CHAPTER 4

PV SUPPORTED DSTATCOM WITH SOGI-PLL BASED
UVT CONTROL SCHEME

4.1 INTRODUCTION

In the chapter 3, the PV integrated DSTATCOM with UVT control scheme has been presented. The simulation results obtained for PV-DSTATCOM employing UVT control algorithm show that THD level has been reasonably reduced at the source current. The obtained results from the UVT control scheme inferred that the current harmonic alleviation may be improved by using the modified PLL. In this chapter, the obtained results of SOGI-PLL based UVT control algorithm used for PV-DSTATCOM show that the current harmonic distortions in the source current are quiet diminished below 2%. In order to enhance the performance of the UVT control algorithm, the SOGI based PLL has been proposed in the UVT generator. The PV integrated DSTATCOM provides the long lasting current based compensation in the three-phase four-wire distribution systems. The detailed simulation studies are carried out for different voltage and load conditions to confirm the compensation ability of the proposed PV integrated DSTATCOM with SOGI-PLL based UVT control scheme.

4.2 SOGI-PLL BASED UVT CONTROL SCHEME

The performance of the PV supported DSTATCOM be determined by the reference current signal generation scheme. The reference current signal is used to revoke the harmonic component and balance the reactive power of the power distribution system. As a result of the connection of a nonlinear load in the distribution system, a non-sinusoidal load current flows
through the system impedance and imposes distorted voltage at the PCC. The SOGI-PLL based UVT control scheme for PV-STATCOM is shown in Figure 4.1.

![Figure 4.1 SOGI-PLL based UVT control scheme for PV-DSTATCOM](image)

The instantaneous load current can be expressed in the Equations (4.1), (4.2) and (4.3)

\[
i_{La} = I_{La1} \sin (wt - \phi_{a1}) + \sum_{n=2}^{\infty} I_{Lan} \sin (n wt - \phi_{an})
\]

\[
i_{Lb} = I_{Lb1} \sin (wt - \phi_{b1}) + \sum_{n=2}^{\infty} I_{Lbn} \sin (n wt - \phi_{bn})
\]

\[
i_{Lc} = I_{Lc1} \sin (wt - \phi_{c1}) + \sum_{n=2}^{\infty} I_{Lcn} \sin (n wt - \phi_{cn})
\]

After the compensation, the fundamental real component of the source current is estimated at the Equations (4.4), (4.5) and (4.6)

\[
I_{sum} = \left| I_{La1} \right| \cos \phi_{a1}
\]
\[ I_{shm} = \left| I_{Lb1} \right| \cos \phi_{b1} \quad (4.5) \]
\[ I_{scm} = \left| I_{Lc1} \right| \cos \phi_{c1} \quad (4.6) \]

The DC link voltage of DSTATCOM may vary from its reference value due to the switching losses, filter losses and changing load. The DC link voltage of the DSTATCOM is regulated by using a PI controller (Yada & Murthy 2014; Singh & Solanki 2009; Fallah et al. 2015). The output of the voltage regulator \( I_{SR} \) is added in to the amplitude of the source current to be supplied for compensation. In the balanced system, the peak value of current supplied by the source can be expressed as:

\[ I_{sm} = \left( \frac{I_{sam} + I_{shm} + I_{scm}}{3} \right) + I_{SR} \quad (4.7) \]

The reference source current should be sinusoidal with the magnitude identical to \( I_{sm} \) and as well in phase with the source voltage for providing better compensation. Hence, the estimated peak value of the source current is multiplied with the unit template \( (U_a, U_b, U_c) \), which are in phase with the source voltage. The unit templates are derived with the use of SOGI PLL is shown Figure 4.2. The SOGI-PLL generates the orthogonal signals. At this instant, the orthogonal signals in a Cartesian coordinate frame are converted into a polar coordinate frame. The mandatory phase correction is executed through the sine generator. The internal structure of the SOGI-PLL is shown in Figure 4.3.

