
DESIGN AND PERFORMANCE ANALYSIS OF THREE-PHASE SOLAR PV INTEGRATED UPQC

MOTUKURI VISHNU 1*, K KATYAIENI 2*
1. II. M.Tech , Dept of EEE, AM Reddy Memorial College of Engineering & Technology, Petlurivaripalem.
2. Asst. Prof, Dept. of EEE, AM Reddy Memorial College of Engineering & Technology, Petlurivaripalem.

ABSTRACT: In this paper, the design and performance of a three-phase solar PV (photovoltaic) integrated UPQC (PV-UPQC) are presented. The proposed system combines both the benefits of distributed generation and active power filtering. The shunt compensator of the PV-UPQC compensates for the load current harmonics and reactive power. The shunt compensator is also extracting maximum power from solar PV array by operating it at its maximum power point (MPP). The series compensator compensates for the grid side power quality problems such as grid voltage sags/swells by injecting appropriate voltage in phase with the grid voltage. The dynamic performance of the proposed system is simulated in Mat lab-Simulink under a nonlinear load consisting of a bridge rectifier with voltage-fed load.

Keywords— Power Quality, DSTATCOM, DVR, UPQC, Solar PV, MPPT, PCC, PV-UPQC

I. INTRODUCTION

In the modern electrical world with the increase in integration of renewable energy systems such as solar PV energy and wind energy into modern electrical distribution systems owing to its benefits of being eco-friendly. However, these energy sources are discontinuous in nature. With the proliferation of the power semiconductor devices such as power diodes, thyristors, IGBTs, GTOs etc. over the last quarter a century. They increase controllability of the equipment but at the same time power quality and efficiency decreases. They provide the polluted load current and voltage waveforms. With the increase in installation of renewable energy sources and nonlinear loads results in various power quality problems both at load side and grid side. Since renewable energy sources like solar PV energy and wind energy are intermittent, their increased used in distribution systems leads to power quality problems like voltage sags/swells, interruption, flicker and eventually instability in the grid [1]. These power quality problems can also lead to frequent malfunctioning of power electronic systems and
false triggering of electronic systems and increased capacitor banks heating etc [2]–[4].

Current quality issues are usually caused by the nonlinear loads connected in the power distribution systems. These nonlinear loads inject harmonics into distribution system. These current harmonics distorts the point of coupling (PCC) voltage especially in weak grids apart from causing distribution cables losses and transformers. Custom power devices such as distribution static compensator (DSTATCOM), dynamic voltage restorer (DVR) and unified power quality conditioner (UPQC) are used to mitigate power quality problems caused at the load side as well as at grid side. DSTATCOM [5] is a shunt connected power electronic device which compensates for the power quality issues caused by loads such as reactive current, harmonics in the system. DVR is a series connected power electronic device which counteracts for the grid voltage sag/swells [6]–[10]. UPQC is the combination of shunt and series compensator which combines functionality of both DSTATCOM and DVR for the power quality enhancement [7]. Recently the concept of integration of distributed generation sources with active power filters [8]–[10] have been reported in the literature. The integration of PV array with UPQC [11]–[12] has numerous advantages such as grid power quality enhancement, load side power quality improvement, active power injection. In this paper, the design and performance analysis of a three-phase PV-UPQC is presented. The dynamic performance of PV-UPQC is analyzed under conditions of grid voltage disturbances and irradiation variations. The load used is a nonlinear load consisting of an uncontrolled bridge rectifier along with.

II. SYSTEM CONFIGURATION AND DESIGN

The structure of the PV-UPQC is shown in Fig.1. The PV-UPQC is designed for a three-phase system. The shunt compensator is connected at the load side to handle the current quality issues. The solar PV array is directly integrated to the DC-link of UPQC through a reverse blocking diode. The series compensator is connected at the grid side to compensate for the grid voltage sags/swells and other voltage disturbances. The shunt and series compensators are integrated to the grid through interfacing inductors. A series injection transformer is used to inject the generated voltage by the series compensator into the grid[2]. Ripple filters are used to filter harmonics generated due to switching action of

![Fig. 1. System Configuration PV-UPQC](image-url)
power electronic converters. The load used is a nonlinear load along with the bridge rectifier.

The design of PV-UPQC involves the appropriate sizing of PV array, DC-link capacitor, DC-Link voltage level etc. The rating of solar PV module used to realize PV array is given in Table-I. The PV array rating is selected as 18 kW as given in Table-II. The rating is such that, under nominal conditions the PV array supplies a part of the load active power and remaining load active power is drawn from the grid[2][3]. The shunt compensator is simulated to compensate a nonlinear load consisting of a bridge rectifier with R-L load of 5Ω and 20mH and also supply a peak power output of 18 kW from the PV array at the same time. As the PV array is directly integrated to the DC-link of UPQC, the PV array sizing is such that the MPP voltage and desired DC-link voltage is equal[3]. The PV module is based on Panasonic Solar Module PE255PBBB. The solar PV array is made with a combination of three strings each containing 23 SPV modules. The SPV module and SPV array specification is given in Table-1.1 and Table-1.2 respectively.

