Sustainable Cities and Society xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Sustainable Cities and Society

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

Evaluation of Maximum Power Point Tracking algorithm for off-grid photovoltaic pumping

Imene Yahyaoui [a,*], Maher Chaabene [b], Fernando Tadeo [a]

[a] Industrial Engineering School, University of Valladolid, Spain
[b] National School of Electronics and Telecommunications, Tunisia

ARTICLE INFO

Article history:
Received 17 July 2015
Received in revised form
18 September 2015
Accepted 23 November 2015
Available online xxx

Keywords:
Photovoltaic energy
Distributed Maximum Power Point
Tracking
Irrigation
Water pumping

ABSTRACT

The paper is concerned with the evaluation of some distributed Maximum Power Point Tracking techniques for an autonomous photovoltaic water pumping installation in a rural area in the Mediterranean. The efficiency of using Maximum Power Point Tracking algorithms for water pumping is proved. Then, some widely used Maximum Power Point Tracking algorithm performances (Look-up table, Neuro-Fuzzy, Incremental conductance and Perturb and Observe) are evaluated and compared using measured data from the target area. Despite the rapid change in the measured climatic parameters (solar radiation and ambient temperature), the Perturb and Observe algorithm shows a good dynamic performance. Hence, it is selected and successfully tested on a detailed model of the installation and then used to evaluate the relevance of the distributed Maximum Power Point Tracking for such installations.

1. Introduction

The need to save water and energy is a serious issue that has increased in importance over the last few years and will become more important in the near future (Sameh, Elattar, & Fouda, 2015; Young, 2013). The low price of fuel was the reason why renewable energy sources were not widely used in several agricultural applications, including water pumping (Young, 2013; Liu, Jiang, & Yao, 2014). In addition, the use of renewable energies depends on the users' likelihood of investing in renewable-based pumping systems, their awareness and knowledge of the technology for water pumping, and also on the availability, reliability, and economics of conventional options (Hast, Alimohammadisagvand, & Syri, 2015; Sree Manju, Ramaprabha, & Mathur, 2011; Yahyaoui, Ammous, & Tadeo, 2015; Yahyaoui, Jeddi, Charfi, Chaabene, & Tadeo, 2015; Yahyaoui, Chaabene, & Tadeo, 2015). Moreover, the evaluation of the groundwater volume required for irrigation and its availability in the area are also relevant in determining the profitability of renewable energies for the agriculture (Hast, Alimohammadisagvand, & Syri, 2015; Ben Ammar, 2011; Yahyaoui, Jeddi, 2015; Yahyaoui, Chaabene, 2015).

Consequently, pumping systems based on renewable energies are still scarce, even though they have clear and promising advantages, namely, low generating costs, suitability for remote areas, and being environmentally friendly (Nelson, Nehrir, & Wang, 2006). In fact, for agricultural areas, the use of renewable energies is a promising solution, especially for remote sites (Kumar & Kandpal, 2007). In fact, much research has studied the efficiency of renewable energies in agriculture and other critical sectors (Purohit, 2007; Purohit & Kandpal, 2005). Modern cultivation techniques require regular irrigation; especially in arid and semi-arid climates (Rana, Katerji, Lazzara, & Ferrara, 2012), for which, farmers generally use diesel engine water pumps. Although this solution was efficient in the past, the instability in the fuel price and the requirement that the user be present are considered the main disadvantages of these installations (Sumaila, Teh, Watson, Tyedmers, & Pauly, 2008). Hence, renewable energies are considered a good solution for farmers without easy access to fuel or for remote sites (Bilgili, Ozbek, Sahin, & Kahraman, 2015).

In this sense, over the last few decades, photovoltaic (PV) has become an effective source for electricity production, especially for well sunny sites. The PV energy generated is either used in isolated sites or injected into the grid (Yahyaoui, Ammous, & Tadeo, 2015; Hast, Alimohammadisagv, & Syri, 2015; Ben Ammar, 2011; Yahyaoui, Jeddi, 2015; Yahyaoui, Chaabene, 2015). In particular, for isolated areas, photovoltaic can be installed for pumping water for agriculture or human purposes (cleaning, drinking, etc), since

* Corresponding author. Tel.: +0034 983 184 859; fax: +0034 983 423161.
E-mail addresses: imene.yahyaoui66@gmail.com (I. Yahyaoui), maher.chaabene@cmerp.net (M. Chaabene), fernando@autom.uva.es (F. Tadeo).

http://dx.doi.org/10.1016/j.scs.2015.11.005
2210-6707/

Please cite this article in press as: Yahyaoui, I., et al. Evaluation of Maximum Power Point Tracking algorithm for off-grid photovoltaic pumping. *Sustainable Cities and Society* (2015), http://dx.doi.org/10.1016/j.scs.2015.11.005

Nomenclature

a	temperature coefficient
AC	alternating current
dod	depth of discharge
DC	direct current
G	solar radiation (W/m^2)
I_{pv}	current produced by the photovoltaic panel (A)
I_{mpp}	photovoltaic current at MPP (A)
MPPT	maximum power point tracking
NMBE	normalized mean bias error
NRMSE	normalized root-mean-square error
P_L	load power (W)
P_{mpp}	panel power at MPP (W)
P_{pv}	photovoltaic power (W)
PVP	photovoltaic panel
P&O	perturb and observe method for *MPPT*
R_{mpp}	panel impedance at the MPP
R_{pump}	pump impedance
T_a	ambient temperature at the panel surface (°C)
V_{mpp}	photovoltaic voltage at MPP (V)
V_{pv}	photovoltaic voltage panel (V)
Δt	pumping duration (min)
$\pm$	duty cycle

photovoltaic systems are easy to install and, after installation, the maintenance cost is low (Yahyaoui, Sallem, Kamoun,& Tadeo, 2014; Yahyaoui, Chaabene, & Tadeo, 2014). However, the inherent variability of the sources (solar energy) means that the photovoltaic power has to be used carefully (Ben Ammar, 2011).

