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Bond graph modeling and optimization of photovoltaic pumping system: Simulation and experimental results

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ABSTRACT

Bond graphs are a promising possibility for modeling complex physical systems. This paper explores its potential by undertaking the analysis, modeling and design of a water pumping photovoltaic system. The effectiveness of photovoltaic water pumping systems depends on the sufficiency between the generated energy and the volume of pumped water. Another point developed in this paper presents the optimization of a photovoltaic (PV) water pumping system using maximum power point tracking technique (MPPT). The optimization is based on the detection of the optimal power. This optimization technique is developed to optimize the usage of power. The presented MPPT technique is used in photovoltaic water pumping system in order to increasing its efficiency. A buck–boost chopper allows an adaptation interface between the panel and the battery checked by a tracking mechanism known as the MPPT (Maximum Power Point Tracking). A new algorithm is presented to control a maximum power point tracker MPPT through a bond graph. From the chemical reactions in the batteries to the control laws of the power electronics structures, a bond graph model is proposed for every single part of the system. The model is used in simulations and the results compared to actual measurements. The model is used in simulations and the results compared to actual measurements, showing an accuracy of nearly 99%.

1. Introduction

Improvements in quality of life and rapid industrialization in many countries are increasing energy demand significantly, and the potential future gap between energy supply and demand is predicted to be large [1]. Interest in sustainable development and growth has also grown in recent years, motivating the development of environmental energy technologies [2].

Nowadays photovoltaic energy is one of the most popular renewable sources since it is clean, inexhaustible and requires little maintenance [3,4]. However, it still presents a vast area of competition comparing to conventional energy resources due to its high cost and low efficiency during energy conversion [5]. The photovoltaic power conversion has been an active research topic for renewable energy conversion applications [6–8].

Algeria has one of the fastest growing economies in Africa. However, its remotely isolated rural areas pose problems to rural energy management and development. Development of renewable energy sources, therefore, has a vast potential in

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Algeria. Thus, for rural applications, various established models [9,10], sizing techniques [11], and optimization methods [12] of photovoltaic water pumping system (PWPS) have been reported in the literature. Solar energy, with excellent sun shine of over 2000 h per year, is paramount for these applications. Photovoltaic water pumping systems are particularly suitable for water supply in remote areas, where no electricity supply is available. The pumped water can be used in many applications such as domestic use, water for irrigation and village water supplies.

The major drawback of solar energy stays in its low conversion efficiency, as well as its high cost, The second major problem is that the Photovoltaic Generator (PVG), is non-linear, and its optimum operating point depends on the temperature, the solar radiation and the load variations. This point is called the Maximum Power Point (MPP) in the literature. In order to constantly produce at its MPP, a dedicated power electronics DC–DC converter system called Maximum Power Point Tracker (MPPT) is used.

For stand-alone solar water pumping systems, there has been a significant amount of research performed. A model was developed for simulating solar-PV water pumping systems [13], and this reference also includes an excellent literature review of past research on solar water pumping systems.

Other researches published in photovoltaic water pumping were interested essentially either in water pump modeling and control [14–16] or in overall system modeling and simulation [17] so as to bring a contribution to the study of the behaviors of the photovoltaic generators and converters used to feed an asynchronous machine actuating a centrifugal pump [18].

The mathematical models of the inverter and the motor pump set are described in a great number of research papers. Thus, we can quote [14,19,20,10]. These models describe the characteristic of each component of the pumping subsystem as the inverter, the motor or the pump. But these models do not give a direct relationship between the operating electrical power of the pumping subsystem and the water flow rate of the pump. In this paper, we use a graphical (bond graph) model which directly links the output water flow rate versus the input operating electric power and total head.

The main objective of the present work is to develop a general method for the evaluation of the long term performance of a photovoltaic powered water pumping system with maximum power point tracker. In the present work, the variations in system performance resulting from solar source variations have been taken into consideration to establish a model for the complete system. Also, a bond graph model is developed for each component to simulate the performance of the different components of the PV pumping system.

In this context, emphasis is given in the present study in order first to simulate the operational modes of a typical PVPS and secondly to provide an analysis based on experimental measurements, concerning the flow water, the rotation speed of motor, the voltage and the current of the PV generator.

Many maximum power point tracking techniques for photovoltaic systems have been developed to maximize the produced energy and a lot of these are well established in the literature. These techniques vary in many aspects as: simplicity, convergence speed, digital or analogical implementation, sensors required, cost, range of effectiveness, and in other aspects.

In this work, an algorithm to control a maximum power point tracker through a bond graph (BG-MPPT) is developed. Its objective is to improve the performances of the control system dedicated to a photovoltaic water pumping system. The system itself and its components are explained in Section 2. A detailed bond graph model of the MPPT is proposed in Section 3. Experimental results of the system are shown in Section 4. The simulation results are shown in Section 5.

2. system description

The use of solar energy for the water pumping is particularly well adapted to the rural zones, where water is cruelly lacking. The increasing demand for water in these zones makes that a paramount interest is related to the use of the solar modules like energy source to the power packs. A pumping system can be distinguished according to its electric motor type and water storage equipment. Most systems are either equipped with a DC current motor or a synchronous one.

The structure studied in this work is given by Fig. 1. It is composed of an array of photovoltaic panels, implemented in series and/or parallel connection depending on the power of the system. The Buck–Boost DC/DC converters use bond graph MPPT for PV array to extract the maximum available power from them. The battery which is of Lead-Acid type is used to store the energy, to regulate the DC-Bus voltage through a reversible current DC/DC converter and to supply the motor-pump when low solar radiation conditions.

The energy produced for PV source is transferred from the DC-Bus to the load through a DC/AC inverter controlled and filtered by an LC filter, while the excess power feeds the utility grid. Based on the data acquisition (Temperature, Irradiance, DC-Bus voltage, etc.) the supervisory controller send the commands to the different converters in order to optimize and control the energy.

2.1. Photovoltaic generator modeling

The basic device of a PV system is the photovoltaic cell, which are grouped to form modules. These, in turn, are grouped to form arrays [21]. Fig. 2 shows a model currently available in the literature [22] and involves: a current generator for modeling the incident luminous flux, two diodes for the cell polarization phenomena, and two resistors for the losses (Fig. 2).