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Three Phase Three Level Distribution STATCOM Integrated with Solar

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Abstract: ***Static compensator (STATCOM) is a shunt compensation installed to eliminate harmonics generated by non-linear and unbalanced loading condition. Also there has been an increase use of Power Electronic Devices (PED) in control and sensitive equipments. Due to this sinusoidal voltage and current waveforms get distorted both at source side and load side. In this paper three phase-three level Distribution STATCOM (DSTATCOM) is designed to eliminate harmonics and to mitigate PQ issues generated due to harmonics. Also, the designed DSTATCOM is capable of integrating solar power with the AC utility system. Hence PV-DSTATCOM supplies active as well as reactive power demand of the system.***

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

I. 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). The PEC has their own power requirement which is generally supplied by DC-batteries. These batteries are conventionally charged via grid. In this work the Photovoltaic (PV) generated DC power is utilized to charge the battery of DSTATCOM. Hence STATCOM here provide duple application of providing PQ compensation as well as integrating Photo-Voltaic (PV) with the utility system as PV-DSTATCOM. PV here operates in two modes;

1) Supplying active power to the load.
2) Supplying reactive power for providing PQ compensation.

Simulation results in MATLAB are presented to corroborate the effectiveness of the approach.

II. PV Connected STATCOM (PV-DSTASTCM)

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 Figure 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 also PV with three-phase inverter and other harmonics producing loads such as personal computers, television sets, energy efficient lamps (fluorescent and LED). The D-STATCOM is shunt-connected and injects current to mitigate harmonic and to make current drawn from the source (I_s) sinusoidal and in phase with the voltage.

The D-STATCOM in the figure 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. In the proposed work, this capacitor is charged through PV power as shown in Figure 2. This serves two purposed; one reduces the dependency on Non-Renewable Sources (NRS) and another is compensating for the harmonic currents generated due to non-linear and reactive loading [6].

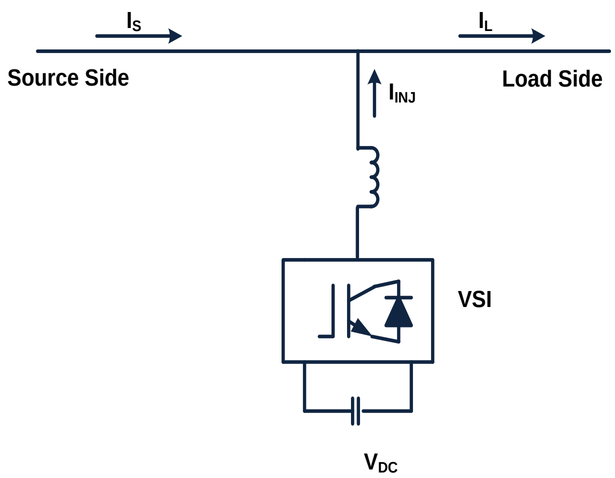

Figure 1: Schematic diagram of D-STATCOM

A PV-array is designed with 10 series and 20-parallel module generating 60 KW of power. PV has intermittent behavior that means with the change in solar irradiance and temperature, output generated varies. To track the maximum output at particular instant, incremental and conductance MPPT algorithm is applied. MPPT helps in tracking maximum voltage as well as current for the given irradiance and temperature.

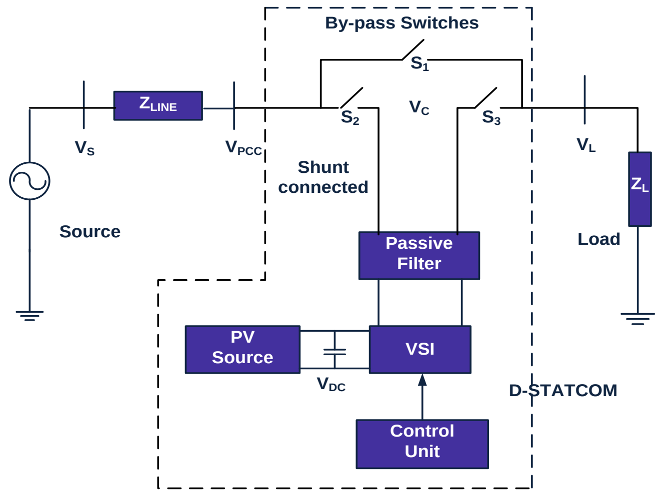

Figure 2: Schematic diagram of PV-D-STATCOM

III. Control of PV-DSTATCOM

The performance of the PV-DSTATCOM 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.