The reference source current is estimated at

\[ i_{sa}^* = I_{sm} \ U_a = I_{sm} \ \sin (wt) \quad (4.9) \]
\[ i_{sb}^* = I_{sm} \ U_b = I_{sm} \ \sin (wt - 120^\circ) \quad (4.10) \]
\[ i_{sc}^* = I_{sm} \quad U_c = I_{sm} \sin (wt + 120^\circ) \] (4.11)

The actual measured load current is compared with the estimated reference source current to calculate the filter reference current. This filter reference current is compared with the measured filter current and the error signal \((\Delta i_{abc})\) is given to a hysteresis comparator to produce the switching pulses to the VSI of the DSTATCOM.

\[ \text{Figure 4.2 SOGI PLL is employed to derive Unit Templates} \]

\[ \text{Figure 4.3 Internal structure of SOGI-PLL} \]

4.3 SIMULATION RESULTS OF SOGI-PLL BASED UVT CONTROL SCHEME

In this paper, the SOGI-PLL based UVT control scheme for the photovoltaic supported DSTATCOM is assessed through the digital
simulation using MATLAB/Simulink. This simulation study has been carried for different load conditions such as balanced voltages and load currents, balanced voltages with unbalanced load currents and unbalanced voltages with unbalanced load currents. The simulation study described before and after the installation of compensator.

4.3.1 Case 1: Balanced Voltages with Balanced Loads

In this case, the balanced supply voltage and balanced load are applied to the distribution system. Figure 4.4 shows the simulation output waveforms for case 1: distorted load current without implementation of DSTATCOM, the current supplied by the DSTATCOM and compensated source current with the implementation of DSTATCOM.

![Simulation output waveforms for case 1](image)

**Figure 4.4** Simulation output waveforms for case 1: (a) distorted load currents without implementation of DSTATCOM (b) Current supplied by DSTATCOM (c) Compensated source current with the implementation of DSTATCOM
(b) Current supplied by the DSTATCOM

(c) Compensated source currents with the implementation of DSTATCOM

Figure 4.4 (continued)
The compensated voltage and source current in phase with source voltage is depicted in Figure 4.5. The proposed DSTATCOM identifies the current based distortions and injects suitable compensating current into the PCC.

(a) Load voltage after the installation of DSTATCOM

(b) Source voltage and source current in phase-A

Figure 4.5 Active and reactive power compensation results
The single-phase APF with Zig-zag transformer is employed for compensating the neutral current. Figure 4.6 shows the neutral current compensation results: Neutral current before and after implementation of the single-phase APF with Zig-zag transformer.

![Diagram](image)

(*a*) Before installation of APF

![Diagram](image)

(*b*) After installation of APF

**Figure 4.6 Neutral current before and after installation of APF**

For the testing voltage interruption compensation, the supply voltage is reduced to 0V from its nominal voltage level. When the voltage interruption
is detected, the DTSATCOM injects the compensating voltage to the system; hence the voltage interruption does not affect the sensitive/critical load. Figure 4.7 shows the simulated supply voltage during voltage interruption and compensated load voltage with the implementation of DSTATCOM.

(a) Simulated supply voltage during voltage interruption

(b) Compensated load voltage

Figure 4.7 Simulated supply voltage with and without voltage interruption compensation
The PV array output voltage (120V) is given to the voltage-doubler boost converter, which is stepped up to 520V for maintaining the DC link of the DSTATCOM. The PV array output voltage, voltage-doubler boost converter and DC link voltage of the DSTATCOM are shown in Figure 4.8.

Figure 4.8 PV array output voltage, Voltage-Doubler boost converter output voltage and DC-link voltage of DSTATCOM
The DC-link voltage changes during the connection of non-linear load and disconnection of non-linear load is shown in Figure 4.9. During the connection non-linear load voltage dip occurs in the DC link voltage after a few power cycle, it reaches the stable state. Because of the new reference voltage attained based on the connected load current. Whenever disconnect the nonlinear load in the distribution system, DC link voltage rises a few power cycles after it comes to a stable state.
The calibrated harmonic distortions in the source current without and with the installation of PV supported DSTATCOM with UVT based control scheme are depicted in Figure 4.10 and 4.11. The values of harmonic distortion were 24.36%, 24.35 and 25.01% before the PV supported DSTATCOM was installed. After the installation of PV supported DSTATCOM, the values
decrease to the feasible levels. The measured values are 1.16%, 1.15% and 1.02% as shown in Figure 3.15.

Figure 4.10 Current harmonic distortions in the source currents before installation of compensator
Figure 4.11 Current harmonic distortions in the source currents after installation of compensator

Fundamental (50Hz) = 21.54, THD = 1.16%

Fundamental (50Hz) = 21.55, THD = 1.15%

Fundamental (50Hz) = 21.55, THD = 1.02%
4.3.2 Case 2: Balanced voltages with unbalanced Loads

In this case, the performance of the PV-DSTATCOM is tested under a balanced voltage and unbalanced load condition. Figure 4.12 shows the simulation results of load current prior to installation of the PV-DSTATCOM, the current supplied by DSTATCOM, compensated source currents after installation of PV-DSTATCOM and source voltages after compensation.

(a) Distorted load current without compensation

(b) Current supplied by DSTATCOM

Figure 4.12 Simulation output waveforms for case: 2 balanced voltages with unbalanced Loads
The current harmonic distortions in the source current before installing the PV supported DSTATCOM is 25.13%, 26.10% and 27.60% in the phase-A, B and C respectively are shown in Figure 4.13 and Figure 4.14 shows the harmonic distortion level in the source current after the mitigation with the installation of the PV supported DSTATCOM; its measured distortion level is 1.50%, 1.28% and 1.15%.
Figure 4.13 Current harmonic disturbances in the load without implementation of compensator
Figure 4.14 Current harmonic disturbances in the source with implementation of compensator
During the supply voltage interruption the PV/battery bank provides the continuous supply voltage to the load associated in the power distribution system. The backup capacity of the battery is analyzed from its discharge characteristic curves. The battery discharge characteristics for different load currents are shown in Figure 3.15. The simulated discharge characteristics show the backup time for different load current ratings.

![Discharge characteristics of the battery for different load currents](image)

**Figure 4.15 Discharge characteristics of the battery for different load currents**

### 4.3.3 Case 3: Unbalanced voltages with unbalanced loads

The proposed topology is validated performance under the unstable voltages and load currents. The unbalanced load current before installing the compensator, the compensation current and source current after compensation is depicted in Figure 4.16. The proposed DSTATCOM identifies the current based distortions and injects suitable compensating current into the PCC. The voltage and reactive power compensation results are shown in Figure 4.17. The compensated voltage and source current in phase with source voltage is depicted in Figure 4.17(b).
(a) Load current before implementation of DSTATCOM

(b) Injected current by the compensator

Figure 4.16 Current compensation results for case: 3 unbalanced voltages with unbalanced loads
(c) Source current after the implementation of compensator

Figure 4.16 (continued)

(a) Load voltages after installing the compensator

Figure 4.17 Active and reactive power compensation results
The measured harmonic distortions in the source current without and with the installation of PV supported DSTATCOM with UVT based control scheme are depicted in Figure 4.18 and 4.19. The values of harmonic distortions were 24.53%, 25.11% and 29.64% before the compensator was installed. After the installation of the compensator, the values decrease to the feasible THD levels. The measured values are 1.42%, 1.35% and 1.06% as shown in Figure 4.19. Simulation results display that the PV supported DSTATCOM with UVT based control scheme compensates harmonic components as well as other disturbances in the power distribution system.
Figure 4.18 Current harmonic distortions in the source current before installation of compensator
Figure 4.19 Current harmonic distortions in the source current after installation of compensator
4.4 SUMMARY

SOGI-PLL based UVT control scheme for PV integrated DSTATCOM and its simulation results are presented in this chapter. SOGI based PLL and internal structure of the SOGI are also described. The PV system/battery supplies the power to the DC link of the DSTATCOM. The proposed PV integrated DSTATCOM provides long duration compensation against current based distortions and reactive power burden. In this chapter, the obtained results of SOGI-PLL based UVT control algorithm used for PV-DSTATCOM show that the current harmonic distortions in the source current are quiet diminished below 2%.