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## Improving Power Quality Using S-Transform Based D-STATCOM

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**ABSTRACT:** The electrical energy is one of the easily used forms of energy. It can be easily converted to other forms of energy. With the advancement of technology, the dependency on the electrical energy has been increased greatly. However, the quality of power supplied is affected by various internal and external factors of the power system. The presence of harmonics, voltage and frequency variations deteriorate the performance of the system.

In this literature, the frequently occurring power quality problem- voltage variation, swell, is discussed. The voltage sag/dip is the most frequently occurring problem. S-Transform and Wavelet Transform method are used to detect this problem. There are many methods to overcome this problem. Among them the use of FACT devices is an efficient one. The reduction of voltage sags is possible 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.

**KEYWORDS:** D-STATCOM, Power quality, VSC, FACTS, Distribution Line

### I. INTRODUCTION

Now-days most of the loads in industry, homes, are electrical. In the case of these inductive loads currents drawn by the loads from source is lagging with respect to the voltage. So the reactive power burden on the system increases, which will increase losses in the distribution system and capacity of active power flow through the distribution system gets reduced. Due to advancement of power electronics technology, non-linear loads in the system are increasing, such as rectifiers, inverters, uninterruptible power supply (UPS), computers, etc. These Non-linear loads can cause the production of frequency component of the currents in the system which are not fundamental frequency components. So due to such harmonic component of currents the quality of power gets affected [1]. Also, there is the impact of the unbalancing on transformers and generators operation. The solution to power quality improvement is the use of custom power device like DSTATCOM. Control schemes reported in the literature for controlling of the DSTATCOM are synchronous reference frame (SRF) theory, current compensation using DC bus regulation, instantaneous reactive power (IRP) theory, and ascheme based on the neural network technique.

### II. DISTRIBUTED STATIC COMPENSATOR

The Distribution Static Compensator (DSTATCOM) is a voltage source inverter based static compensator that is used for the correction of bus voltage sags. Connection (shunt) to the distribution network is via a standard power distribution transformer. The DSTATCOM is capable of generating continuously variable inductive or capacitive shunt compensation at a level up its maximum MVA rating. The DSTATCOM continuously checks the line waveform with respect to a reference ac signal, and therefore, it can provide the correct amount of leading or lagging reactive current compensation to reduce the amount of voltage fluctuations. The major components of a DSTATCOM are shown in Fig. 1. [2] It consists of a dc capacitor, one or more inverter modules, an AC filter, a transformer to match the inverter output

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to the line voltage, and a PWM control strategy. In this DSTATCOM implementation, a voltage-source inverter converts a dc voltage into a three-phase ac voltage that is synchronized with, and connected to, the ac line through a small tie reactor and capacitor (ac filter).

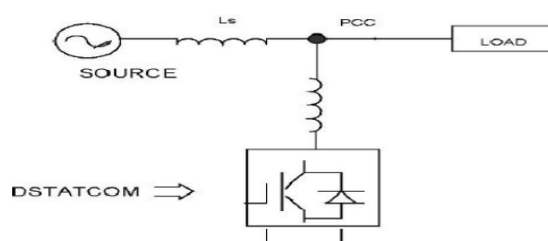


Figure 1- DSTATCOM model

DSTATCOM involves mainly three parts IGBT or GTO based dc-to-ac inverters that are used to create an output voltage wave that's controlled in magnitude and phase angle to produce either leading or lagging reactive current, depending on the compensation required. The LC filter is used which reduces harmonics and matches inverter output impedance to enable multiple parallel inverters to share current. The LC filter is chosen in accordance with the type of the system and the harmonics present at the output of the inverter. There is a control block which switch Pure Wave DSTATCOM modules as required. They can control external devices such as mechanically switched capacitor banks too. These control blocks are designed based on the various control theories and algorithms.[3]

## III. BASIC OPERATING PRINCIPLE

Basic operating principle of a DSATCOM is similar to that of synchronous machine. The synchronous machine will provide lagging current when under excited and leading current when over excited. DSTATCOM can generate and absorb reactive power similar to that of synchronous machine and it can also exchange real power if provided with an external device DC source.

