Control of a multi-functional grid-connected solar PV system using instantaneous reactive power (PQ) theory for current harmonic alleviations

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Abstract: In recent years, the advance usages of non-linear loads have led to the serious power quality problem in the distribution system. Non-linear load will inject the current harmonics and cause power quality problem at Point of Common Coupling (PCC). This problem can be improved by using power filter. Power filter can be divided into passive power filter and active power filter. Passive filter is an appropriate solution to solve power quality problem in term of harmonic mitigation due to a simple circuit, low cost and less energy requirement. However, active power filter (APF) is more suitable due to better performance to solve power quality problem for current harmonics issue. This paper focuses in designing the application of a multi-functional grid-connected solar PV system integrated with DSTATCOM by using Instantaneous Reactive Power (PQ) theory controller to mitigate the current harmonics injected by non-linear load at the distribution system. MATLAB/SIMULINK software is used to simulate the performance of the multi-functional GCPV based SAPF according to IEEE Standard 519:2014 which THD of the line current at the Point of Common Coupling (PCC) should be less than 8%.

1. Introduction

The increasing of global energy demand due to economic globalization has introduced advance usage of power electronic devices for home appliances and industrial automations. The widespread use of power electronics devices for home appliances are air conditioning, lighting, refrigerators, personal computers, battery chargers and etc. Meanwhile, since industrial automation requires higher energy efficient operation, thus the industrial loads are mostly driven by power electronic devices like variable speed drives and convertor for accurate controllability, higher efficiency and faster response. However, these extensive usages of power electronic devices in the distribution system have increased power quality problems like harmonics distortion, flickers, notches, sags, swells and others that can affect other loads i.e microelectronic devices which are sensitive to disturbance from AC mains supply[1]–[3].The modern major problem that always occurs is harmonics distortion. Most of the domestic loads behave as non-linear loads because of the widely usage of switching devices such as MOSFET, BGT and IGBT. The switching operation by these device leads to power factor reduction and increase the harmonic distortions. Non-sinusoidal current waveforms have been formed by these switching actions. These switching operations also will inject the harmonic current to the grid system. Harmonic current will affect the voltage supply that make the voltage drop excessively and losses of grid line. Besides that, system efficiency will decrease and the value of power factor increase when the harmonic occur in the system[4].
Topology of DSTATCOM is important to improve the power quality in the distribution system. The best technology to eliminate the current harmonic is by DSTATCOM. There are two types of topologies in the DSTATCOM which are voltage source inverter (VSI) and current source inverter (CSI). The different topologies between VSI and CSI are the connection of capacitor and inductor at the DC and AC side where for the VSI, the series inductor is connected at the AC side and the capacitor is connected at the DC link. On the other hand, the series capacitor is connected at the AC side and the inductor is connected at the DC link for CSI. However, VSI commonly is the most choice of user in DSTATCOM application. DSTATCOM is created on different application in distribution system. The application can be in three different application which are single-phase two-wire, three-phase three-wire and three-phase four-wire [5]–[8].

A multi-functional grid-connected solar photovoltaic (GCPV) integrated with DSTATCOM have been proposed by many researchers for providing active power as well as improving the power quality of the distribution system. The combination of GCPV based DSTATCOM is capable to supply DC power from the sunlight and convert the power through inverter system to get AC power for the distribution system during daytime. Then, DSTATCOM will perform its capability as a power quality improvement device in the absence of solar irradiances and cloudy days which can increase the functionality of the GCPV. DC-DC boost converter is used to regulate PV output at the DC side of the voltage source inverter (VSI) of the GCPV and also acts as an important component to fully utilise the PV power by tracking the MPPT of PV modules[9].

2. Methodology

Figure 1 shows the schematic diagram of a three-phase three-wire GCPV based DSTATCOM which involves the AC mains, PV array, DC link capacitor, interfacing filter, nonlinear load and VSI based DSTATCOM at the distribution system. The selection of DC bus voltage (V$_{dc}$), DC link capacitor (C$_{dc}$), and interfacing inductor (L$_{f}$) are based on Equation (1) – (3) which given the V$_{dc}$ to be chosen as 700 V, 0.01 F for the C$_{dc}$ and 2.5 mH for the L$_{f}$[10]. The detail parameters of the Sunpower SPR-415E-WHT-D PV array with peak power capacity of 32.5 kW is tabulated in Table 1.