Thus, many studies have focused on the optimization of photovoltaic plants. In fact, some authors have developed algorithms to determine the optimum size of the PV water-pumping installation, depending on the load demand and the site characteristics (Yahyaoui, Ammous, 2015;Yahyaoui, Jeddi, 2015; Yahyaoui, Chaabene, 2015; Kaldellis, Zafirakis, & Kondili, 2010), demonstrating that an optimum sizing allows the water-pumping installation cost to be lowered considerably (López-Luque, Reca, & Martínez, 2015). Other researchers concentrated on the optimum use of the photovoltaic energy generated by establishing management algorithms using intelligent tools, namely Fuzzy logic (Aurilio, Balato, Graditi, Landi, Luiso, & Vitelli, 2014).

Since the optimum sizing and the efficient energy use of PV systems require an efficient extraction of the photovoltaic power, the use of a technique that allows the maximum PV power generated to be extracted is necessary. This is known as Maximum Power Point Tracking (MPPT) (Aurilio, Balato, Graditi, Landi, Luiso, & Vitelli, 2014). In this context, several algorithms for the Maximum Power Point Tracking (MPPT) have been developed and validated (Femia, Petrone, Spagnuolo, & Vitelli, 2005; Padmavathi & Daniel, 2011), namely, the Look-up table MPPT (Chenni, Makhlouf, Kerbache, & Bouzid, 2007), the Neuro-Fuzzy (Oi, 2005), the Incremental Conductance (Oi, 2005) and the Perturbation and Observation (P&O) (Salas, Olias, Barrado, & Lazaro, 2006) algorithms. In fact, these MPPT methods differ in complexity and precision, but they all require the sensing of the PV current I_{pv} and voltage V_{pv} using the off-the-shelf hardware to generate the duty cycle α used to control the converters (Chenni, Makhlouf, Kerbache, & Bouzid, 2007), such as choppers (in our case) (Fig. 1) and to adapt the photovoltaic impedance to the load.

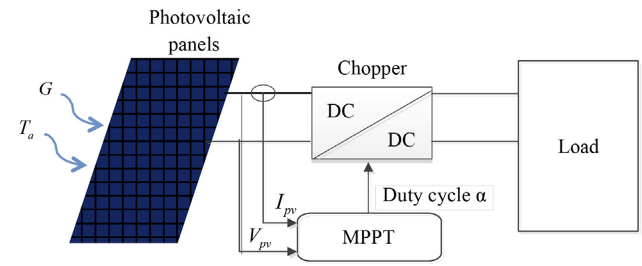

Fig. 1. DC-DC adaptation of the PV generator to a load.

In a previous published work (Yahyaoui, Ammous, 2015;Yahyaoui, Jeddi, 2015; Yahyaoui, Chaabene, 2015), we presented and evaluated some MPPT methods to extract the maximum power from photovoltaic panels for water pumping using measured data from the target site (Fig. 2).

In this paper, we conduct a study of some Maximum Power Point Tracking (MPPT) techniques and then test the performance of the distributed P&O using measured climatic data from the target area. So, we first focus on studying each MPPT method mentioned above. Then, the relevance of using such techniques in gaining energy, for a specific application (water pumping installation in a rural area) is detailed by comparing their efficiencies with a similar installation that is not equipped with MPPT. After that, based on the MPPT technique comparison, the control results of the Buck converter, which is used to track the MPP, are presented. Finally, a comparison between the central and distributed MPPT is discussed.

2. MPPT algorithms

2.1. Look-up table MPPT

Indeed, the Look-up table algorithm for MPPT consists in dividing the possible solar radiation G and ambient temperature T_a values into intervals, then attributing the value of the duty cycle to the corresponding measured climatic data. In the intervals, the duty cycle values are deduced by interpolation. This offline optimization method allows the oscillations to be decreased around the Maximum Power Ponit (MPP) and hence to converge rapidly,

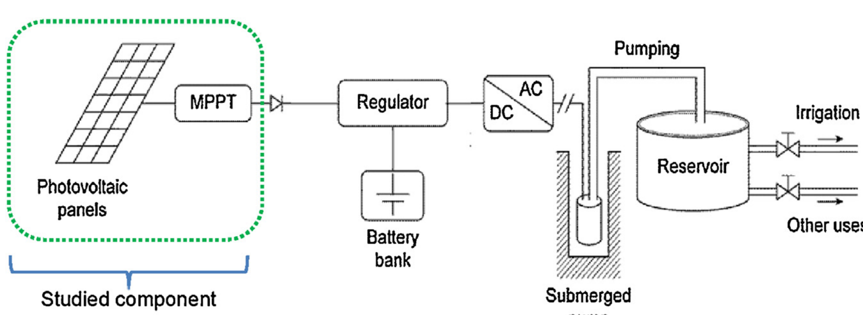

Fig. 2. Photovoltaic pumping system.

Please cite this article in press as: Yahyaoui, I., et al. Evaluation of Maximum Power Point Tracking algorithm for off-grid photovoltaic pumping. *Sustainable Cities and Society* (2015), http://dx.doi.org/10.1016/j.scs.2015.11.005