1) Exchange of reactive power if the output voltage of the voltage source converter is greater than the system voltage then the DSATCOM will act as capacitor and generate reactive power(i.e.. provide lagging current to the system)  
2) Exchange of real power: as the switching devices are not loss less there is a need for the DC capacitor to provide the required real power to the switches. Hence there is a need for real power exchange with an AC system to make the capacitor voltage constant in case of direct voltage control. There is also a real power exchange with the AC system if DSTATCOM is provided with an external DC source to regulate the voltage in-case of very low voltage in the distribution system or in case of faults. And if the VSC output voltage leads the system voltage then the real power from the capacitor or the DC source will be supplied to the AC system to regulate the system voltage to 1p.u or to make the capacitor voltage constant.[4]

Hence the exchange of real power and reactive power of the voltage source converter with AC system is the major required phenomenon for the regulation in the transmission as well as in the distribution system. For reactive power compensation, DSTATCOM provides reactive power as needed by the load and therefore the source current remains at unity power factor. Since only real power is being supplied by the source, load balancing is achieved by making the source reference current balanced. The reference source current used to decide the switching of the DSTATCOM has real fundamental frequency component of the load current which is being extracted by these techniques.

The main objective of any compensation scheme is that it should have a fast response, flexible and easy to implement. The control algorithms of a DSTATCOM are mainly implemented in the following steps:

- Measurements of system voltages and current and Signal conditioning
- Calculation of compensating signals
- Generation of firing angles of switching devices

Generation of proper PWM firing is the most important part of DSTATCOM control and has a great impact on the compensation objectives, transient as well as steady state performance. Since a DSTATCOM shares many concepts to that of a STATCOM at transmission level, a few control algorithms have been directly implemented to a DSTATCOM, incorporating Pulse Width Modulation (PWM) switching, rather than Fundamental Frequency switching (FFS) methods. This project makes attempt to compare the following schemes of a DSTATCOM for reactive power compensation and power factor correction based on [5]:

- Phase Shift Control
- Decoupled Current Control (p-q theory)
- Regulation of ac bus and dc link voltage
- Synchronous Reference Frame (SRF) Method

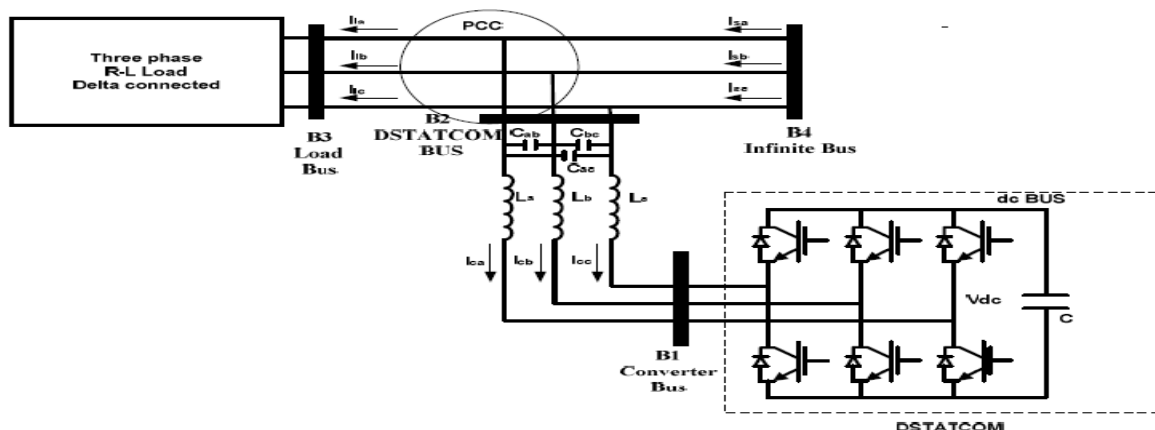


Figure 3- Distribution system compensated by DSTATCOM

#### IV. DSTATCOM CONTROL ALGORITHM

The essential features of any control scheme are fast response, flexibility, robustness and ease of implementation. For a DSTATCOM, the control algorithm is implemented by using the following steps:

- The supply and the load voltages & currents are measured using either Hall Effect transducers or any other sensor.
- The supply reference current is calculated first.
- The compensating current of the DSTATCOM is then calculated.
- Comparing the load current with the compensating current, the triggering pulses for the IGBTs of the inverter bridge are then produced.
- This causes the inverter to produce the requisite compensating current to perform the load compensation.

The Phase Shift Control scheme is simple. The objective is to maintain a constant voltage at the load terminal. The control algorithm exerts a voltage angle control and generates a phase shift in the output voltage of the VSC with respect to the ac supply voltage. An error signal is generated by comparing the measured PCC voltage with the desired or the reference voltage. The error signal is fed to a PI controller to generate an angle to drive the voltage error to zero. Thus the PCC voltage is regulated at the desired value. [6]

The PWM generator phase-modulates the sinusoidal voltage signal by angle  $\alpha$  and generates the switching signals for the VSC switches by comparing it with a triangular carrier signal. The dc side voltage is maintained by a separate dc source. A schematic diagram for phase shift control of DSTATCOM is shown in Figure 3.

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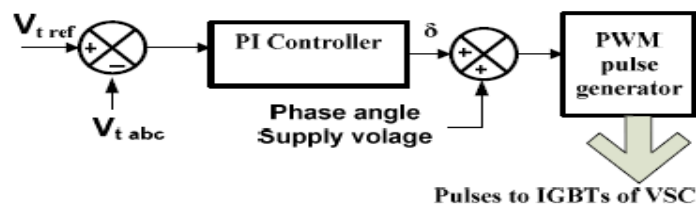


Figure 3- Schematic Phase Shift Control

## V. SYSTEM UNDER CONSIDERATION

A distribution feeder connected to unbalanced and non-linear load is shown in the below Fig. 4. Working performance of the DSTATCOM using instantaneous reactive power theory (IRP) is analysed by the modelling system shown in Fig.4 in MATLAB Simulink tool.

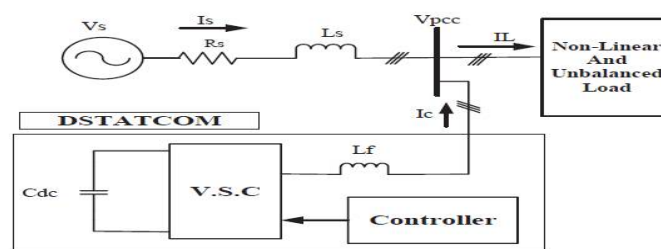


Figure 4- DSTATCOM Connection

In the system diagram shown in above Fig. 4,  $R_s$  and  $L_s$  represents source resistance and source inductance. The nonlinear load is realized by connecting the three phase diode rectifier to a Resistive-Inductive load (R-L). Unbalanced load is realized by connecting different values of impedances in three phases. Three phase voltage source converter (VSC) act as the DSTATCOM which consist of the six insulated gate bipolar transistor (IGBT) and anti-parallel diodes are connected to each IGBT [2]. DC side of the Voltage source converter (VSC) consists of a capacitor which is used to maintain constant voltage for the switching operation of the IGBT switches. The DC capacitor is not used for any reactive power compensation. Interfacing inductor,  $L_f$  is connected on the AC side of the voltage source converter for compensating high frequency components of the compensating currents [5]. Storage capacitor  $C_{dc}$  does not exchange any active power between DSTATCOM and the load. Breaker is used to observe the performance of the DSTATCOM before compensation and after compensation (i.e. for connecting and removing DSTATCOM to and from the system).

## DISTURBANCE DETECTION METHODS

### a) Discrete Wavelet Transform (DWT)

Wavelets have been used in various research areas to obtain the effective results, Such as signal processing, image processing, data compression, de-noising and numerical solution of differential equations. The discrete wavelet techniques are used as a new tool for expected results in fault detection and various power systems. The DWT to represent the time domain signal  $S(t)$  can be represented at various input signal levels in terms of the coefficients are:

$$C_s = [A \mid D \mid D \mid \dots \mid D]$$

where, A, D is representing the approximate and detailed coefficients at various input signal levels. The convolution and decimation can be achieved by Wavelet transform and it is used to achieve a better performance using the Haar wavelet transform. The input voltages signals are used in different cut-off frequencies and used at different scales are analysed. The input signal is processed through two different ways to implement the wavelet transform. First one should consider the high frequency feed through a series connected high pass filters and second one should consider the

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lower frequency feed through a series connected low pass filter. The reconstructed output time signal is  $R(n)$  in terms of approximated and detailed output signal is given by:

$$a_0(n) = \sum_l x(l-2n)R_{c0}(l)$$

$$d_0(n) = \sum_l y(l-2n)R_{c0}(l)$$

b) S- Transform:

The discrete S-transform is defined as follows. Let  $h[xT]$ ,  $i = 0, 1, \dots, n-1$  denote a discrete time series corresponding to  $h(t)$  with a time sampling interval of  $T$ . The discrete Fourier transform of  $h[kT]$  is obtained as:

$$H\left[\frac{x}{XT}\right] = \frac{1}{X} \sum_{i=0}^{X-1} h[iT] e^{\frac{j2\pi xi}{X}}$$

Where,  $n = 0, 1 \dots N-1$ . Each basis vector is divided into  $N$  localized vectors by an element by its product with  $N$  shifted Gaussian windows. S-transform of a discrete time series  $h[xT]$  is obtained by letting  $f$  tending to  $x/(XT)$  and tending to  $jT$ . Thus discrete S-transform is given by:

$$S\left[jT, \frac{x}{XT}\right] = \sum_{l=0}^{X-1} H\left[\frac{l+x}{XT}\right] K(l, x) e^{\frac{j2\pi xi}{X}}$$

Where,

$$K(l, x) = e^{-\frac{2\pi^2 l^2 \alpha^2}{x^2}}$$

$N$  = total number of samples.

For low frequencies, a high value of  $b$  is chosen and for high frequencies, lower value of  $b$  is chosen to provide suitable frequency resolutions. In continuous wavelet transform the information is about the phase of the spectrum and also the amplitude. The input signal phase can be obtaining in the continuous wavelet transform (CWT). The CWT of a function  $h(t)$  is defined as:

$$w(\tau, a) = \int_{-\infty}^{\infty} h(t) \omega(t - \tau, a)$$

where,  $W(a)$  is a measured model of the fundamental wavelet transform. The S-transform is obtained by multiplying the CWT with a phase factor as:

$$S(\tau, f) = \exp(i2\pi ft) \cdot W(\tau, a)$$

where, the wavelet for this particular case is defined as:

$$\omega(\tau, f) = \left( \frac{|f|}{\sqrt{2\pi}} \exp\left(-\frac{t^2 f^2}{2}\right) \cdot \exp(-i2\pi ft) \right)$$

In this equation the just dilation factor is the inverse of the input signal frequency. Thus, the final form of the continuous S-transform is obtained as:

$$S(t, f) = \int_{-\infty}^{\infty} h(t) \cdot \frac{f}{\sqrt{2\pi}} \exp\left(-\frac{t^2 f^2}{2}\right) \cdot \exp(-i2\pi ft) dt$$

## CONCLUSION

Each transmission line has its load ability limit that is often determined by either stability constraints or by thermal limits or by the dielectric limits. It is however to be noted that while most problems associated with the transmission

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systems arise due to the forces of nature or due to the interconnection of power systems, individual customers are responsible for more substantial fraction of the problems of power distribution systems.

DSTATCOM offers an easy method to work on the power quality management. S-transform based control of DSTATCOM offers an efficient and optimal control operation 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.

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