Analysis of Open Loop Distribution Static Compensator for Improving Power Quality

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Abstract - *This paper presents Distribution Static Compensator (D-STATCOM) modeled in the MATLAB SIMULINK toolbox for the mitigation of the power quality issues in the distribution system. DSTATCOM is one of the custom power device used in distribution system for power conditioning. DSTATCOM is developed for the compensating reactive power demanded by non-linear and unbalanced load. Also power factor of the source is improved and the Total Harmonic Distortion in the source currents is reduced. DSTATCOM can correct voltage sag, swell, unbalance by injecting the reactive current into the system. Instantaneous reactive power theory is used for obtaining reference source current for controlling DSTATCOM. The performance of the DSTATCOM for unbalanced and nonlinear load is demonstrated with the MATLAB simulation results.*

***Key Words*: Distribution Static Compensator (D-STATCOM); Power Quality; Battery energy storage system (BESS); Total Harmonic Distortion (THD).**

1. INTRODUCTION

Utility and customer-side disturbances result in terminal voltage fluctuations, transients, and waveform distortions on the electric grid. Just as flexible ac transmission systems (FACTS) controllers permit to improve the reliability and quality of transmission systems, these devices can be used in the distribution level with comparable benefits for bringing solutions to a wide range of problems. In this sense, FACTS based power electronic controllers for distribution systems, namely custom power devices, are able to enhance the reliability and quality of power that is delivered to customers. A distribution static compensator or DSTATCOM is a fast response, solid-state power controller that provides flexible voltage control at the point of connection to the utility distribution feeder for power quality (PQ) improvements. The primary aims of a shunt compensator in a distribution system are to cancel or suppress the effect of poor load power factor such that the current drawn from the source has a near unity power factor, the effect of harmonic contents in loads such that current drawn from the source is nearly sinusoidal, the dc offset in loads such that the current drawn from the source has no offset, the effect of unbalanced loads such that the current drawn from the source is balanced. It can exchange both active and reactive power with the distribution system by varying the amplitude and phase angle of the converter voltage with respect to the line terminal voltage, if an energy storage system (ESS) is included into the dc bus. The result is a controlled current flow through the tie reactance between the DSTATCOM and the distribution network. This enables the DSTATCOM to mitigate voltage fluctuations and to correct the power factor of weak distribution systems in instantaneous real-time. This paper discusses the dynamic performance of a DSTATCOM with ESS for improving the power quality of distribution systems. Modelling approaches are proposed, including a detailed modelling of the DSTATCOM.

1.1 Modeling of The STATCOM

A DSTATCOM consists of a three-phase voltage source inverter shunt-connected to the distribution network by means of a coupling transformer, as depicted in Fig. 1. Its topology allows the device to generate a set of three almost sinusoidal voltages at the fundamental frequency, with controllable amplitude and phase angle. In general, the DSTATCOM can be utilized for providing voltage regulation, power factor correction, harmonics compensation and load levelling. The addition of energy storage through an appropriate interface to the power custom device leads to a more flexible integrated controller. The ability of the DSTATCOM/ESS of supplying effectively extra active power allows expanding its compensating actions, reducing transmission losses and enhancing the operation of the electric grid. Various types of energy storage technologies can be incorporated into the dc bus of the DSTATCOM, namely superconducting magnetic energy storage (SMES), super capacitors (SC), flywheels and battery energy storage systems (BESS), among others.

However, lead-acid batteries offer a more economical solution for applications in the distribution level that require small devices for supplying power for short periods of time and intermittently. Moreover, BESS can be directly added to the dc bus of the inverter, thus avoiding the necessity of an extra coupling interface and thus reducing investment costs to illustrate the functioning of shunt compensator.

The use of power electronics based loads such as variable speed drive, inverter-based air conditioning, distributed generation and storage system, personal electronics and electric vehicle has given rise in issue of power quality. This Paper proposed a D-STATCOM for harmonic current mitigation and power factor correction, which result due to the use of non-linear loads in the modern EDN.

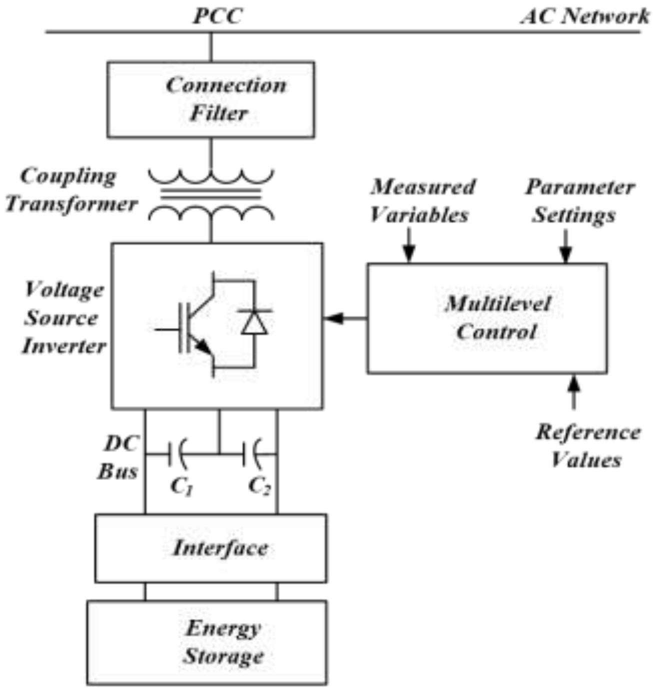

Fig -1: Block Diagram of D-STATCOM

Consider the three phase, four-wire (3p-4w) distribution system shown in Figure. All the currents and voltages that are indicated in this figure are instantaneous quantities. Here a three-phase balanced supply *(V_{sa}, V_{sb}, V_{sc})* is connected across a star (Y) connected load. The loads are such that the load currents *(i_{la}, i_{lb}, i_{lc})* may not be balanced, may contain harmonics and de offset. In addition, the power factor of the load may be poor. One implication of load not being balanced in this system is that there may be zero-sequence current i_{Nn} flowing in the 4th wire, i.e., in the path *n-n* as shown in Figure 2.

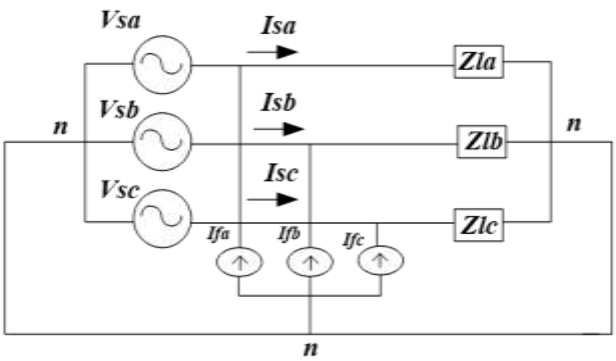

Fig -2: Distribution system

The shunt compensator is represented by three ideal current sources i_{la} , i_{lb} and i_{lc} The point of common coupling (PCC) is encircled in Figure 7.3. The current sources are connected in Y with their neutral *n'* being connected to the 4th wire. The purpose of the shunt compensator is to inject currents in such a way that the source currents *I_{sa}, I_{sb} I_{sc})* are harmonic free balanced sinusoids and their phase angle with respect to the source voltages *(Vsa Vsb Vsc)* has a desired value.

2. SYSTEM CONFIGURATION

A distribution feeder connected to unbalanced and nonlinear load is shown in the below Fig. 3 Working performance of the DSTATCOM using instantaneous reactive power theory (IRP) is analyzed by the modelling system shown in Fig.1 in MATLAB Simulink tool.

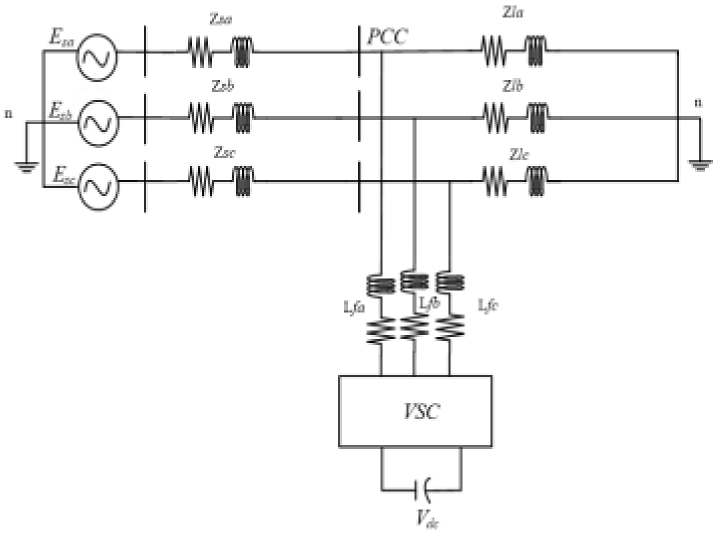

Fig -3: Distribution system with D-STATCOM

In the system diagram shown in above Fig. 3, Zs represents total impedance of phase which includes Rs and Ls 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. 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, Lf is connected on the AC side of the voltage source converter for compensating high frequency components of the compensating currents. Storage capacitor Cdc 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)

3. OPERATING MODE OF DSTATCOM

The DSTATCOM can be operated in two different modes as follows:

1. Voltage regulations mode
2. Current regulation mode

The current regulation mode can be divided into

A. Reactive power compensation mode

B. Active power compensation mode

3.1 Reactive power compensations mode

The static synchronous compensator regulate voltage as it's connection point by controlling the amount of reactive power that is absorbed from or injected into power system through a voltage source converter. This mode is analyzed by considering below three cases:

Case 1: When Vs = Vc

When source voltage Vs and voltage source converter [VSI] voltage are in phase as well as same in magnitude then both active and reactive power in the system is zero i.e. Q = 0 and P = 0. This is represented by phasor diagram as shown below:

Fig -4: Vs and Vc are in phase with equal magnitude

Case 2: When Vs <Vc

In this case, when source voltage is less than the voltage source converter [VSC] voltage i.e. in phase but different in magnitude then, the reactive power will inject by the STATCOM from the system and active power in the system is zero i.e. Q = some value and P = 0. Therefore, it is also known as capacitive mode, which is represented in phasor as shown below

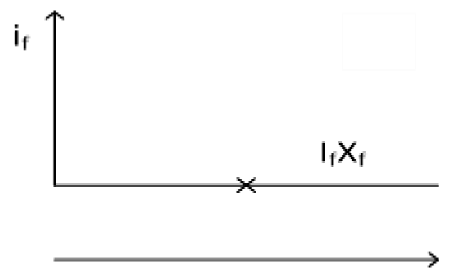

Fig -4: Vs< Vc are in phase with unequal magnitude

From the fig it shows that current lead the voltage drops by 90 degrees and also it leads 90 degrees by converter voltage

Case 3: When Vs >Vc

In this case, when source voltage is greater than the voltage source converter [VSC] voltage i.e. in phase but different in magnitude then, the reactive power absorbed by the STATCOM to the line and active power in the system is zero i.e. Q = some value and P = 0. Therefore, it is also known as inductive mode, which is represented in phasor as shown below

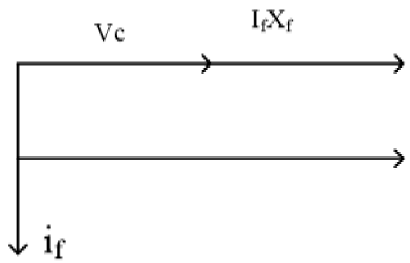

Fig -5: Vs> Vc are in phase with unequal magnitude

From the fig it shows that current lag the voltage drops by 90 degrees and also it lags 90 degrees by converter voltage

3.2 Active power compensations mode

The active power absorbed or injected by STATCOM is depends upon the angle between source voltage and voltage source converter [VSI] voltage. This mode is analyzed by considering below two cases

Case 1: When Vc < Vs

In this case, when the voltage source converter [VSI] voltage i.e. Vc lags the source voltage i.e. Vs then, active as well as reactive power it absorbed by the STATCOM from the system which is represented in below phasor

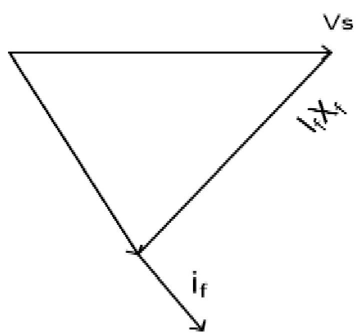

Fig -6: Vc<Vs with equal magnitude

Case 2: When Vc > Vs

In this case, when the voltage source converter [VSI] voltage i.e. Vc leads the source voltage i.e. Vs then, active as well as reactive power injected by the STATCOM from the system which is represented in below phasor

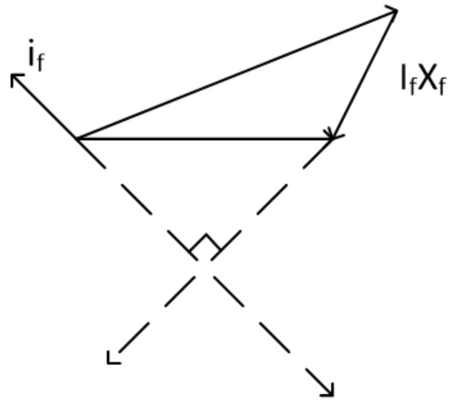

Fig -7: Vc<Vs with unequal magnitude

4. SIMULATION RESULTS

The performance of the DSTATCOM for power quality improvement in the distribution system is studied by observing waveforms of the different parameters of the system before compensation and after compensation.

A. Results before Compensation

It is observed that due to unbalanced and non-linear load, source currents and load currents get unbalanced and some distortion is present in their waveform. Also power factor of the source is not unity, as voltage at PCC and source currents are not in Phase with each other.

Fig. 8 shows the supply side voltage results of simulation without connecting the DSTATCOM for static unbalance load

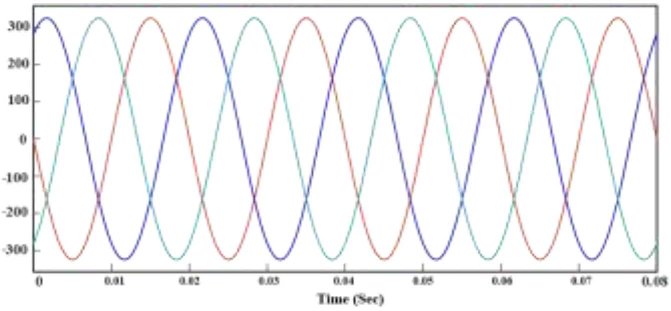

Fig -8: Supply side Voltage (v)

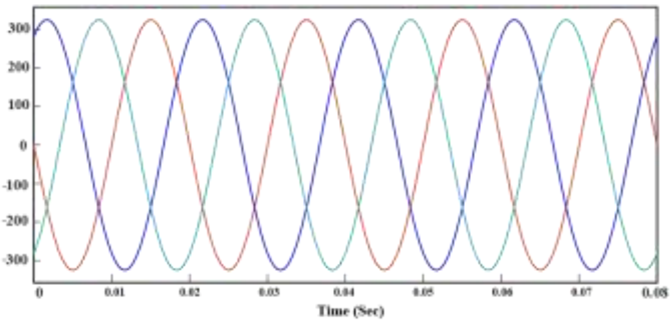

Fig -9: Load side Voltage (V)

Fig. 9 shows the Load side voltage results of simulation without connecting the DSTATCOM for static unbalance load

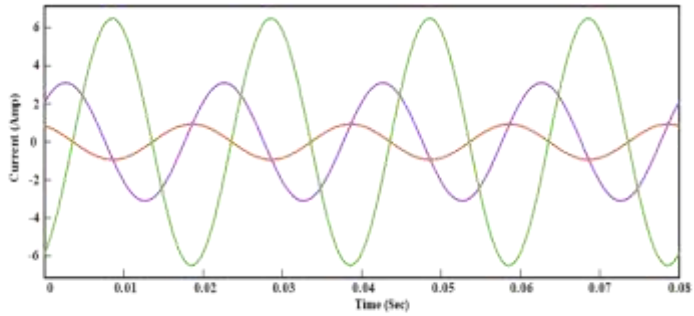

Fig -10: Load side Current (A)

Fig. 10 shows the Load Side Current results of simulation without connecting the DSTATCOM for static unbalance load

As the non-linear load is the sources of Harmonics. When the non -linear load is added in the load side, it introduced harmonics in the system. When nonlinear load added in the system the whole system becomes unstable and the waveform of the voltage and current distracted. In this paper Rectifier which is generally used to convert AC into DC considered as a non-linear load connected at the load side which introduce harmonics in the system. Power Electronics devices is the source of Harmonics and same power electronics device are used to mitigate the Harmonics.

Fig. 11 shows the Load Side Voltage results of simulation after the connections of nonlinear load without connecting the DSTATCOM

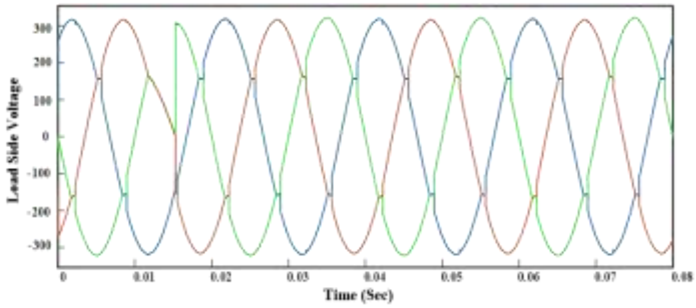

Fig -11: Supply side Voltage(V) after connection of Non linear Load

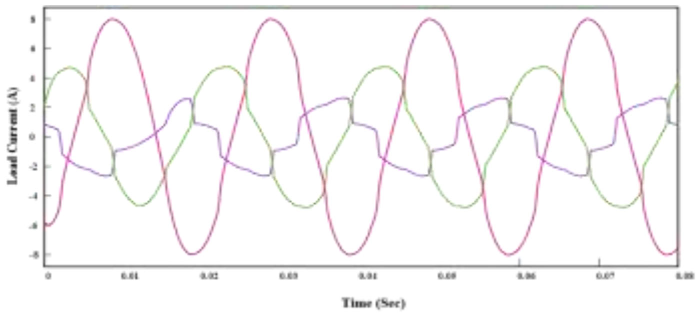

Fig -12: Supply side Current (A) after connection of Non linear Load

Fig. 12 shows the Load Side Current results of simulation after the connections of nonlinear load without connecting the DSTATCOM.

It is Observed that when any nonlinear load connected in the system then all system becomes unstable and harmonics is introduced in the system. Now Distribution Static Compensator is device which is used to improve Quality of power which means it make distorted waveform into purely sinusoidal waveform. Now After connection of such type of device the system becomes stable and remove harmonic contain from the voltage and current.

B. Results After Compensation

The main function of DSTATCOM is to provide reactive power as demanded by the load and mitigate the harmonics from the system. Therefore, with the help of DSTATCOM source currents are maintained at unity power factor and reactive power burden on the system gets reduced. Due to the compensation of the reactive power by DSTATCOM source has to supply only real power.