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

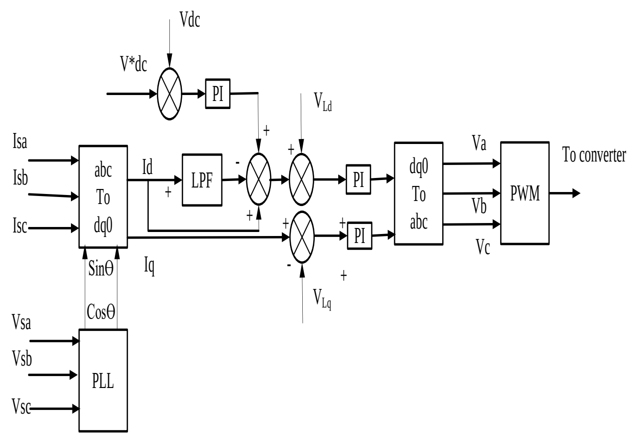

Figure 3: Schematic diagram for the control of converters

IV. Modeling and Simulation of PV-DSTATCOM

The proposed PV-DSTATCOM has been analysed using MATLAB (R2016a) in simulation environment of simulink tool-kit. Simulation model have been built with the configuration shown in 4. The parameters used for designing the system is presented in Table 1.

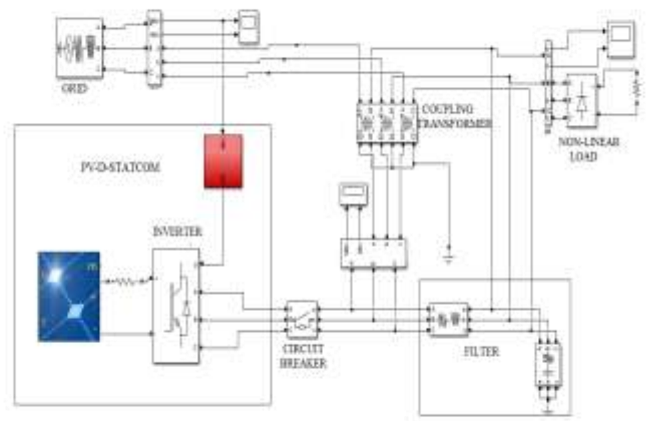

Figure 4: Simulation model of PV-D-STATCOM

Table I: Design Parameters

Parameter	***Values selected***
Voltage, RMS (L-L)	415 V
Source impedance	1.58mH
Frequency	50 Hz
PV rating	60 KW
PV DC voltage	600 V
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 Figure 5. 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 Figure 6 for voltage and for current is presented in Figure 7.

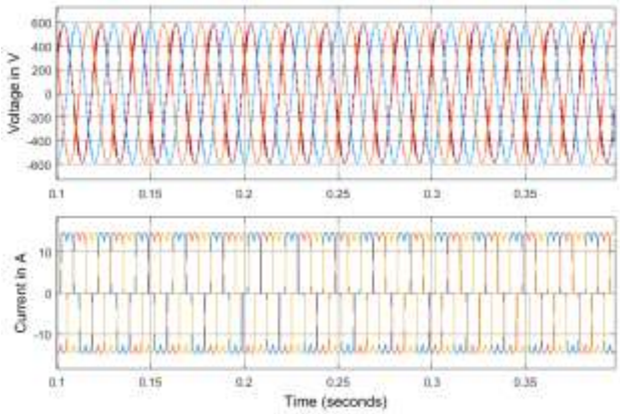

Figure 5: Voltage and current both at grid side as well as load side for non-linear loading without PV-D-STATCOM

