INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 40 (2015) 15267–15277

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/he

# Design and simulation of a unified power quality conditioner fed by solar energy

Yahia Bouzelata [a], Erol Kurt [b,*], Rachid Chenni [a], Necmi Altın [b]

[a] University Constantine, Faculty of Technology, Department of Electrotechnic, MoDERNa Laboratory, Constantine 25000, Algeria

[b] Gazi University, Faculty of Technology, Department of Electrical and Electronics Engineering, 06500 Teknikokullar, Ankara, Turkey

ARTICLE INFO

Article history:
Received 7 January 2015
Received in revised form
15 February 2015
Accepted 21 February 2015
Available online 16 March 2015

Keywords:
Power quality
Unified power quality conditioner
PV
THD active power filter

ABSTRACT

Presently, quality problems in grid-integrated applications take great interest because of the growing applications in power electronics. The elimination of the harmonics in the grid and the usage of clean energy resources in the power electronics applications become popular world widely. In the present paper, a unified power quality conditioner fed by solar energy which can also export active power to the grid is proposed. The conditioner uses a photovoltaic (PV) system and its topology is made up of a hybrid active power filter combination. This combination bases on a parallel active power filter, which shares a common DC voltage assured by the photovoltaic system with a serial active power filter. According to the analyzes, the proposed unified power quality conditioner eliminates both the supply current distortion caused by a non-linear load and the load voltage distortion introduced after adding fifth and seventh harmonics to the AC main voltage. In addition, the proposed unified power quality conditioner exports the photovoltaic power to the grid using a boost converter, perturbed and observed maximum power point tracking algorithm, compensates the reactive power and filters the current and voltage harmonics confirmed by the total harmonic distortion values, such as 4.76% and 3.86%, respectively. The design and the analyses have been performed with MATLAB/Simulink software. The simulation system determines the performances of such system and offers future perspectives on unified power quality conditioners.


## Introduction

The renewable energy resources are the best solutions for the clean energy requirement of the recent communities. Due to its wide application areas, easy construction and maintenance, the photovoltaic (PV) solar energy is the most promising green energy field [1–3]. Thus, the numerous examples of successfully deployed PV systems are already available for commercial usages and also technical researches [4–6]. The PV based solar energy explorations have been improved further by focusing on their grid integration. In fact, the improvements in power electronics technology have accelerated the usage of PV supplied inverter systems as

* Corresponding author.
E-mail address: ekurt@gazi.edu.tr (E. Kurt).
http://dx.doi.org/10.1016/j.ijhydene.2015.02.077

**Nomenclature**

| | |
|---|---|
| $I_{pv}$ | photocurrent, A |
| $I_0$ | diode saturation current, A |
| $q$ | coulomb constant, $1.602 \times 10^{-1\ 9}$C |
| $k_B$ | Boltzmann's constant, $1.381 \times 10^{-23}$ J/K |
| THD | total harmonic distortion |
| $V_m$ | maximum voltage, V |
| $\omega$ | modulation which is given by $2\pi f$ |
| $p$ | active power |
| $\bar{p}$ | DC component of $p$ |
| $\tilde{p}$ | AC component of $p$ |
| PWM | pulse-width modulation |
| IGBT | insulated-gate bipolar transistor |
| T | cell temperature, 25 °C = 298 K |
| $\alpha$ | P–N junction ideality factor |
| $R_s$ | series resistance of the cell, Ω |
| $R_{sh}$ | shunt resistance of the cell, Ω |
| $V_{dc}$ | DC voltage, V |
| K | gain which is given by $1/V_m$ |
| * | reference quantities |
| $q$ | reactive power |
| $\bar{q}$ | DC component of $q$ |
| $\tilde{q}$ | AC component of $q$ |
| GTO | gate turn-off thyristor |
| LPF | low-pass filter |

much as grid integration capabilities efficiently [7]. However, the proliferation of nonlinear loads due to their compact size and better controllability such as static power converters has deteriorated power quality by switching actions. Whenever, these systems are connected to the utility, they cause certain harmonics, subharmonics or superharmonics in voltage and current patterns [8,9]. They also pose themselves as loads having poor displacement, which draw considerable reactive power from the utility [10], thereby these problems can cause a malfunctioning in the electrical equipment. Different types of passive filters have been proposed to filter these harmonics and to compensate reactive power. On the other hand, a numerous drawbacks of the passive filters exist such as causing larger system size and resonant problems, being effective for only specified harmonic ranges such as 5th, 7th, 11th and 13th and for specific loads [10–12]. Therefore that gives a good motivation to carry out researches in the area of passive filter.

In order to enhance the quality of power by considering voltage and current distortion limits for non-linear loads, many systems have been proposed [8–11]. In addition to suppress the current/voltage distortion, one may also handle other problems for instance, swells, sags, current/voltage imbalance, flickers, surges, reactive currents, frequency oscillation, interruptions [13]. Mainly the systems are classified into three categories: First is the unified power flow controller (UPFC) which performs power flow control, voltage regulation and reactive power compensation as an equipment for compensation at the system frequency. Second is the unified power quality conditioner (UPQC) which combines a series active filter for harmonics-voltage compensation with a shunt active filter for harmonic-current compensation as a new equipment controlled to perform current and voltage compensation. Third is the universal active power line conditioner (UPLC) which aggregates the functions of the UPFC and the UPQC into a signal power conditioner [9].

To avoid an additional cost and hardware for the UPQC system, some studies discussed these systems with the PV. This latter injects active power to the grid and filters the load current/voltage harmonics. Furthermore, in one of our previous papers [6], a shunt active power filter (APF) fed by a PV system has been confirmed in terms of performance.

In the present study, a UPQC has been adopted and modeled to improve the power quality influenced by a harmonic disturbance and to export active power to the grid. The proposed system is supplied by the PVs containing a combination of two active power filters, in parallel and series shared a common DC voltage generated by the PVs. While the parallel APF has been controlled by the instantaneous reactive power theory in order to compensate the current distortion caused by a non-linear load, it is also export energy generated by PV system to the grid. The series APF has used the unit vector templates generation to filter the load voltage distortion in the power supply. The PVs have also exported a certain amount of active power to the grid through the parallel APF, the boost converter and the maximum power point tracking (MPPT) unit. The latter have defined the current reference signal to control the active power injected to the grid. The paper is organized as follows: The configuration of the UPQC fed by the PV will be presented in Section 2. It also underlines the required units such as power source, nonlinear load, UPQC and the control technique algorithms. Later, the main simulation results, current and voltage waveforms and THD analyses will be discussed in Section 3. Finally, the paper will be completed by the concluding remarks.

## Configuration of a UPQC supplied by PV

### *Description of PV system*

Despite of high specific costs, PV systems present an attractive solution for the electricity supply especially for remote locations because of low maintenance requirement, high reliability, long lifetime and stability with unrotating units [5–7]. Frequently, the application areas of PVs are dominated by the stand-alone systems such as household electrification and water pumping, however the grid-connected applications of PVs also flourish in cities as well as rural areas. In order to provide a concrete definition for a PV connected system, one should handle some components like PV cells, inverters, MPPT units and grid connection elements.

The basic equation of the PV current for a PV cell is defined by [14,15],

$$I = I_{pv} - I_0\left(e^{\left(\frac{q(V+R_sI)}{\alpha k_B T}\right)} - 1\right) - \frac{V + R_sI}{R_{sh}}, \quad (1)$$

In order to improve the efficiency of the electricity generation by the PV system, several methods have been suggested