![Figure 1. Schematic Diagram of a GCPV based DSTATCOM.](image-url)
In order to develop the PWM switching of the DSTATCOM compensating current at the PCC, the value of $V_{dc}$ must be greater than the AC mains voltage. $V_{dc}$ can be calculated by using Equation (1) with the modulation index, $m$ which is assumed as 1 and line-to-line voltage of the AC mains, $V_{ll}$ is 415V. Hence, the calculated $V_{dc}$ is 677.69V which can be rounded to 700V. The value of $C_{dc}$ can be obtained by Equation (2) where, $V_{dc}$ is 700V and $V_{dc1}$ is 677.69V. The overloading factor ($a$), the variation of energy during extreme transient conditions at load perturbation($k$) and time ($t$) are assumed as 1.2, 0.1 and 0.04sec. Hence, the calculated $C_{dc}$ is 0.0088 F and rounded to 0.01 F. The value of $L_f$ can be determined by Equation (3) which results of 2.5mH. The value of $V_{dc}$ is selected as 700V, $i_{crpp}$ as 3.9A, the modulation index ($m$), the overload factor ($a$), switching frequency ($f_s$) are 1, 1.2 and 10kHz respectively.

$$L_f = \frac{\sqrt{3} m V_{dc}}{12 \times a \times f_s \times i_{crpp}}$$  \hspace{1cm} (3)$$

### Table 1. Solar PV Array Parameters.

| Parameter                        | Rating |
|----------------------------------|--------|
| Voltage at maximum point, $V_{mpp}$ | 72.9 V |
| Current at maximum point, $I_{mpp}$   | 5.69 A |
| No. of PV panel in series      | 2      |
| No. of PV panel in parallel    | 40     |

The instantaneous reactive power (PQ) theory is used for extraction the real fundamental frequency component of the load current which will be used as the reference line current for DSTATCOM switching as shown in Figure 2. The VSI based DSTATCOM is controlled through Clark transformation of three phase quantities ($a$, $b$, $c$) to two quantities of $\alpha$ and $\beta$ frame as well as the calculation of its active and reactive power in this frame and the hysteresis current controller. The PWM switching produced by the DSTATCOM consists of six signals for the compensating currents[11].

![Figure 2. Block diagram of instantaneous reactive power (PQ) theory for GCPV based DSTATCOM.](image)

### 3. Result & Discussions

The steady state performance of the GCPV based DSTATCOM under nonlinear load is shown in Figure 3 (a-d). It can be observed that the distorted line currents at the PCC ($i_{sa}$, $i_{sb}$, $i_{sc}$) in Figure 3 (b) due to the connected nonlinear load can be improved with GCPV based DSTATCOM as the line currents become almost balanced and sinusoidal as depicted in Figure 3 (a). By using the instantaneous reactive power (PQ) theory for GCPV based DSTATCOM controller, the harmonic contents in the line currents are also reduced from 30.54% to 7.08% according to the IEEE-519:2014 guidelines on the order of THD less than 8% as shown in Figure 3 (c) – (d).

The performance of GCPV based DSTATCOM have been shown in Figure 4 (a) – (e) for the impact of varying solar irradiances in PV array supporting the DC link capacitor from 1000 W/m$^2$ to 200 W/m$^2$. The decrease in solar irradiances will decrease the solar PV output but the DC bus voltage remains stable during the variation. Thus, the GCPV based DSTATCOM can provide harmonic elimination with the THD of the line currents are still acceptable below 7.08%.
Figure 3. (a) Three phase line current at PCC \(i_{La}, i_{Lb}, i_{Lc}\) (b) Load currents \(i_{Lr}, i_{Ld}, i_{Lc}\) (c) THD of line currents after compensation (d) THD of line currents before compensation

Figure 4. THD of line currents after compensation under varying solar irradiances
(a) 1000W/m\(^2\) (b) 800 W/m\(^2\) (c) 600W/m\(^2\) (d) 400 W/m\(^2\) (e) 200 W/m\(^2\)

4. Conclusions

This paper presents the modeling and simulation of multi-functional grid-connected solar PV system integrated with DSTATCOM by using Instantaneous Reactive Power (PQ) theory for current harmonic elimination due to the connected non-linear load at the distribution system. The performance of the GCPV based DSTATCOM is evaluated with varying solar irradiances for the solar PV array connected at the DC link capacitance of the VSI in the DSTATCOM system. Test results have demonstrated the satisfactory performance of the GCPV based DSTATCOM for current
harmonic alleviations under variable solar irradiance cases with THD of the line currents at the PCC are found to be within the limit of IEEE-519:2014 guideline.

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