ABSTRACT

Load voltage control is an indispensable task in electrical power distributed systems in the presence of nonlinear probabilities of load. Traditionally series compensators and voltage-source converter-based shunt are used for load voltage control. Deeper study into the load voltage control mechanisms in power distribution systems can ascertain facts pertaining to performance bottlenecks. This knowhow can help in improving systems of power distribution. Towards this end many researches came into existence in the recent past. Recently studies on the role and performance of series compensators and VSC-Based shunt in power distribution systems for load voltage control. There are many power quality problems like unbalancing, load voltage harmonic distortions, and voltage swells. They used DVR (Dynamic Voltage Restorer) as series device and DSTATCOM (Distribution Static Compensator) as shunt device in order to address quality problems. In this review a custom simulator to analyze these problems further and also compare the performance of compensators with strong and weak ac-supply besides studying the effect of parameters on control performance of these compensators. We made extensive simulations to demonstrate the proof of concept. The empirical results revealed significant differences between compensators of the two kinds.

I. INTRODUCTION

Power distribution systems face many problems pertaining to voltage related power quality. The problems include harmonic distortions, voltage dips, swells and sags due to voltage unbalancing in power distribution systems. Therefore theses problems are to be addressed in case of loads which are voltage sensitive. Of late there were many researches on the usage of VSC for solving voltage problems in all grid-connected applications. There have been new devices coming up in power distribution systems that cause non-linear load which causes plethora of problems. Loads are associated with distribution systems with difference loads and levels of power based on the applications. Due to this Short Circuit Current (SCC) levels at various lengths is experienced by power distribution systems. The factors such as volt-ampere ratings, voltage, location of load and the size of distribution system are to be considered. Feeder impedance also has its role to play in power distribution systems. Based on the location on the feeder where load is connected, we can classify it into two types. When the long feeder has load connected at the end with small short-circuit current value, it is known as weak ac-supply system. The current value of short-circuit and length of the feeders has impact on line impedance. When load is connected close to the feeder, it is known as strong ac-supply where line impedance is negligible. There are two VSC-based devices that can be used to reduce voltage sags. The first device is known as DSTATCOM and other device is DVR which was widely explored. As power quality issues are addressed by these two devices in power distribution systems. The former device uses reactive power compensation while the latter uses load voltage control methods like closed loop and open loop. As experiments proved in the closed
loop voltage control is best. Shunt and series compensators are used in the experiments in as a common strategy. However, detailed study of these devices, their role and performance in the power distribution systems is the need of the hour. In this review assume a three-phase system as explored where phases are controlled independently. As per the phase basis, the results can be easily analyzed and used for further investigations. In this review use of two devices such as DVR and DSTATCOM for analyzing voltage control in the presence of non-linear distribution of power. Figure 1 shows the structure of compensator consisting of feeder, load and compensator.

II. DEFINATION

D-STATCOM (Distribution Static Compensator) is a shunt device which is generally used to solve power quality problems in distribution systems. D-STATCOM is a shunt device used in correcting power factor, maintaining constant distribution voltage and mitigating harmonics in a distribution network. D STATCOM is used for Grid Connected Power System, for Voltage Fluctuation, for Wind Power Smoothening and Hydrogen Generation etc. Relevant solutions which applied nowadays to improve power quality of electric network according to the five aspects of power quality- harmonics, fluctuation and flick of voltage, Voltage deviation, unbalance of 3-phase voltage and current frequency deviation. Simulation is done using Sim Power Systems of MATLAB/Simulink to validate the proposed global system. The measurement system containing two main parts: - Hardware part and the virtual part- software (Recording, Processing, Graphical interfacing). The performance of the proposed DSTATCOM system is validated through simulations using MATLAB software with its Simulink and Power System Blockset (PSB) toolboxes.

As can be seen in figure 1, there are three district parts in the compensator. They are known as feeder, load and compensator. Closed loop frequency – response characteristics. Feeder impedance plays an important role in the performance of the two devices. Performance comparison is made for weak and strong ac-systems for both DVR and DSTATCOM. Three phase distribution systems are used for the experiments based on VSC modulation. The voltage source type is presented in figure 1 for nonlinear load.
As can be seen in figure 2, the non-linear load considered in this review is of bridge rectifier kind. The input impedance is represented as \( L_{lac}, R_{lac} \) as explored. Output voltage is fed to resistive load \( R_{ldc} \) which is supported by a capacitor \( C_{ldc} \). For a given large ac inductance \( L_{lac} \) and dc capacitor \( C_{ldc} \), the Thevenin equivalent voltage source is represented by \( (L_{lac}, R_{lac}) \) as explored in many researches. In this review, use of experiments with the said devices and compared performance of series compensator and VSC-Based shunt in load voltage control in distribution power systems.