Traditionally, power quality issues have been addressed by the use basic devices such as passive filter, and more advanced filtering technologies, such as a static synchronous compensator, active power filter(APF), Dynamic Voltage Regulator, and Unified power quality conditioner (UPQC). After connecting DSTATCOM to the system it is observed from Fig. that load current is same which is drawn by load but source current is approximately sine wave, also source current and voltage at PCC are in phase with each other. So, power factor is maintained equal to unity.

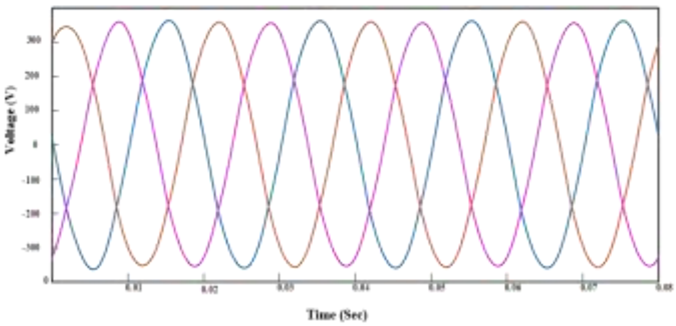

Fig -13: Supply Side Voltage(V) after the connection of D-STATCOM

As result shown in fig 13. The waveform of supply side voltage is become exactly sinusoidal after the connecting D-STATCOM; this is because of the mitigation of Harmonics from the system voltage.

Similarly, the harmonic mitigation done with the help of D-STATCOM from Load side voltage also. The result of Load side voltage after the connection of D-STATCOM is shown in Fig14

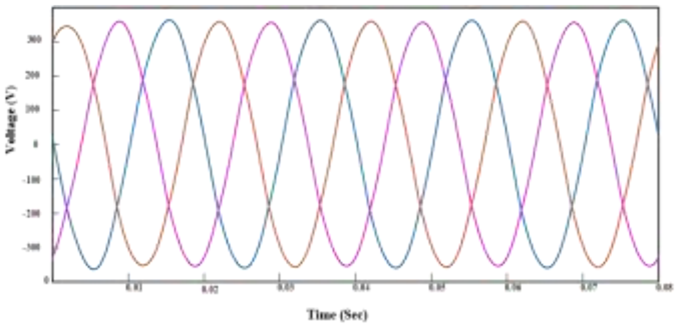

Fig -14: Load Side Voltage(V) after the connection of D-STATCOM

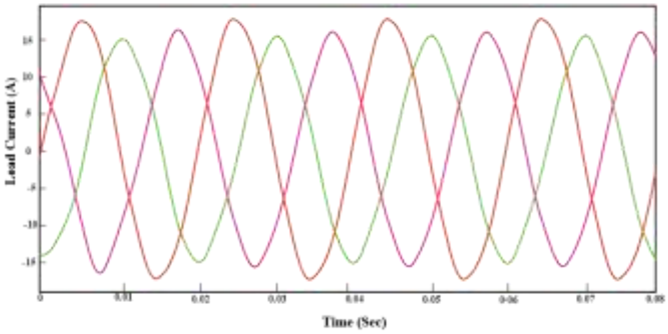

Fig -15: Load Side Current(A) after the connection of D-STATCOM

As the D-STATCOM is mitigate the harmonics from the system fig15 shows the current waveform of load which is nearly sinusoidal after the connection of custom power device like D-STATCOM.

VI. CONCLUSION

A Static compensator (STATCOM) is a flexible AC transmission system(FACTS) controller, which can either absorb or deliver reactive power to a power system. Distribution static Compensator(D-STATCOM) is proposed for compensation of reactive power and unbalance caused by various load in distribution system. Custom power devices can be used for power quality improvement in the distribution system. This paper proposed the working principal of D-STATCOM which is based on VSC principle and analysis done in system for normal operation, introduce harmonics in the system then connect D-STATCOM and Annalise the system after the connection of device. A D-STATCOM inject a current into the system to correct the voltage sag, swell, and power factor and also mitigate the harmonic contain introduce in the system because of non linear load.

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