among these, the D-STATCOM is one of the most effective devices. The DSTATCOM protects the utility transmission or distribution system from voltage sags and/or flicker caused by rapidly varying reactive current demand. In utility applications, a DSTATCOM provides leading or lagging reactive power to achieve system stability during transient conditions.[5,6]

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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. BASIC PRINCIPAL OF D-STSTCOM

The D-STATCOM is similar to Transmission STATCOM in that it uses a VSV of the required rating. The D-STATCOM is viewed as a variable current source determined by a control functions. A fixed capacitor/filter can be used in parallel with DSTATCOM to increase dynamic rating in the capacitive range. And by connecting energy storage device such as SMES supercon-ducting magnetic energy storage) on the DC side it is possible to exchange real power with the network for a limited time(during large voltage sag).

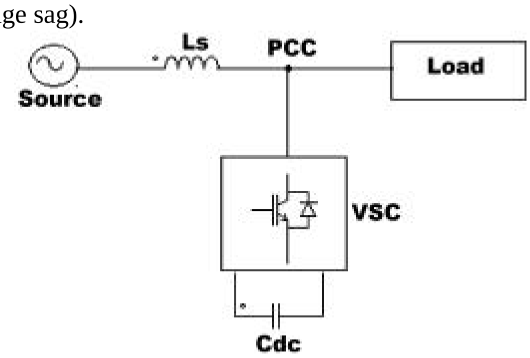


Fig 2.1BASIC DIAG OF DSTATCOM

The AC terminals of the VSC are connected to the Point of Common Coupling (PCC) through an inductance, which could be a filter inductance or the leakage inductance of the coupling transformer, as shown in figure 1. The DC side of the converter is connected to a DC capacitor, which carries the input ripple current of the converter and is the main reactive energy storage element. This capacitor could be charged by a battery source, or could be recharged by the converter itself. If the output voltage 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 DSTATCOM is in the capacitive mode of operation and vice versa. The quantity of reactive power flow is proportional to the difference in the two voltages.

$$I_{out} = I_L - I_S = I_L - \frac{V_{th} - V_L}{Z_{th}}$$

$$I_{out} < \gamma = I_L < (-\theta) - \frac{V_{th}}{Z_{th}} < (\delta - \beta) + \frac{V_L}{Z_{th}} < (-\beta)$$

The complex power injection of the DSTATCOM can be expressed as:

$\mathbf{S_{Out} = V_L I_{Out}^{*}}$

I_{out}= output current I_L= Load current

I_S= output current V_{Th}=Thevenin voltage

V_L= load voltage V_{Th}= output current

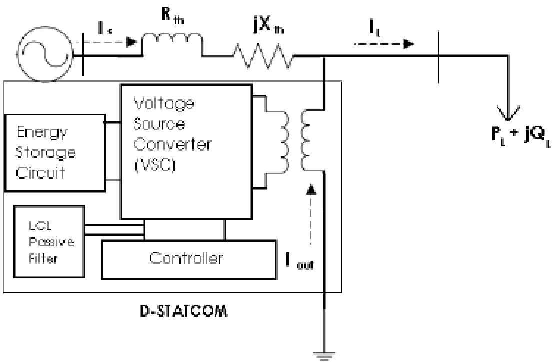
According to above equation, The voltage sag is corrected by the current I_{out} which adjusts the voltage drop across the system impedance Z_{th} ($Z_{th} = R+jX_{Th}$) The value of I_{out} can be controlled by adjusting the output voltage of the converter.

Correction of voltage sag depends upon:

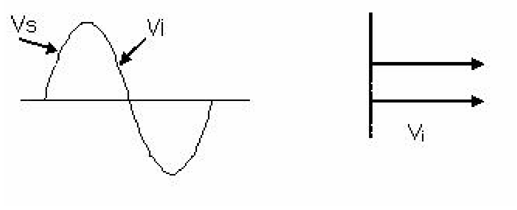
1. The value of impedance
2. Fault level

III. CONFIGURATION & OPERATION OF DSTATCOM:

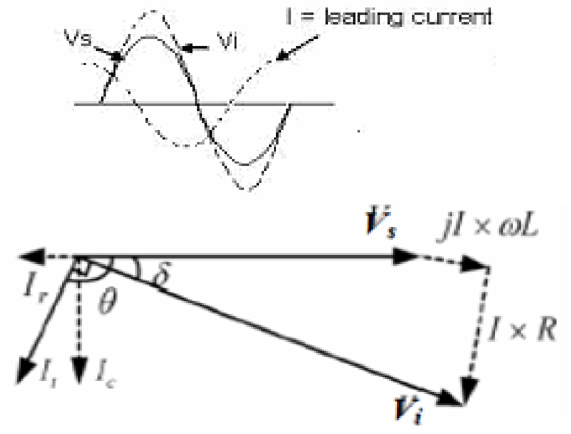
FIG shows the inductance *L* and resistance *R* which represent the equivalent circuit elements of the stepdown transformer and the inverter is the main component of the D-STATCOM. the three basic operation modes of the DSTATCOM output current I_{Out} which varies depending upon Vi. If Vi is equal to Vs, the reactive power is zero and the D-STATCOM does not generate or absorb reactive power. When Vi is greater than Vs, the D-STATCOM shows an inductive reactance connected at its terminal. The current I, flows through the transformer reactance from the D-STATCOM to the ac system, and the device generates capacitive reactive power. If Vs is greater than Vi, the D-STATCOM shows the system as a capacitive reactance. Then the current flows from the ac system to the D-STATCOM, resulting in the device absorbing inductive reactive power.



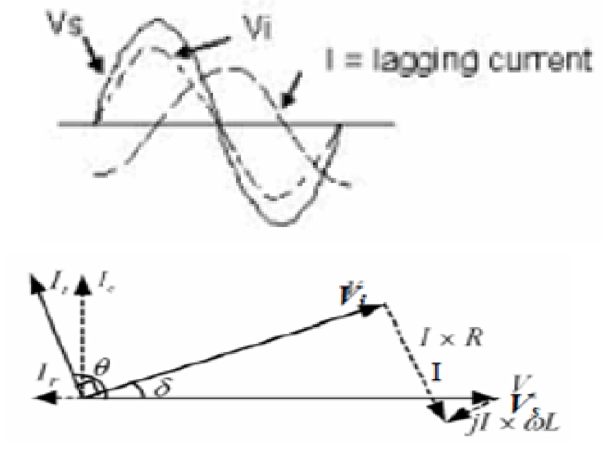
3.1 Operation modes of D-STATCOM



3.2 No-load mode (Vs = Vi)



3.3 Capacitive mode (Vi >Vs)



3.4 Inductive mode (Vi <Vs)

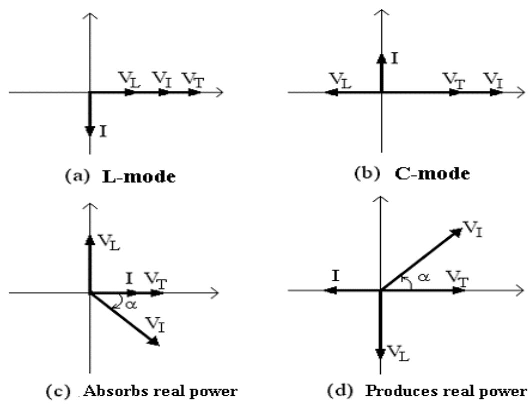


Fig 3.5 Vector diagrams of DSTATCOM

A.Voltage Source Converter (VSC):

A VSC is a power electronic device, which can generate a sinusoidal voltage with any required magnitude, frequency and phase angle.

Voltage source converters are widely used in adjustable-speed drives, but can also be used to mitigate voltage dips. The VSC is 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. The converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage.[2]

The voltage source rectifier operates by keeping the dc link voltage at a desired reference value, using a feedback control loop as shown in Fig. To accomplish this task, the dc link voltage is measured and compared with a reference VREF. The error signal generated from this comparison is used to switch the six valves of the rectifier ON and OFF. In this way, power can come or return to the ac source according to dc link voltage requirements. Addition, the ac current waveforms can be maintained as almost sinusoidal, which reduces harmonic contamination to the mains supply.

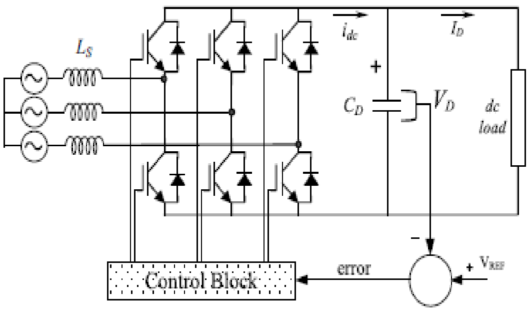


Fig 3.6 Operation principle of the voltage source Controller.

B. Controller for DSTATCOM:

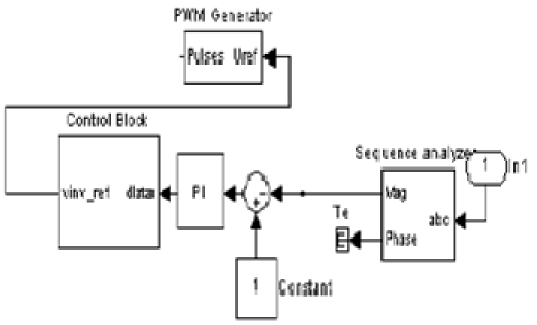


Fig 3.7 Block diagram of Controller

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 is2 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.[3]

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:

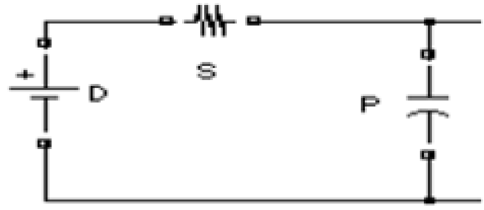


Fig 3.8 Circuit Diagram of DC storage

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 filters:

For reduction of harmonic distortion LCL filters are very effective. The main drawback with this is that the LCL-filter will introduce a resonance frequency into the system. Harmonic components in the output voltage can lead to resonance oscillations and instability problems unless they are properly handled. One way of reducing the resonance current is by adding a passive damping circuit to the filter. This damping circuit can be purely resistive, causing relatively high losses, or a more complex solutions consisting of a combination of resistors, capacitors and inductors. [2]

To design it following equations are required,

$$L_g = \frac{E_n}{2\sqrt{6}\, i_{ripm} f_{sw}}$$

$$L_c = \frac{L_g}{2}$$

$$C_f = \frac{L + L_g}{L L_g \left(2\pi f_{res}\right)^2}$$

To design an efficient LCL Passive filters make sure that,

$$10 f_n \le f_{res} \le 0.5 f_{sw}$$

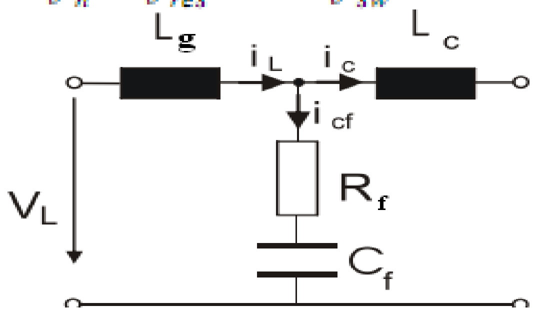


Fig 3.9 LCL Passive filter

IV. TOTAL HARMONIC DISTORTION:

THD is defined as the RMS value of the waveform remaining when the fundamental is removed. A perfect sine wave is 100%, the fundamental is the system frequency of 50 or 60Hz.

Harmonic distortion is caused by the introduction of waveforms at frequencies in multiplies of the fundamental ie: 3rd harmonic is 3x the fundamental frequency / 150Hz. Total harmonic distortion is a measurement of the sum value of the waveform that is distorted.

Harmonic distortion is caused by the high use of non-linear load equipment such as computer power supplies, electronic ballasts, compact fluorescent lamps and variable speed drives etc, which create high current flow with harmonic frequency components. The limiting rating for most electrical circuit elements is determined by the amount of heat that can be dissipated to avoid overheating of bus bars, circuit breakers, neutral conductors, transformer windings or generator alternators.

V. SIMULATION MODEL FOR TEST SYSTEM WITHOUT DSTSTCOM:

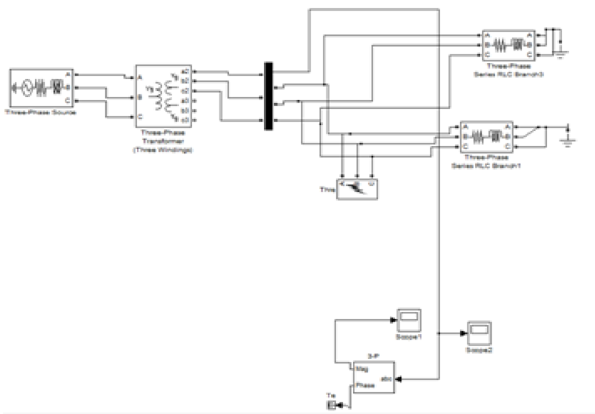


Table.1 Results of voltage sag Without insertion of D-STATCOM:

Fault Resistance R_f, Ω	Voltage sags for TPG fault (p.u)	Voltage sags for DLG fault (p.u)	Voltage sags for LL fault (p.u)	Voltage sags for SLG fault (p.u)
0.66	0.661	0.706	0.760	0.825
0.76	0.711	0.749	0.792	0.848
0.86	0.751	0.782	0.819	0.953

Without insertion of D-STATCOM

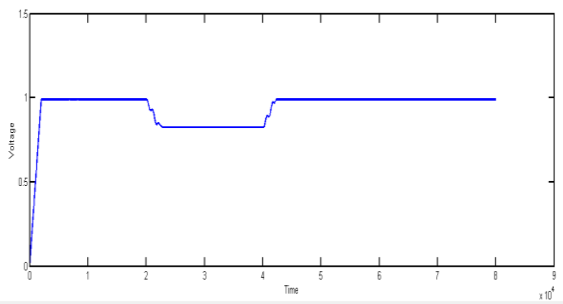


Figure (a).voltage at load point is 0.661 p.u (TPG)

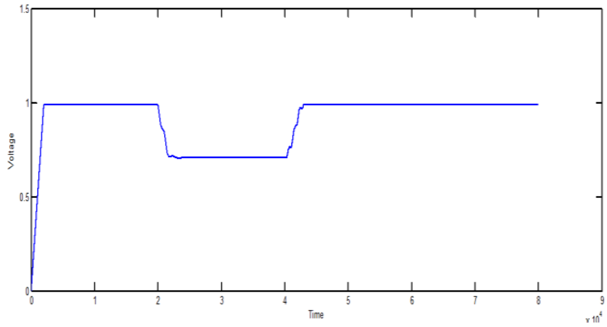
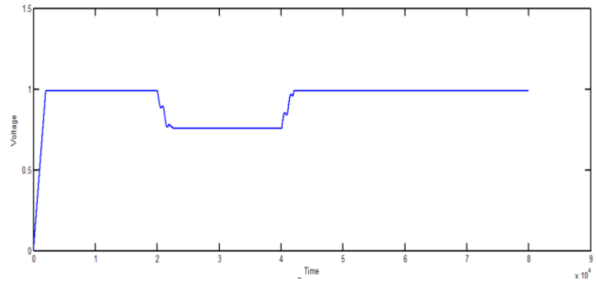
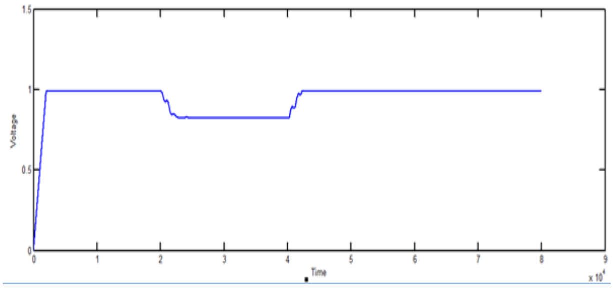


Figure (b).voltage at load point is 0.706 p.u(DLG)



Figure(c).voltage at load point is 0.76 p.u(LL)



Figure(d).voltage at load point is 0.825 p.u(SLG)

VI. SIMULATION MODEL FOR TEST SYSTEM:

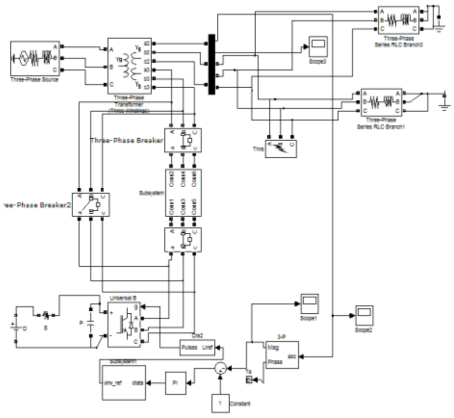


Table.2 Results of voltage sag With insertion of D-STATCOM:

Fault Resistance R_f, Ω	Voltage sags for TPG fault (p.u)	Voltage sags for DLG fault (p.u)	Voltage sags for LL fault (p.u)	Voltage sags for SLG fault (p.u)
0.66	0.940	0.940	0.940	0.934
0.76	0.952	0.931	0.945	0.945
0.86	0.96	0.961	0.954	0.868

With insertion of D-STATCOM

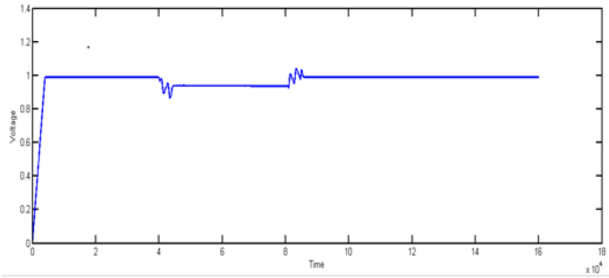


Figure (a).voltage at load point is 0.940 p.u (TPG)

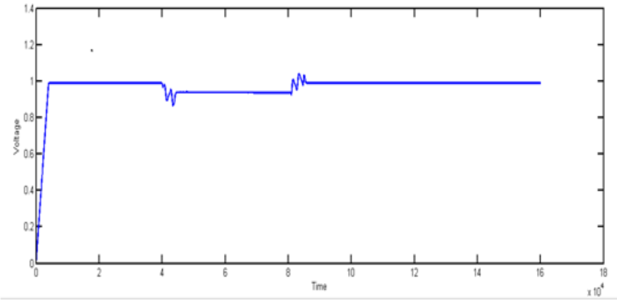
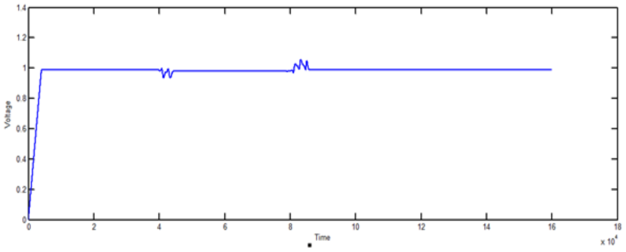
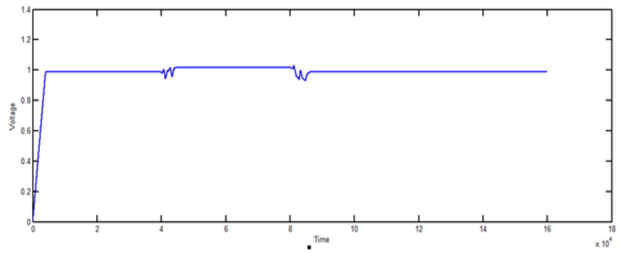


Figure (b).voltage at load point is 0.940 p.u(DLG)

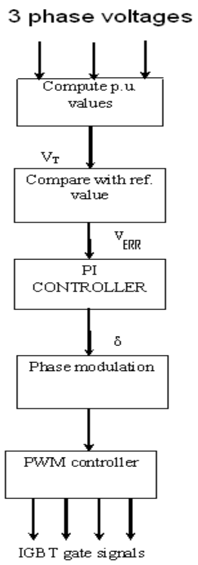


Figure(c).voltage at load point is 0.940 p.u(LL)



Figure(d).voltage at load point is 0.934 p.u(SLG)

VII. CONTROL ALGORITHM OF DSTSTCOM



VIII. CONCLUSION:

This paper presents the detailed modeling of one of the custom power products i.e DSTATCOM.The voltage sags can be mitigate by inserting D-STATCOM to the distribution system. By adding LCL Passive filter to D-STATCOM, the THD is reduced. 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. PWM control scheme only requires voltage measurements. It is concluded that a DSTATCOM is conceptually similar to a STATCOM at the transmission level; its control scheme should be such that in addition to complete reactive power compensation, power factor correction and voltage regulation the harmonics are also checked, and for achieving improved power quality levels at the distribution end.

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