### III. OPERATING PRINCIPLES OF THE D-STATCOM

STATCOM is the solid-state-based power converter version of the SVC. Operating as a shunt-connected SVC, its capacitive or inductive output currents can be controlled independently from its connected AC bus voltage. Because of the fast-switching characteristic of power converters, the STATCOM provides much faster response as compared to the SVC. In addition, in the event of a rapid change in system voltage, the capacitor voltage does not change instantaneously; therefore, the STATCOM effectively reacts for the desired responses. For example, if the system voltage drops for any reason, there is a tendency for the STATCOM to inject capacitive power to support the dipped voltages. Theoretically, the power converter employed in the STATCOM can be either a VSC or a current-source converter (CSC).

In practice, however, the VSC is preferred because of the bi-directional voltage-blocking capability required by the power semiconductor devices used in CSCs. In general, a CSC derives its terminal power from a current source, i.e., a reactor. In comparison, a charged reactor is much noisier than a charged capacitor. Moreover, the VSC requires a current-source filter at its AC terminals, which is naturally provided by the coupling transformer leakage inductance, while additional capacitor banks are needed at the AC terminals of the CSC. In conclusion, the VSCs can operate with higher efficiency than the CSCs do in high-power applications.

A suitable VSC is selected based on the following considerations: the voltage rating of the power network, the current harmonic requirement, the control system complexity, etc. Basically, the STATCOM system is comprised of three main parts: a VSC, a set of coupling reactors or a step-up transformer, and a controller. In a very-high-voltage system, the leakage inductances of the step-up power transformers can function as coupling reactors. The main purpose of the coupling inductors is to filter out the current harmonic components that are generated mainly by the pulsating output voltage of the power converters. The STATCOM is connected to the power networks at a PCC, where the voltage-quality problem is a concern. All required voltages and currents are measured and are fed into the controller to be compared with the commands. The controller then performs feedback control and outputs a set of switching signals to drive the main semiconductor switches of the power converter accordingly.

### IV. VSC – BASED SHUNT AND SERIES COMPENSATORS

We used DVR (Dynamic Voltage Restorer) as series device and DSTATCOM (Distribution Static Compensator) as shunt device in order to address quality problems. This section provides details about these devices and how they are able to address the quality problems in power distribution systems. These are the two compensator devices that can be used for load voltage control in power distribution systems. These devices work differently and their functionality is explored here in terms of two models namely DSTATCOM model and DVR model.
DSTATCOM Model

The DSTATCOM compensator with single-phase equivalent circuit is presented in figure 3 where VSC is best used to inject voltage under the closed loop settings. Dc link voltage is helped by a dc link capacitor. The voltage source is non-linear in nature. In the shunt path current is injected. The state space representation in case of DSTATCOM compensator is derived as follows.

\[ X = Ax + b_1 V_s + b_2 V + b_1 V_d V_l = cx \]  

As can be seen in figure 3, the DSTATCOM compensator is capable of addressing power quality problems in power distribution system. The next sub section explores the other compensator model named DVR model.

4.1 Basic Configuration and Operation of D-Statcom

The D-STATCOM is a three-phase and shunt connected power electronics based device. It is connected near the load at the distribution systems. The major components of a D-STATCOM are shown in figure 2. It consists of a dc capacitor, three-phase inverter (IGBT, thyristor) module, ac filter, coupling transformer and a control strategy. The basic electronic block of the D-STATCOM is the voltage-sourced inverter that converts an input dc voltage into a three-phase output voltage at fundamental frequency. The D-STATCOM employs an inverter to convert the DC link voltage \( V_{dc} \) on the capacitor to a voltage source of adjustable magnitude and phase. Therefore the D-STATCOM can be treated as a voltage-controlled source. The D-STATCOM can also be seen as a current-controlled source. Figure 2 shows the inductance \( L \) and resistance \( R \) which represent the equivalent circuit elements of the step-down transformer and the inverter will is the main component of the D-STATCOM. The voltage \( V_i \) is the effective output voltage of the D-STATCOM and \( \delta \) is the power angle. The reactive power output of the D-STATCOM inductive or capacitive depending can be either on the operation mode of the DSTATCOM. The construction controller of the D-STATCOM is used to operate the inverter in such a way that the phase angle between the inverter voltage and the line voltage is dynamically adjusted so that the D-STATCOM generates or absorbs the desired VAR at the point of connection. The phase of the output voltage of the thyristor-based inverter, \( V_i \), is controlled in the same way as the distribution system voltage, \( V_s \).

The situation of marine power quality inclined to worse. The reasons are listed in the following:

i. A large amount of control equipments and power electronic devices are put into marine use in order to promote automatization of ship operation and to save energy. e.g., concerning the variation of main engine cooling water temperature, the conventional control method of regulation of valve baffle position is now substituted by speed regulation of motors of cooling water pumps in order to save energy. As well as more and more frequent application of shaft driven generator has been observed. But the operation of all these equipments and devices contributes to the power quality deterioration to a wide extension.
ii. Since the capacity of marine electric facilities is always with a plentiful margin, the power factor of marine power plant under normal operation is rather low.

**Operation modes of D-STATCOM**

![Operation modes of D-STATCOM](image)

solutions have been selected to solve the problem of fluctuation and flick of voltage and almost all these solutions simultaneously have the function of harmonic suppression.

iii. To suppress harmonics in electrical power quality. The most effective solution is to apply filters. The commonly applied filters are passive power filter (usually passive LC filter) and active power filter (APF). APF normally has two types according to the ways it connects to the object that is compensated shunt APF and series APF. Among which, shunt APF is common in practical application.

### 4.2 Control Strategies

Satisfactory performance, fast response, flexible and easy implementation are the main objectives of any compensation strategy. The control strategies of a DSTATCOM are mainly implemented in the following steps:

- Measurements of system variables and signal conditioning
- Extraction of reference compensating signals
- Generation of firing angles for switching devices

![Fig.5 Schematic Diagram of DSTATCOM Control](image)
4.2.1 Basic Building Blocks of the D-STATCOM

Commonly Used Solutions to Improve Electric Power Quality

1). There are three ways that is commonly applied to improve voltage deviation of electrical power system. The most effective solution is reactive power compensation, as SVC - Static Var Compensator (typically, TCR-Thyristor Controlled Reactors and TSC-Thyristor Switched Capacitors), SVG - Static Var Generator and APFCC-Active Power Factor Correction Circuit. Other solutions include regulation of field current of synchromotor, application of on-load voltage regulation transformer.

2). A large number of When the STATCOM is applied in distribution system is called DSTACOM (Distribution-STACOM) and its configuration is the same, or with small modifications, oriented to a possible future amplification of its possibilities in the distribution network at low and medium voltage, implementing the function so that we can describe as flicker damping, harmonic filtering and long and short interruption compensation.

![Basic D-STATCOM Diagram](image)

Fig. 6 Basic D-STATCOM Diagram

Generally, the D-STATCOM configuration consists of a typical 12 pulse inverter arrangement, a dc energy storage device; a coupling transformer connected in shunt with ac system, and associated control circuits, as shown in Figure 6. The voltage source inverter converts an input dc voltage into a three phase output voltage at fundamental frequency. These voltages are in phase and coupled with the ac system through the reactance of the coupling transformer.

4.2.2 The Control Methods for the D-STATCOM

This section presents some recent approaches for controlling of D-STATCOM

(i) PWM based Control with only Voltage Measurement: This presented a new PWM based control scheme has been proposed that only requires voltage measurements and no reactive power measurements are required. The proposed control system only measures the rms voltage at the load point i.e., no reactive power measurements are required. The VSC switching strategy is based on a sinusoidal PWM technique which offers simplicity and good response. Because distribution network is a relatively low-power application, PWM methods offer a more flexible option than the fundamental frequency switching methods favored in FACTS applications. Besides, high switching frequencies can be used to improve on the efficiency of the converter, without incurring significant switching losses. The simulations carried out showed that the D-STATCOM provide excellent voltage regulation capabilities.

