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Approach for dimensioning stand-alone photovoltaic systems

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Abstract

The intermittent nature of renewable energy sources has attracted much interest for integrating storage devices towards the deployment of micro-grid systems. In fact, these devices could be deployed into the system by decoupling energy production from consumption mainly by storing the extra produced energy from RES during the day for eventual usage at night. However, for standalone systems, computing the optimum size of energy production systems and storage devices is required for continuous electricity supply. In this paper, a micro-grid system is modeled, sized, and experimented according to a given consumption profile using a deployed prototype at our EEBLab.

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Keywords: Micro-grid, RES and storage devices, sizing, photovoltaic and batteries systems, modeling and performance evaluation;

1. Introduction

Renewable energy sources have important advantages and benefits compared to those of conventional energy sources (e.g., clean, abundant). Currently, Morocco is focusing on renewable energies (especially solar with an average daily global radiation of around 5kWh/m² [1]) to reduce its external energy dependence, which is around 95% for

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products, such as coal, fuel, oil and others. However, due to the mismatch between the load demand and the intermittent solar energy, it is important to store the solar energy produced in other forms in order to operate the buildings appliances at night and on cloudy days. On the other hand, there are several energy storage systems (e.g., battery, superconductor, flywheel energy storage systems, STEP) [2]. Batteries are among the most used storage devices in stand-alone PV systems because of their benefits (e.g., fast response, modularity, and good energy efficiency).

Modeling and sizing stand -alone PV systems have been widely studied in the past years in order to facilitate their installation and enhance their behavior [3]. The sizing of each component of these systems requires a prior knowledge of many important parameters (e.g., solar irradiation, ambient temperature, consumption profile) [4-6]. There are several models that have been proposed for each component in order to evaluate their behavior under various conditions [6-7]. For instance, a mathematical model of the electrical circuit of solar cells, which takes into account different weather conditions (e.g., solar irradiation, temperature), was developed in the past years in order to evaluate the system's behavior. Regarding batteries, there are many parameters that vary during the charge and the discharge cycles, e.g., voltage, current, temperature. This leads to a complicated behavior of this device and thus makes predictions of the state of charge (SOC) much more complicated [7]. Numerous models have been developed in order to predict batteries' behavior (e.g., electrochemical models, electrical-circuit models) [8]. Other methods and techniques have been also proposed for estimating and monitoring the SOC of the battery. Examples are coulomb counting, artificial neural network, kalman filter (KF), and Extended Kalman Filter (EKF) as reviewed by Piller et al. in [9]. Coulomb counting or current integration is considered among the simplest techniques of keeping track of the battery's SOC [10], which requires dynamic measurement of the battery current. Nevertheless, because of the errors in current measurement due to noise, large SOC errors can be resulted [7, 10]. KF and EKF had been proposed as intelligent methods for predicting and estimating the SOC values [7, 10-13]. Furthermore, the integration of batteries as auxiliary storage systems requires a management system. In our case, the management system is represented by a regulator, which aims to control the charge and discharge of the battery in order to avoid the over -charging and the over-discharging cycles. This could lead to some damages, which influence on the battery life time [6].

However, most of the work to date uses simulations in order to study the behavior of micro-grid (MG) systems. Deploying these systems in real-sitting in order to validate each component's model under different circumstances (e.g., weather conditions, occupancy) is highly required [5]. The work presented in this paper is a part of the work we are undertaking under an ongoing project aiming at deploying a MG system for simulation and experimental purposes especially dimensioning and control approaches [14, 15]. The MG system is composed of five main components, PV panels in order to generate electricity from solar radiation, batteries are used as an energy storage system to operate the appliances at night and on cloudy days when there is no PV production, a regulator to control charging and discharging of the batteries, AC/DC converter that converts the alternating current (AC) received from the electric grid into a direct current (DC), and the electric grid that aims to supply electricity to the system where there is no production and the batteries are empty. The system was evaluated and its performance was first studied in order to figure out their behavior as well as the amount of electricity supplied from the electric grid. A sizing method was then developed in order to make it a standalone system. In other words, we focus firstly on modeling this system and conducting simulations using similar experimental parameters. These models will be then used for validating the proposed sizing method towards zero consumption from the electrical grid.

The remainder of this paper is structured as follows. The PV system is first described, and then the modeling together with the obtained results compared to the experimental result, are introduced in Section 2. In Section 3, the size of each component of the stand-alone MG system is computed together with simulation and experimental results. Finally, the conclusions and perspectives are given Section 4.

2. MG Architecture with simulation and experimental results

The architecture of the proposed MG system that we have developed and deployed in our EEBLAB is illustrated in Figure 1-a. It is mainly composed of a PV panel with a peak power of 265 Watts, a battery 24 Ah, and a ventilation system, which is composed of two ventilators operating with a PWM control with 24 Watts as a maximum power and 12V as voltage. The grid is connected to the system by an AC/DC converter that provides an output voltage equal to 12V. A platform composed of a set of current, voltage sensors and a relay, which are connected to an Arduino board, was also deployed in order to measure the current and the voltage in each branch of the system as illustrated in Figure

1-b. The relay is controlled by the Arduino board in order to switch between the PV-Battery system and the electric grid when the battery's SoC reach a given threshold (e.g., 40% in our experiments). The purpose of this installation is to show the behavior of the system and the switching between the PV-Battery system and the electrical grid, especially at night.

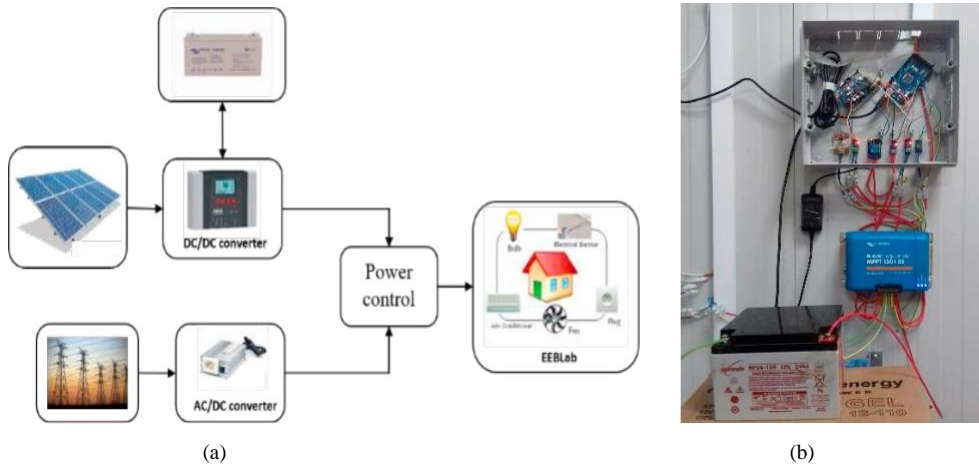


Fig. 1. a) Block diagram of the proposed MG system, b) the deployed prototype

This work focuses firstly on modeling this system and conducting simulations and experiments. Therefore, the MG system is modeled and simulated under MATLAB/Simulink using similar experimental conditions (see Figure 2). Hence, the models of PV panel, regulator, battery, AC/DC converter and the electric grid are developed. The models of the PV panel and the regulator are described with more details in our previous work presented in [6].

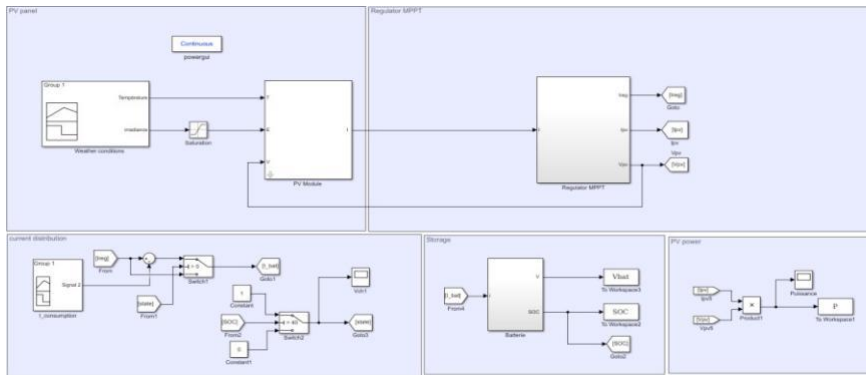


Fig. 2. MG Simulink model

Concerning the model of the battery, we have used the Tremblay model in order to estimate the behaviour of the battery [16, 17, 18]. We have also used the battery voltage as a parameter in order to estimate the SoC according to the method presented in [9, 19] and then compared it with the coulomb counting method, also named Ah method [20].

We have conducted several simulations and experiments during a sunny day in order to show the behaviour of the system and the switching operations between the PV-battery system and the electric grid. Figure 3 shows the simulation and experimental results of the deployed MG system. We observe that during the day, the main power supply of the ventilation system is the PV panel (the relay is switched to the PV-Battery system). However, a part of the electricity needed by the load is supplied by the grid especially after 5AM when the battery's SoC is less than a given threshold (e.g., 40% in this experiment).

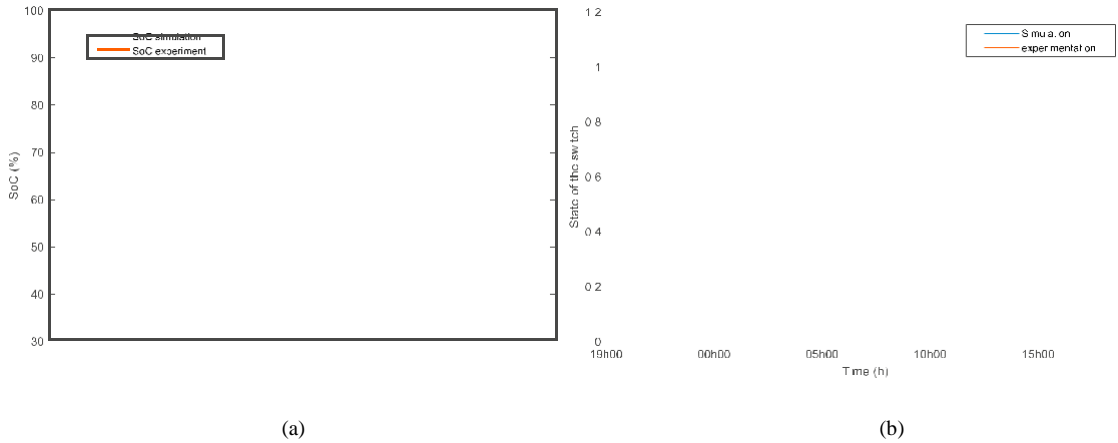


Fig. 3. a) The SoC behaviour, b) The state of the relay (0: grid, 1: PV-Battery system)

According to these results, the electricity produced by the PV is not enough to supply totally the load. A sizing method is then introduced with the aim to make the system a standalone without using the electric grid. Simulations and experiments have been conducted for validating the proposed sizing method towards zero consumption from the electrical grid.

3. Sizing of the stand-alone PV system

The micro -grid system presented in the previous section is sized in order to have a stand-alone PV system (i.e. zero consumption from the grid).

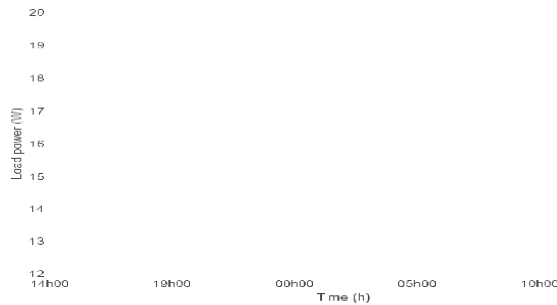


Fig. 4. Daily electricity consumption of the ventilation system

The sizing of the whole system requires a prior knowledge of many important parameters (e.g., solar irradiation, consumption profile) [4, 5, 6]. For the solar irradiation, we have used the measurement data provided from PVGIS. Regarding the consumption, a platform composed of current and voltage sensors was deployed in order to measure the daily electricity consumption [14] of our ventilation system (see Figure 4). The total daily electricity consumption is approximately equal to 430 Wh. Furthermore, the peak power of the PV panels is calculated by the following expression [5, 6]:

$$P_c = \frac{E_{elec}}{E_i} \quad (1)$$

where E_{elec} is the maximal daily consumption (kWh/day), E_i is the irradiance at standard conditions STC (equal to 1000W/m^2), E_l is the lowest solar irradiation in the year ($\text{kWh/m}^2/\text{day}$); for our site, it is equal to $4,790 \text{ kWh/m}^2/\text{day}$,

PR is the performance ratio, which is a correction coefficient for systems with batteries, its value is between 0.55 and 0.75 [5]. However, this parameter depends on many parameters, such as battery efficiency, regulator efficiency, inverter efficiency, voltage drop in the cables, other losses in the installation, the integration mode. The value used in our case is equal to 0.70.

The minimum peak power of the PV panels required to meet the daily electricity needs over the whole year, is 128.243 Wc. As stated above, the PV panels used in this experimentation have a peak power of 265 Watts, an open circuit voltage of 38.3 V and 8.98 A as short-circuit current. As a result, one module is required in order to ensure the system operation throughout the year, which is calculated by the following equation: $N_r = \frac{E_{elec}}{P_{peak} \times \eta_{bat} \times \eta_{reg} \times \eta_{inv} \times PR}$, with a total peak power of 265 Watts and a total area of 1.63 m². The power of the regulator must be compatible with the power of the panel. For that, we have chosen the regulator “BlueSolar MPPT 75/15 from Victron energy” with a rated power of 220W, a maximal input voltage of 75V, and a maximal input current of 15A. The capacity of the battery (C_{Ah}) is expressed by the following equation [5]:

$$C_{Ah} = \frac{E_{elec}}{\eta_{bat} \times \eta_{reg} \times \eta_{inv} \times PR \times V_{bat} \times DoD} \times N_{Aut} \quad (2)$$

where E_{elec} is the maximal daily consumption (Wh/day), N_{Aut} is the number of days of autonomy (day), DoD is the Depth of Discharge (%), η_{bat} is the battery efficiency (%), and V_{bat} is the battery voltage (V).

The capacity estimation of the battery needs to take into consideration the number of days of autonomy, which varies according to weather conditions of the given test-site. The aim is to operate appliances from the batteries with zero production at night and during cloudy days. For our test-site, the number of days of autonomy varies between 2 and 5 days. In our calculations, the value used is 2 days. We also choose a battery of 12V and 24 Ah with a DoD equal to 60% and a battery efficiency of 85%. After calculating the necessary capacity to install, we found 140.52 Ah. Moreover, the grid is connected to the system by a transformer that provides an output voltage equal to 12 V with the current desired by the ventilation system. In order to validate this sizing method, we have conducted several experiments and simulations, and results depicted in Figure 5 show that the battery is the main supply source for the ventilation system. These preliminary results validate the proposed sizing method and its efficiency in sizing standalone PV systems.

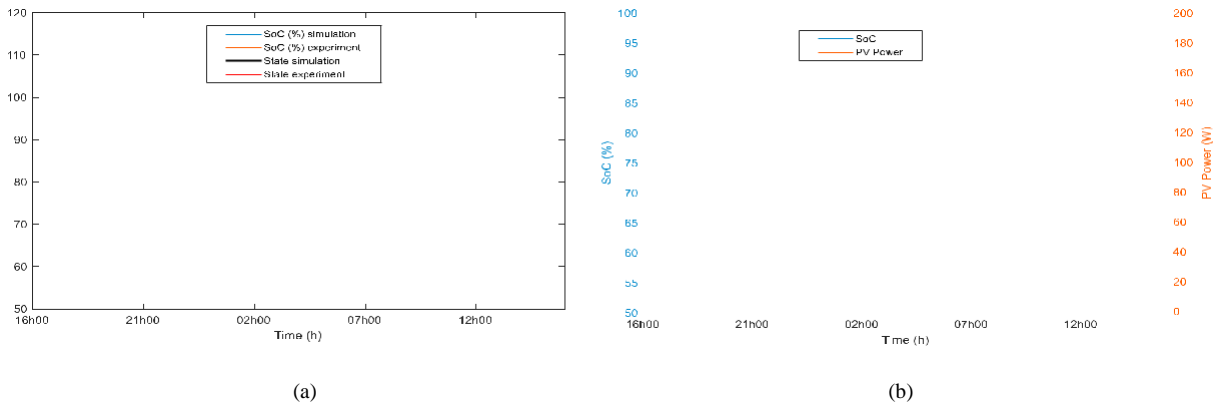


Fig. 5. a) The battery’s SoC from the simulation and the experiment, b) The battery’s SoC and the PV power

4. Conclusions and Perspectives

In this work, we have first deployed a small micro-grid system and connected it to the ventilation system of our EEBlab. Experimental results are reported and showed the behavior of the power control that allows switching between the PV -battery system and the electric grid. In fact, these results showed that the deployed PV-Battery system does not satisfy totally the power needed to operate the ventilation system. A sizing model was then introduced using

the consumption profile of the ventilation system. The MG was then upgraded in order to meet the load demand and obtained results showed the efficiency of the proposed model for dimensioning this type of systems. Simulations have been conducted using same MG system and results showed similar behavior when compared to experimental results. Our ongoing work focuses on integrating AC load together with more simulations and experimental results.

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