### III. SYSTEM MODELING AND DESCRIPTION

#### CONTROL ALGORITHM

The UPQC system consists of a three-phase supply and three-phase nonlinear loads. A shunt connected VSC is interfaced to the supply system via interfacing inductor. The DSTATCOM is modeled using the MATLAB/Simulink environment. The control objective for the shunt portion of the UPQC is described below. The control algorithm for the DSTATCOM portion of the UPQC [4]. The objective of the DSTATCOM is to enhance the power quality of the supply current as well as to support the common DC bus of the DSTATCOM and DVR by absorbing active power and to estimate the reference supply currents and the gating pulses for the IGBTs of the VSC of the DSTATCOM. The reference supply currents are derived from the sensed PCC voltages (v,sa,v,sb,v,sc), load currents (i,La,i,Lb,i,Lc), and the common DC bus voltage (v,dc)[4]. The load currents from the abc frame are first converted to the dq0 frame as follows:

$$
\begin{bmatrix}
\text{d}i_a \\
\text{d}i_b \\
\text{d}i_c \\
\end{bmatrix} =
\begin{bmatrix}
\cos \theta & \cos(\theta - 2\pi/3) & \cos(\theta + 2\pi/3) \\
\sin \theta & \sin(\theta - 2\pi/3) & \sin(\theta + 2\pi/3) \\
1/2 & 1/2 & 1/2 \\
\end{bmatrix}
\begin{bmatrix}
i_a \\
i_b \\
i_c \\
\end{bmatrix}
$$
Where \( \cos \theta \) and \( \sin \theta \) are obtained using a three phase PLL over PCC voltages. A PLL signal is obtained from PCC terminal voltages for generating fundamental unit vectors for conversion of sensed currents to the dqo reference frame. The SRF controller extracts DC quantities by low pass filter (LPFs) and hence the non-DC quantities (ripple) are separated from the reference signal[4]. The d-axis and q-axis currents consists of DC and ripple (negative sequence and harmonics) components:

\[
\begin{align*}
i_{ld} &= i_{idc} + i_{idac} \\
i_{iq} &= i_{idc} + i_{idac} \\
i_{sc} &= i_{idc} + i_{idac}
\end{align*}
\]

The control strategy considers that the supply must deliver the mean value of the direct-axis component of the load current along with the active power component current for maintaining the DC bus and the meeting losses (\(i_{loss}\)) in the UPQC. The output of the PI controller at the DC bus voltage of the UPQC is considered as the current (\(i_{loss}\)) for meeting its losses[4].

\[
i_{loss}(n) = i_{loss}(n-1) + k_{pd} \left(v_{dl}(n) - v_{de}(n-1) + k_{id}v_{de}(n)\right)
\]

(1.4)

where \(v_{de}(n) = v^*_{de} - v_{DC}(n)\) is the error between the reference (\(v^*_{DC}\)) and sensed (\(v_{DC}\)) DC voltage at the \(n\)th sampling instant. And the \(K_{pd}\) and \(K_{id}\) are the proportional and integral gain constants of the DC bus voltage PI controller [4]. Therefore, the amplitude of reference supply current is \(i^*_{d} = i_{idc} + i_{loss}\) (1.5) The reference supply current must in phase with voltage at PCC but with no zero-sequence component. It is therefore obtained by the reverse park’s transformation with \(i^*_{q}\) and \(i^*_{0}\) as zero[4]. The resultant dq0 currents are again converted into the reference supply currents using the reverse park’s transformation. A PWM current controller is used over the reference and sensed supply current to generate the gating signals for the IGBTs of the VSC of the DSTATCOM[4].

![Figure 2 Control Algorithm of shunt controller][2]

The available model (in MATLAB) of IGBTs with an antiparallel diode is used to realize the VSC of the DVR. The series RLC component of SPS block set is used to realize the filter inductor and ripple filter of the DVR. The linear transformers, which include losses, are used for modeling the series injection transformers of the DVR[4]. The control algorithm is implemented using Simulink blocks. The control algorithm for the DVR of the UPQC in which the synchronous reference frame theory is used for reference signal generation. The PCC voltages(\(v_{s}\)), supply currents (\(i_{s}\)), the load terminal voltage (\(v_{L}\)) are sensed for deriving the IGBT gate signals[4]. The PCC voltages are converted to the rotating reference frame using the abc – dq0 conversion using the park’s transformation with unit vectors (\(\sin \theta, \cos \theta\)) derived from the supply currents using a PLL.

\[
\begin{bmatrix}
    v_{sq} \\
    v_{sd} \\
    v_{so}
\end{bmatrix} =
\begin{bmatrix}
    \cos \theta & \cos(\theta - 2\pi/3) & \cos(\theta + 2\pi/3) \\
    \cos(\theta - 2\pi/3) & \cos(\theta) & \cos(\theta + 2\pi/3) \\
    \cos(\theta + 2\pi/3) & \cos(\theta) & \cos(\theta - 2\pi/3)
\end{bmatrix}
\begin{bmatrix}
    v_{sa} \\
    v_{sb} \\
    v_{sc}
\end{bmatrix}
\]

(1.6)

The reference load voltage in the abc frame is obtained by reverse park’s transformation.
The reference load voltage \(v^*_{La}, v^*_{Lb}, v^*_{Lc}\) and the sensed load voltages \(v_{La}, v_{Lb}, v_{Lc}\) are used in PWM voltage controller unit to generate gating pulses to the VSC of DVR. The PWM voltage controller is operated with a switching frequency of 10kHz.

The PV-UPQC is designed for a three-phase system. The shunt compensator is connected at the load side. The solar PV array is directly integrated to the DClink of UPQC through a reverse blocking diode. The series compensator operates in voltage control mode and compensates for the grid voltage sags/swells. The shunt and series compensators are integrated to the grid through interfacing inductors. A series injection transformer is used to inject voltage generated by the series compensator into the grid. Ripple filters are used to filter harmonics generated due to switching action of converters. The load used is a nonlinear load consisting of a bridge rectifier with a voltage-fed load.[2]

**SIMULATION RESULT AND PERFORMANCE EVALUATION**

The steady state and dynamic performance of PV-UPQC is analyzed by simulating the PV-UPQC system in Matlab-Simulink. The load used is a non-linear load of \(R=5\) Ω and \(L=20\) mH consisting of three phase diode bridge rectifier. The grid is modeled with a source impedance of \(2\) mH. The PV module is modeled based on Panasonic Solar Module PE255PBBB.

**A. STEADY STATE OPERATION OF PV-UPQC**
The steady state operation of PV-UPQC is shown in Fig. 5 and 6. The sensed signals are point of common coupling (PCC) voltages, load voltages, DC-link voltage, solar PV array current, solar PV array power, grid currents, phase a, b, c load current, phase a, b, c shunt compensator currents and irradiation. All three phases are shown in case of load current and shunt compensator currents and they are symmetrically 120 degree apart. The DC-link voltage is maintained at 700V which is the MPPT point of the solar PV array. The load current harmonics are compensated by the shunt compensator thus maintaining the grid currents sinusoidal.

The harmonic spectra and THD at point of common coupling (PCC) voltage, load voltage, load current and grid current are shown in Fig. 7, Fig. 8, Fig. 9 and Fig. 10. It is observed that the load current THD is 21.4% and the grid current THD is 1.44%. The load current harmonics are compensated by the shunt compensator thus maintaining the grid currents sinusoidal and at unity power factor. The PCC voltage THD and load voltage THD are also limited to below 5%, thus meeting the requirements of IEEE-519 standard[13].
It is observed that the load voltage THD is 4.54% and the grid voltage THD is 0.43%. The load voltage harmonics are compensated by the series compensator thus maintaining the grid voltage pure sinusoidal. The PCC voltage THD and load voltage THD are also limited to below 5%, thus meeting the requirements of IEEE-519 standard[13].

**PERFORMANCE OF PV-UPQC UNDER VARYING IRRADIATION**

The dynamic performance of PV-UPQC under varying solar irradiation is shown in Fig.11. The sensed signals are PCC voltages, load voltages, DC-link voltage, solar PV array current, solar PV array power, grid line current, load currents, shunt compensator currents and irradiation. The solar irradiation is varied from 1000 W/m² to 700 W/m² between 0.4 to 0.68s. It is observed that as irradiation decreases, the PV array output reduces and hence the load draws more active current from the grid and the shunt compensator mainly compensates for load harmonics and reactive power apart from maintaining the DC-link within at desired voltage of 700V.

The simulation results shows that under the varying irradiation between 0.4 to 0.68 , the constant power is maintained at the load side by PV-UPQC.

The dynamic performance of PV-UPQC under conditions of grid sags/swells is shown in Fig.14. The irradiation (Irr) is at 1000 W /m² . The various sensed signals are grid voltages, grid line currents, load currents, series compensator voltages, DC-link voltage, solar PV array current, solar PV array power, grid line currents, load line currents,
shunt compensator currents. Between 0.3 to 0.5 there is a voltage interruptions, but the load voltage is maintained a constant value by the shunt inverter. during the voltage interruptions shunt inverter only provides power to the load side. The voltage of DC bus maintains a constant value by the support of PV array during interruptions. Between 0.5 to 0.7 there is a voltage swell but the load voltage is maintained a constant value by the series inverter. Between 0.7s and 0.8s, there is voltage sag of 0.2 pu and the series compensator compensates for the grid voltage under these conditions by injecting a suitable voltage in opposite phase with the grid voltage disturbance to maintain the load voltage at rated voltage condition. Hence, a constant load voltage is achieved using PV-UPQC.

CONCLUSION:

The dynamic performance of three-phase PV-UPQC has been analyzed under conditions of variable irradiation and grid voltage sags/swells. It is observed that PV-UPQC mitigates the harmonics caused by nonlinear and maintains the THD of grid voltage, load voltage and grid current under limits of IEEE-519 standard. The system is found to be stable under variation of irradiation from 1000 $W/m^2$ to 600 $W/m^2$. It can be seen that PV-UPQC is a good solution for modern distribution system by integrating distributed generation with power quality improvement.

REFERENCES:

