Performance Analysis of DSTATCOM in Harmonic Mitigation Connected Across a Distribution System for Non-linear Load

Mrs. Surbhi Gour, Dr. Shivkumar Tripathi

Department of Electrical and Electronics Engineering
IASSCOM FORTUNE INSTITUTE OF TECHNOLOGY, BHOPAL (M.P.)

---***---

Abstract – *Recent some decades witness the peak in application of power electronic devices such as power converters used in high voltage transmission; customized power quality improvement converters; loads at consumer end like; laptop, power computers, versatile sensitive loads, high frequency drives with variable speed feature, UPS, etc. All these loads draw the harmonic current from the source leading to the injection high degree of distortion of the sinusoidal voltage and current of the distribution system. This harmonics in the supply system may result is sever stability issues. Hence the distortion generated due to non-linear loads must be rectified then and there. In this work a power quality conditioner used in distribution system to mitigate harmonics is presented. A Static Compensator (STATCOM), is a shunt connected active power filter which is widely adopted to reduce the harmonics in source voltage as well as current generated due to non-linear load. The proposed Distribution STATCOM (DSTATCOM) is designed with conventional voltage source converter. The performance analysis is presented for linear and non-linear loading. The harmonic content is compared with and without STATCOM connected. The power quality issues are also discussed with results which the proposed DSTATCOM addresses in distribution system.*

Key Words: Power Electronic Devices (PED), Power Quality (PQ), Modern Distribution System (MDS), Distribution Static Compensator (D-STATCOM), Synchronous Rotating Reference Frame (SRF).

1. INTRODUCTION

In modern power system, power electronic has a very strong predominancy. There has been a versatile load profile available using Power Electronic Devices (PED). These devices are good in efficiency since losses are low in semiconductor devices, highly reliability, life span is long and demands low maintenance cost. But they have disadvantages like; harmonic injection, low Power Factor (PF) and overloading capacity is also low since they perform only at rated voltage and current [1]. The adverse effect of PED is generation of current-related intrusion at their input, which injects noise into the utility system, and voltage intrusion at their outputs which may hinder the system stability and leads to various Power Quality (PQ) issues [2]. The PQ issues generated due to non-linear and unbalance loading can also be rectified by designing a proper PED based Converter (PEC). PECs are network of power/semiconductor switches which provide power conditioning with high efficiency and reliability. In Modern Distribution System (MDS) various PEC based power conditioning devices are available which are installed both at load-end and source-end to improve PQ of the system. This research presents the application of Distribution Static Compensator (D-STATCOM) for power quality compensation in MDS. The proposed topology is based on a Voltage Source Inverter (VSI), controlled by Sinusoidal- Pulse Width Modulation (S-PWM).

2. DSTATCOM

The D-STATCOM is a PEC which provides reactive power compensation. It is shunt-connected at a point of application in the MDS. The main building of the configuration of DSTATCOM is three-phase VSI [3]. VSI consist of three arms for three phase having 6 switches as shown in Fig. 1. Upstream is connected toward the substation and is modelled as three-phase source while downstream is connected across non-linear and unbalance load [4]. This will generate harmonic currents to represent the aggregate behavior of load. In this work control of the with three-phase inverter is designed so as to eliminate the harmonics produced by the loads such as personal computers, television sets, energy efficient lamps (fluorescent and LED). The D-STATCOM is shunt-connected across the load and injects current to mitigate harmonic and to make current drawn from the source (Is) sinusoidal and in phase with the voltage. The source side harmonics are filtered out with the filtering unit connected across the STATCO. The filter is active type whose output is controlled with respect to STATCOM. Hence system retains its characteristics and so as stability.

The D-STATCOM is shown in the figure 1, which consists of VSI unit shunted between source and load [5]. It injects required current I_{INJ} to compensate for harmonic load current in such a way so as the source draws sinusoidal current. The V_{DC} is the DC voltage across the DC side of VSI which is supplied by DC-link-capacitor. VSI is a conventional two level voltage source converter whose reference is the three phase voltages Va, Vb, Vc tracked from the source. Theses references are compared with the calculated three phase voltages of the system in order to obtain error free rectified output signals. This type of control in literature is termed as synchronous statuary frame control which is widely adopted in commercial as well as test system by the researchers.

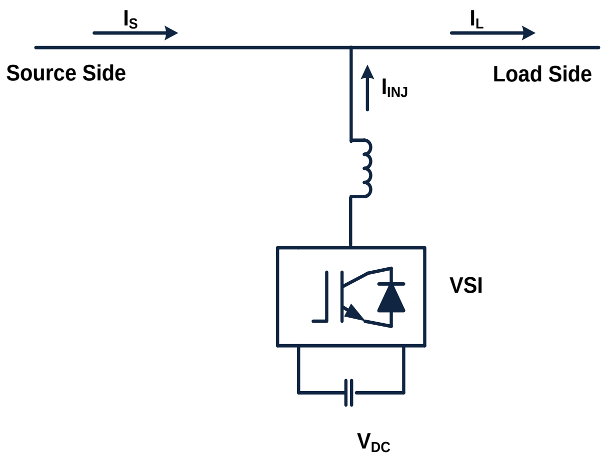

Fig. 1 Schematic of DSTATCOM

3. CONTROL OF DSTATCOM

The performance of the PV-D-STATCOM depends primarily on the control strategy adopted for VSI and the reference current detection technique used [7]. In this paper, for reference current detection, Synchronous Rotating Reference Frame (SRF) method has been adopted. The control for switching of power electronic switches of VSI is presented in figure 3. For gird SRF draws the three-phase reference signal of voltages and currents [8]. Three phase to two phase i.e., abc-dq0 transformation is carried out to obtain direct axis component equivalent in order to simplify the control design as presented Eq. (1). Phase Lock Loop (PLL) is used to calculate the phase angle of the reference signal [9]. A Low Pass Filter (LPF), removes the harmonics from direct axis current component I_d, PI controller calculates the magnitude of the pulses generated and fed to the dq0-abc transform to obtain the equivalent three phase output [10]. The synchronized three phase voltages obtained from PI controller is fed to the PWM generator to obtain the gate pulses for universal bridge.

$$\begin{bmatrix} Id \\ Iq \\ I0 \end{bmatrix} = \frac{\sqrt{2}}{3} \begin{bmatrix} cos\theta & cos(\theta - 120°) & cos(\theta + 120°) \\ -Sin\theta & -sin(\theta - 120°) & -sin(\theta + 120°) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} Ia \\ Ib \\ Ic \end{bmatrix} \quad (1)$$

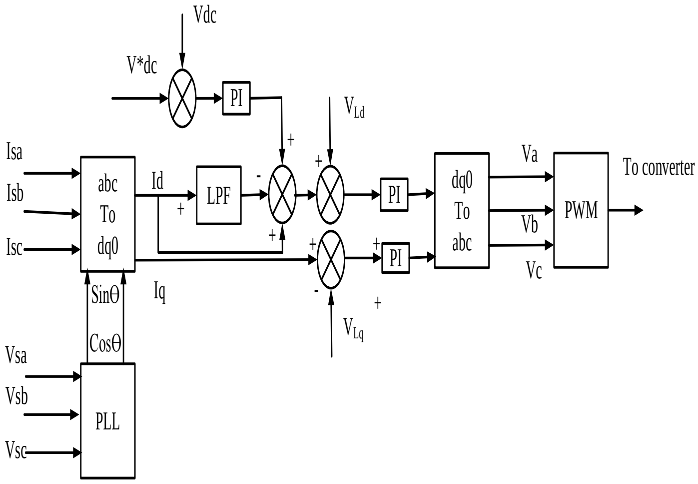

Fig. 2 Schematic diagram for the control of converter

4. SIMULATION RESULTS

In this work performance analysis of D-STATCOM has been presented using MATLAB (R2016a) in simulation environment of simulink tool-kit. Simulation model have been built with the configuration shown in figure 3. The parameters used for designing the system is presented in Table 1.

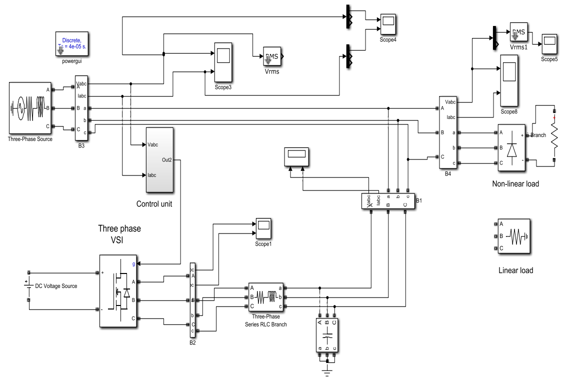

Fig. 3 Simulation model of D-STATCOM with linear and non-linear loading

TABLE I Design Parameters

Parameter	Values selected
Voltage, RMS (L-L)	415 V
Source impedance	1.58mH
Frequency	50 Hz
V_{DC}	1000V
Filter inductance L_f	310mH
Filter resistance R_f	0.1Ω
Filter capacitor C_f	500 uF

Three phase rectifier resistor R_{NLL}	125 Ω
Coupling capacitance	4500 µF
PI gains	0.04, 500
Linear load	1MW
Non-linear load	8KW
Variable load	1 KW, 20 KVAR inductive

The upstream portion of the system is comprising of a balanced three-phase voltage source having series impedance Z_s, and the load side is parallel with a three-phase rectifier connected with resistance of 40 Ω to model the non-linear loads. The voltage and current for non-linear loading without connecting the designed PV-D-STATCOM is presented in Fig. 4. When the controller is not connected, both load and source voltage as well as current get distorted due to the harmonics injected by the non-linear loading. The THD under this condition is presented in Fig. 5 for voltage and for current is presented in Fig. 6.

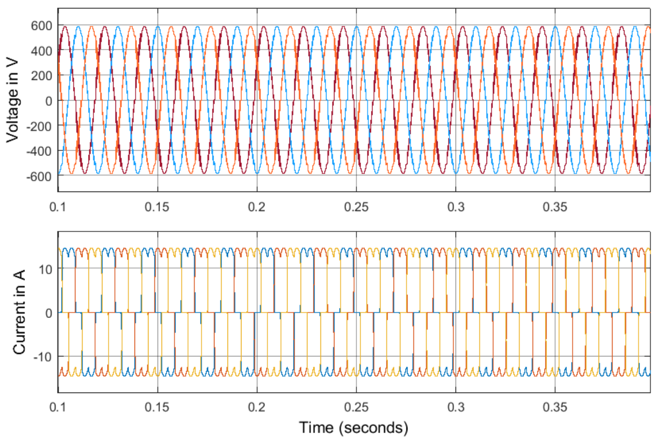

Fig. 4. Voltage and current both at grid side as well as load side for non-linear loading without D-STATCOM

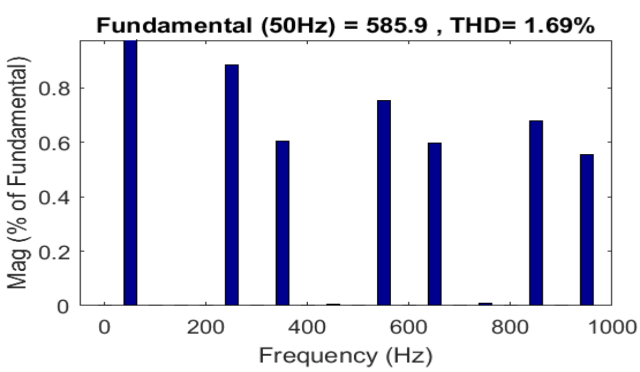

Fig. 5. THD of voltage for non-linear loading without D-STATCOM

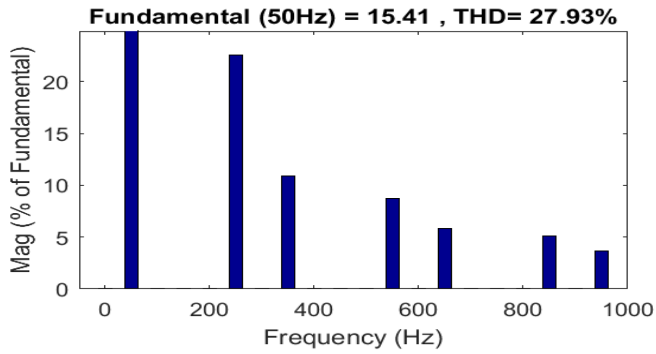

Fig. 6. THD of current for non-linear loading without D-STATCOM

When D-STATCOM is connected into the system, it eliminates the harmonics of voltage and current at source side and source draws the sinusoidal parameters with low THD as shown in Fig. 7. The THD of source voltage and current is presented in Fig. 8 and Fig. 9 respectively. It also reduces the load current as well as load voltage harmonics to 25 % and 0.5% respectively.

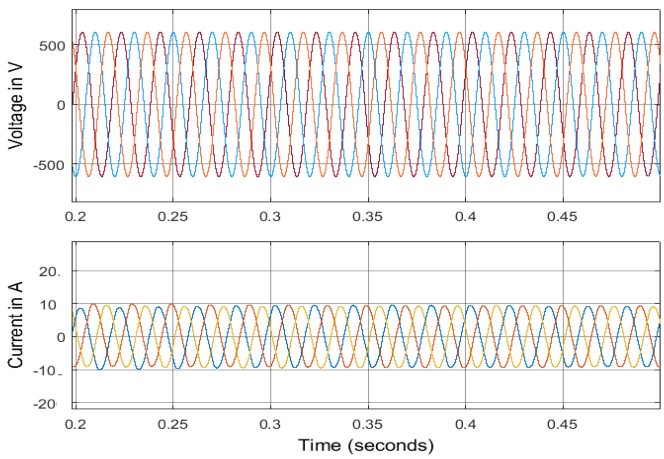

Fig. 7. Voltage and current both at grid side for non-linear loading with PV-D-STATCOM

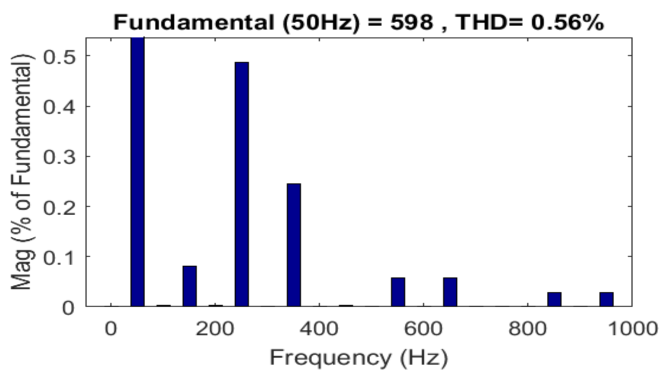

Fig. 9. THD of voltage for non-linear loading with PV-D-STATCOM

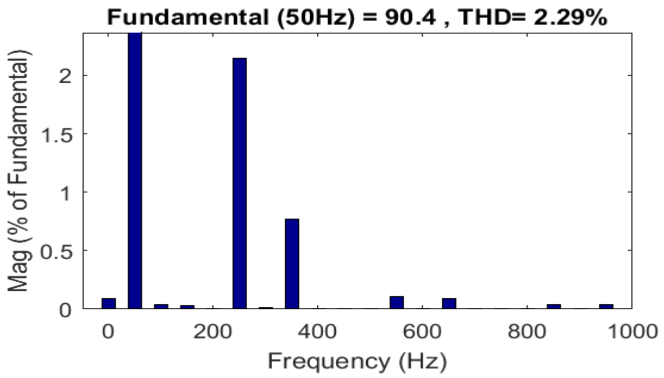

Fig. 10. THD of voltage for non-linear loading with PV-D-STATCOM

For better understanding of working of PV-D-STATCOM, pre and post connection waveforms of voltage is compared as shown in Fig. 11. The DSTATCOM supplies the required compensation current as shown in Fig. 12, to mitigate the source and load harmonics. PV supplies the required reactive power to mitigate the PQ issues generated due to non-linear loading.

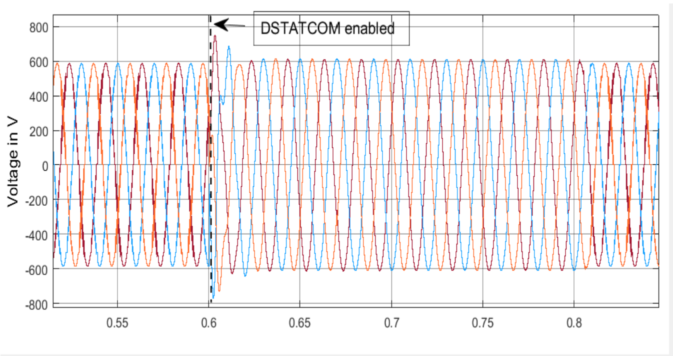

Fig. 11. Simulation results of the source voltage prior to and after enabling the D-STATCOM

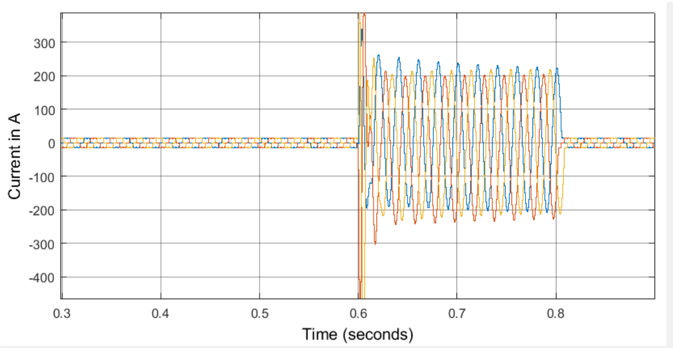

Fig. 12. Compensation current supplied by PV-D-STATCOM

the designed D-STATCOM is also capable of maintaining unity power factor, hence makes the source and load current in-Phase to voltage as shown in Fig. 13.

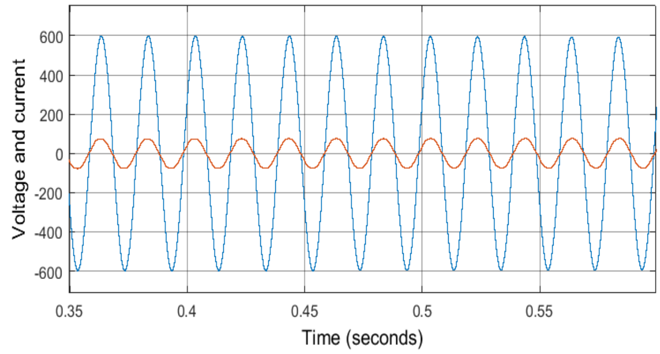

Fig. 13. In-phase voltage and current representing unity power factor

6. CONCLUSIONS

The DSTATCOM is very popular harmonic mitigation controller adopted in distribution system. Harmonics present a very sever threat to the present day highly burdened power system. It not only pollute the sinusoidal voltage and current waveforms but also results in power losses particularly active one since for the harmonics, system feeds the reactive power. This in turn results in the voltage deregulation. Hence harmonics needs a immediate action to mitigate it. In this work a versatile DSTATCOM is presented which affectedly mitigate the harmonics generated by non-linear loads.

REFERENCES

[1] Varma, R. K., & Siavashi, E. M. (2018). PV-STATCOM: A new smart inverter for voltage control in distribution systems. IEEE Transactions on Sustainable Energy, 9(4), 1681-1691.

[2] G. S. Bhattacharyya, J.M.A. Myrzik, W.L. Kling, Consequences of poor power quality - an overview, in: 2007 42nd International Universities Power Engineering Conference, 2007, pp. 651e656.

[3] P. Acuna, L. Moran, M. Rivera, J. Dixon, J. Rodriguez, Improved active power filter performance for renewable power generation systems, IEEE Trans. Power Electron. 29 (2) (2014) 687-694. Feb.

[4] U. Das Gupta, P. Das, M.A. Hoque, A fuzzy controlled shunt active power filter for reducing current harmonics and reactive power compensation, in: Presented at the 2015 International Conference on Electrical Engineering and Information Communication Technology (ICEEICT), 2015, 21-23 May.

[5] W.-K. Chen, Linear Network sand Systems. Belmont, CA: Wadsworth, 1993, pp. 123-135.

[6] Rohouma, W., Balog, R. S., Peerzada, A. A., & Begovic, M. M. (2020). D-STATCOM for harmonic mitigation in low voltage distribution network with high penetration of nonlinear loads. Renewable Energy, 145, 1449-1464.

[7] Kamran, F.; and Habetler, T.G.; (Jan. 1998). Combined deadbeat control of a series-parallel converter combination used as universal power filter. IEEE Transactions on Power Electronics, Vol. 13, No. 1, pp. 160-168.

[8] Aredes, M.; Heumann, K.; and Watanabe, E.H. (April 1998). An universal active power line conditioner. IEEE Transactions on Power Delivery, Vol. 13, No. 2, pp. 545-551.

[9] Muneer, V., & Bhattacharya, A. (December, 2018). Cascaded H Bridge Multi Level Inverter Based Unified Power Quality Conditioner. In 2018 IEEE 8th Power India International Conference (PIICON). pp. 1-6.

[10] Muneer, V., Bhattacharya, A., & Gupta, C. P. (December, 2018). Eight Switch CHB based Three-Phase Shunt Active Filter. In 2018 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES). pp. 1-6.

[11] Kouro, S., Malinowski, M., Gopakumar, K., Pou, J., Franquelo, L. G., Wu, B., & Leon, J. I. (2010). Recent advances and industrial applications of power converters. IEEE Transactions on industrial electronics, 57(8), 2553-2580.