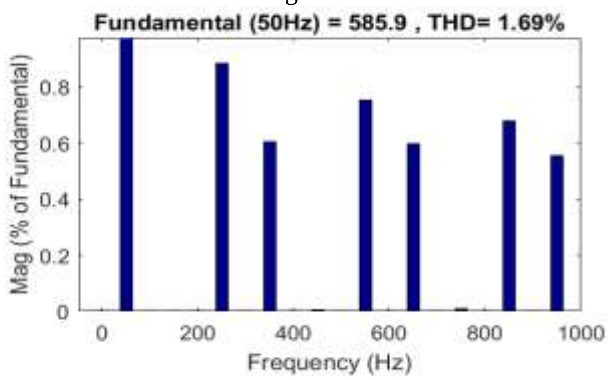

Figure 6: THD of voltage for non-linear loading without PV-D-STATCOM

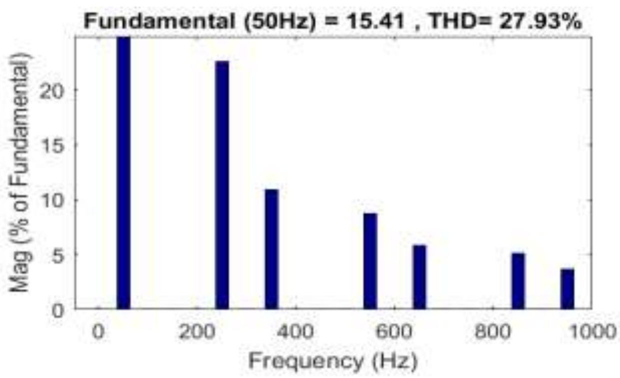

Figure 7: THD of current for non-linear loading without PV-D-STATCOM

When PV-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 Figure 8. The THD of source voltage and current is presented in Figure 9 and Figure 10 respectively. It also reduces the load current as well as load voltage harmonics to 25 % and 0.5% respectively.

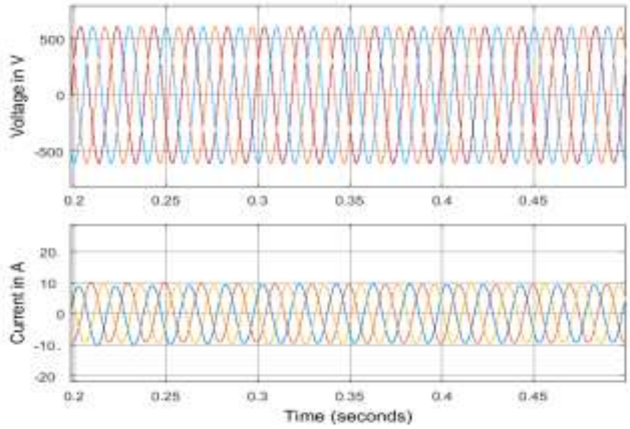

Figure 8: Voltage and current both at grid side for non-linear loading with PV-D-STATCOM

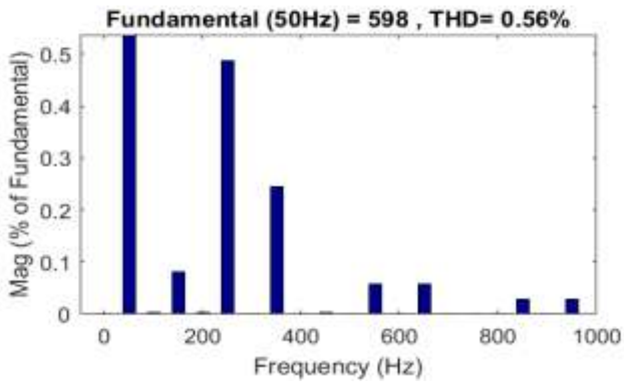

Figure 9: THD of voltage for non-linear loading with PV-D-STATCOM

For better understanding of working of PV-D-STATCOM, pre and post connection waveforms of voltage is compared as shown in Figure 11.