(ii) Adaptive Control Strategy for DSTATCOM: A novel adaptive control strategy for the DSTATCOM based on Artificial Immune System (AIS) is presented. In their proposed system optimal parameters of the controller are obtained first using the particle swarm optimization algorithm. This provides a sort of innate immunity (robustness) to common system disturbances. For unknown and random system disturbances, the controller parameters are modified online, thus providing adaptive immunity to the control system.
The control strategy employed in contains a GTO based square wave voltage source converter (VSC) is used to generate the alternating voltage from the DC bus. In this type of inverters, the fundamental component of the inverter output voltage is proportional to the DC bus voltage. So, the control objective is to regulate VDC as per requirement. Also, the phase angle should be maintained so that the AC generated voltage is in phase with the bus voltage. The schematic diagram of the control circuit is shown in Fig. 7.

(iii) Flexible DSTATCOM operation in voltage or current control mode: discussed the topology and control of a distribution static compensator (DSTATCOM) that can be operated flexibly in the voltage or current control mode. In the voltage control mode, the DSTATCOM can force the voltage of a distribution bus to be balanced sinusoids. In the current control mode, it can cancel distortion caused by the load, such that current drawn by the compensated load is pure balanced sinusoid. The proposed algorithm works properly irrespective of unbalance and harmonic distortions in load currents or source voltages.

(iv) The Lookup Table and Super capacitor energy storage system based DSTATCOM controlling: A new method in which firstly the D-STATCOM and Super-capacitor energy storage system are integrated and secondly, a feedback from out of the PI controller is situated for detecting the suitable proportional gain for any specific fault that is shown in Fig. 8. The Lookup Table arrangement in feedback is based on qualitative testing by individual parameter alterations. The proposed feedback improves the speed of dynamic response of controller system and mitigates the transient states, quickly.

Considering this fact that all types of fault may occur in distribution system, controller system must be able to mitigate any types of voltage sags. The integration and control of energy storage systems, such as super capacitor energy storage system (SCESS) into a DSTATCOM is developed to mitigate such problems, enhance power quality and improve system reliability.

(v) Battery energy storage system (BESS) based DSTATCOM controlling: This presented a BESS based control strategy for wind energy system. In their proposed scheme distribution static compensator
(DSTATCOM) is connected with a battery energy storage system (BESS) to mitigate the power quality issues. The battery energy storage is integrated to sustain the real power source under fluctuating wind power.

(vi) PHASE SHIFT CONTROL: The schematic diagram of phase shift control is shown in figure 3. In this method, the compensation is achieved by the measuring of the rms voltage at the load point, whereas no reactive power measurements are required. Sinusoidal pulse width modulation technique is used with constant switching frequency. The error signal obtained by comparing the measured system rms voltage and the reference voltage is fed to the proportional integral (PI) controller, which generates the angle for deciding the necessary phase shift between the output voltage of the VSC and the AC terminal voltage. This angle is summed with the phase angle of the balanced supply voltages, assumed to be equally spaced at 120 degrees, to produce the desired synchronizing signal required to operate the PWM generator. In this scheme, the DC voltage is maintained constant, using a separate battery source. It is observed that the source current and the source voltage are in phase, correcting the power factor of the system in case of a linearly varying load; whereas, complete compensation is not achieved in case of nonlinear load (source current THD 24.34%) though this strategy is easy to implement, is robust and can provide partial reactive power compensation without harmonic suppression, it has the following disadvantages

1. The controller does not use a self supporting DC bus and thus requires a very large DC source to pre charge the capacitor.
2. Balanced source supply as rms voltages assumed and the supply phase angle are calculated over the fundamental only.
3. No harmonic suppression and partial compensation is achieved in case of nonlinear loads

V. CONCLUSION

This review presented a brief overview of the functionality, topologies and applications of DSTATCOM. The review also presents review of the recent control algorithms used to enhance the performance or for specialized operation of DSTATCOM. The performance of voltage-sourced converter (VSC) with Pulse-width modulation (PWM) provides a faster control that is required for flicker mitigation purpose. The voltage regulation in the distribution feeder is improved by installing a shunt compensator. We proposed DSTATCOM is modeled and its performance is verified for power factor correction and voltage regulation along with neutral current compensation, harmonic elimination and load balancing with linear loads and non-linear loads.
REFERENCES:

