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Energy and water management for drip-irrigation of tomatoes in a semi- arid district

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ABSTRACT

In this research, an autonomous off-grid system for irrigation in semi- arid areas is presented and discussed. In these areas precise irrigation is essential: as they are characterized by availability of solar radiation, solar irrigation (supported by photovoltaic panels and batteries) is considered here. The correct operation of these installations is a necessity to ensure the correct crop irrigation and to extend the components lifetimes (batteries in particular). These objectives can be ensured by a management system that correctly handles energy and water requirements. In this research, the energy and water management for a photovoltaic water pumping installation used for irrigating tomatoes is developed by integrating fuzzy logic inside the control system. This management system first evaluates the water volume needed by tomatoes during the vegetative cycle considering a detailed model for the tomatoes evapotranspiration and irrigation frequency, following the site and crops characteristics. Based on this and the energy availability a control algorithm decides the switching of the relays which connect the main plant components (panels, batteries and water pumps). The control algorithm fulfills the objectives by considering criteria related to the water volume needed to irrigate the crops, to the safe operation of the batteries and the continuous operating of the pump. The algorithm is tested in two cases study: during normal operation and during faults related with water losses. The obtained results confirm that the irrigation demand is fulfilled, and autonomy is ensured during the vegetative season with a reduced use of the batteries.

1. Introduction

Tomato is a drought sensitive plant, since its yield decreases considerably after short periods of water deficiency (Rodríguez et al., 2014). The regularity in watering the plants is important, especially during flowering and fruit formation (Reca et al., 2013; Rinaldi et al., 2013). Indeed, the needed water amount depends essentially on the type of the soil, the site and the weather characteristics, namely the amount of rain, the humidity and the temperature (Hillel, 2012). In semi-arid regions, generally, farmers use furrow or drip irrigation, which is a common method for irrigating tomatoes, thanks to its economic advantages in saving water and increasing the yield production (Hillel, 2012; Reca et al., 2015). Farmers adopt this technique for both greenhouses and outdoor cultivation, for which the frequency and the water volume for tomatoes irrigation depends on the growing stage of the plant, the rainfall and the irrigation installation characteristics (Raes et al., 2000; Farneselli et al., 2015; Liu et al., 2013).

In remote agriculture areas, stand-alone plants are frequently used for electricity generation for systems which provide the water volume needed for tomatoes irrigation. For agriculture applications, diesel engines are generally used for water pumping, especially in isolated and remote areas, since they are reliable, easily available and easy to use (Al-Smairan, 2012). However, experience demonstrated that there are significant limitations associated with using gensets for power generation. For instance, the high operation and maintaining costs are its main disadvantages (D'Ambrosio and Ferrari, 2015; Kumar et al., 2016) and the environmental pollution (Chen and Hashim, 2016; Yahyaoui et al., 2015a). Hence, taking advantage of the decrease in the renewable energy cost, consequently, water pumping installations based on renewable energies are increasingly deployed in remote areas (Campana et al., 2015).

Photovoltaic Powered Electric Water Pumping Systems (PPEWPS) is the most common installation used for water pump-

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Nomenclature[1]

a	temperature coefficient K^{-1}
AC	Alternating current (A)
C_R	Remaining battery capacity (A.h)
C_p	Peukert capacity (A.h)
DC	Direct current (A)
dod	Depth of discharge
FMA	Fuzzy management algorithm
G	solar radiation (W/m^2)
G_{ref}	Reference solar radiation (W/m^2)
I_{bat}	Battery current (A)
I_i	Instantaneous current supplied to the load (A)
I_{ph}	Generated photo-current at a given irradiance G (A).
I_r	Reverse saturation current for a given ambient temperature (A)
$I_{r\_T_{ref}}$	reverse saturation current for the temperature of reference (A)
I_{sc}	short circuit current for a given temperature T_a (A)
$I_{sc\_T_{ref}}$	Short circuit current for the temperature of reference (A)
K	Boltzmann constant
$MPPT$	Maximum power point tracking
R_s	Serial resistance of a photovoltaic module (Ω)
R_p	the parallel resistance of the photovoltaic module (Ω),
k_p	Peukert constant
$M_{1,2,3,4,5,6}$	Function modes 1, 2, 3, 4, 5, 6
n	Coefficient of ideality
n_p	Number of parallel photovoltaic modules
P_{bat}	Battery power (W)
P_i	Instantaneous power supplied to the load (W)
P_{pump}	Power of the pump (W)
P_{pv}	Photovoltaic power (W)
PVP	PhotoVoltaic panel
q	Electron energy (C)
R_1, R_2, R_3	Three switching relays
T_a	Ambient temperature at the panel surface (°C)
T_{ref}	Temperature of reference at the panel surface (°C)
V	Pumped water volume (m^3)
V_c	Open circuit voltage of a photovoltaic module (V)
V_g	Gap energy (e.V)
$V_{t\_T_a}$	Thermal potential at the ambient temperature (ºC)
Δt	Pumping duration (h)

ing (Benghanem et al., 2013; Olcan, 2015; Yahyaoui et al., 2015b). PPEWPS are promising solutions, especially in small scale installations in regions characterized by good amounts of solar energy over the year (Masoudinejad et al., 2015): it is recommended that, for installing Solar Photovoltaic (SPV) pumps, the average daily solar radiation in the least sunny month should be greater than 3.5 kW/m^2 on a horizontal surface (Henrik, 2007). Hence, this type of installations is used in isolated agriculture area, to provide the water volume needed for irrigation, where the photovoltaic energy generated should be optimally used. In this sense, several tools have been used to optimize the use of the PV energy in agricultural applications, namely fuzzy logic (Sami et al., 2014; Paucar et al., 2015).

In fact, this tool (fuzzy logic) showed its efficiency in control issues, namely deciding the irrigation schedule and nutrient injection, depending on the climatic parameters (solar radiation, humidity, etc.) (Reca et al., 2015; Chung et al., 2015), controlling the internal climatic variables in greenhouses (Márquez-Vera et al., 2016) and for the energy management of autonomous water pumping installations, in which Fuzzy Management Algorithms (FMA) have been used to maximize the pumped water, optimize the use of renewable energy and ensure a safe operation of the battery bank (Ouada et al., 2013; Yahyaoui et al., 2014).

The efficiency of this tool in various applications is given by its ease of use. For instance, in energy management works, fuzzy logic is a good decision tool, since it gives the possibility to describe system behaviors, and decide control decisions using linguistic rules (Casillas et al., 2013; García et al., 2013). In addition, based on the expert knowledge, the fuzzy rules are written using a simple linguistic manner, which describes the adopted approach in taking control decision (Yager and Zadeh, 2012; Bezdek et al., 2012).

Hence, this paper presents a continuation of previous published works, in which an energy management algorithm for water pumping system destined to tomatoes irrigating has been studied (Yahyaoui et al., 2015c,d). The present research work focuses on the energy and water management of an autonomous photovoltaic irrigation plant in case of faults related with water losses in the reservoir and discharged battery bank (Fig. 1). Hence, in this research, the correction of the water losses that can occur is studied. In this research work, an autonomous water pumping pump plant composed of photovoltaic panels coupled to a lead-acid battery bank is considered and used to ensure the energy availability between the system components, even while low or intermittent solar radiation, and to supply a centrifuge pump, which pump water into a reservoir. These components are linked via controllable relays, which are used to decide the energy flow between the energy sources. These objectives are performed using an Energy Water Management Algorithm (EWMA) that ensures pumping the sufficient water volume needed for tomatoes irrigation. The EWMA is performed using fuzzy logic, which is used to generate the relays control signals, depending on the measured Photovoltaic Panel Generation, the depth of discharge of the battery bank, the water level in the reservoir and the water flow. In this research, Mamdani-type fuzzy logic is used within the management algorithm, since it is simple to use with little technical training and can be implemented using standard components, namely Programmable Industrial Controllers (Yager and Zadeh, 2012; Bezdek et al., 2012).

Using meteorological measurements, namely the solar radiation and the ambient temperature, and the water volume needed for the crops irrigation, the EWMA decides the switching of the relays, which link the installation's elements. Hence, the water volume needed for the crops irrigation can be pumped, the continuous pump supply and the safe battery bank operation can be guaranteed (Fig. 1).

The paper is organized as follows: Section 2 details the tomatoes irrigation characteristics. The system components models are described in Section 3. The Energy Water Management algorithm principle is explained in Section 4, in which the management strategy and the algorithm's execution are detailed in depth. Obtained results of the EWMA are presented and discussed in Section 5. Finally, Section 6 gives the conclusion.

[1] x_{0i}, d_{0k} ,y_{0j} ,f_{0s} ,e_{0n} andO_{0l} are, respectively, the values of the variables *x, d, y, f* ,*e* and *O* in the membership intervals; and $\varepsilon_{x_{0i}}$, $\varepsilon_{d_{0k}}$,$\varepsilon_{y_{0j}}$, $\varepsilon_{f_{0s}}$, $\varepsilon_{e_{0n}}$ and $\varepsilon_{O_{0l}}$ are the range values of x_{0i}, d_{0k},y_{0j} , f_{0s}, e_{0n} and O_{0l} , respectively.

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