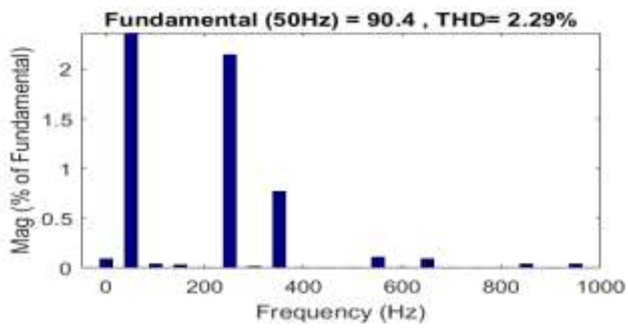

Figure 10: THD of current for non-linear loading with PV-D-STATCOM

The DSTATCOM supplies the required compensation current as shown in Figure 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.

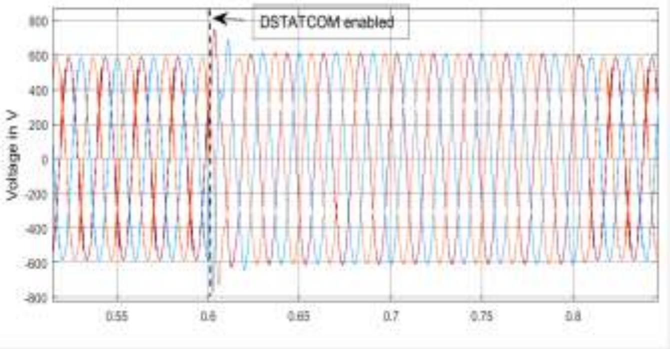

Figure 11: Simulation results of the source voltage prior to and after enabling the D-STATCOM

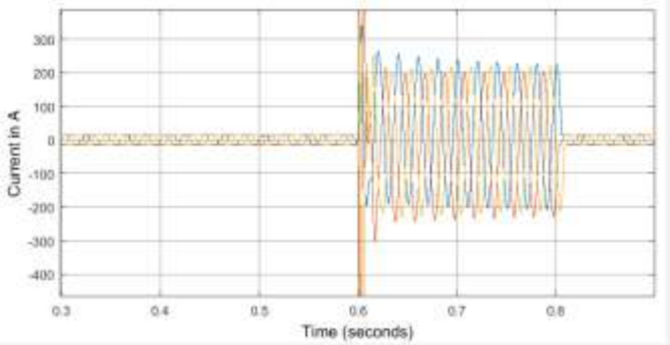

Figure 12: Compensation current supplied by PV-D-STATCOM

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

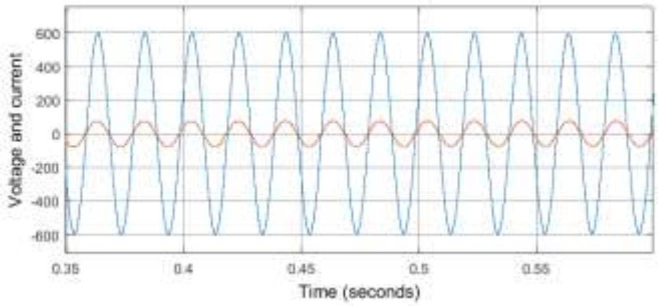

Figure 13: In-phase voltage and current representing unity power factor

V. Conclusion

This paper presents a PV-D-STATCOM which is a simple and robust controller designed for harmonic current mitigation and power factor correction. Due to extensive non-linear loading and increased renewable sources in MDS, there has been an increase in harmonic which results in generation of various PQ issues. The PV-D-STATCOM is designed using conventional three phase two-level VSI. The VSI is controlled using SRF method which enables instantaneous control of the active and reactive power. PV-D-STATCOM is a shunt-connected device which can alleviate the harmonic at the source, also preventing the propagation of undesirable harmonics further into the system which may hinder the operation of other equipments connected in the network. PV plays power is supplied to the load as well as it charges the battery of STATCOM to provide desire compensation. At the time when solar irradiation is not available, it behaves as a classic STATCOM only required reactive power demand to mitigate various PQ issues.

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