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Simulation tool for energy management of photovoltaic systems in electric vehicles

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ABSTRACT

High autonomy is an important goal of most mobile systems, it can be achieved in three ways: reducing energy consumption, increasing the capacity of batteries and replenishing battery energy over time. Another possibility comes from using an on-board generating system: in this context an embedded photovoltaic system (PVS) is a feasible solution. To model the whole system and to evaluate its energy performance, a Simulink model in Matlab environment has been developed. Meteorological variables (radiance and ambient temperature) are essential inputs to estimate the power production of a PVS. In this simulator, measured, forecast as well as calculated values of radiation and temperature can be considered. Once that the path followed by a mobile PVS (MPVS) is known, the Simulink tool calculates both the energy produced by PVS and the energy consumption. Different scenarios concerning the optimization of the PV production, considering the path followed by the MPVS, its consumption and the available solar radiation, have been considered and simulated. This model can become a very helpful tool to estimate the power production of PVS applied to any mobile system in such a way not only to optimize the energy performances but also to refine the sizing of the PVS. A mobile robot is used as test-bed.

1. Introduction

As world energy demands increases, the need for a renewable energy source that will not damage the environment has never been greater. To meet this need the only way is to harvest energy efficiently from the environment. Because of the desirable environmental and safety aspects, it is widely believed that solar energy should be utilized instead of other alternative energy forms because it is clean and can be supplied without environmental pollution [1]. Nowadays, in fact, solar energy harvesting has become increasingly important as a way to improve lifetime and reduce maintenance cost of portable appliances and stand-alone power systems. Some examples of the numerous applications of stand-alone PV systems include: lighting, communications, remote site electrification, disaster relief applications, remote monitoring, charging vehicle batteries, increase autonomy in robotics platforms, and water pumping and control. Therefore, a PV system can be used to increase the autonomy of a mobile system, such as a vehicles or a moving robot, using batteries and recharging them through a solar array. For example, in [2] a stand-alone combined system with electrochemical batteries and super-capacitors is considered. The battery of electric vehicle is charged using PV electricity. In [3] the authors discusses the implementation of some important techniques like sleep scheduling, power saving algorithms for dynamic base stations, indoor distributed antenna systems, femtocells and renewable energy sources like photovoltaic cells, wind turbines and hybrid systems, as a possible solution for achieving the energy optimization and sustainability in wireless mobile networks. Moreover, in the context of robot applications, in order to account for all the objectives: lifetime, flexibility, simplicity, cost, the best compromise appears to be the use of micro solar power system with rechargeable batteries [4,5]. In this paper a Simulink model in Matlab environment is proposed. This paper is specifically devoted to describe the PV generation system on board, whereas the battery model is described in [6]. The main goal is to evaluate PVS energy performances by means of the development of the models concerning all the components in a PVS. The proposed simulating tool has two interesting features: first of all it accepts as input measured, simulated or forecast environmental variables, further the load is modelled in such a way that there is the possibility to correlate the load consumption with both the trajectory followed by the mobile load and with environmental variables. This Simulink simulator can become a powerful tool to estimate the power production of the PVS and therefore the increase of the autonomy of the mobile loads. Moreover, it allows to optimize the PV production choosing the path that the MPVS can follow in order to increase the available solar radiation and to reduce the consumption. Finally, a robotic structure has been chosen as test-bed in the experiments.

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2. Model of a stand-alone photovoltaic system

A typical stand-alone PVS includes a solar array, batteries, regulator and load, in order to evaluate the performance of the whole system, a Simulink model in Matlab environment developed in [7] has been used, improving it in order to evaluate the behavior of a mobile PVS. The block diagram of the implemented model is shown in Fig. 1.

First of all, to estimate the power production of the PVS, it is needed to know meteorological conditions: radiance and temperature; these data can be measured ($G_{TH_{msr}}$ and $T_{a_{msr}}$) or forecast ($G_{TH_{frc}}$ and $T_{a_{frc}}$). There is also the possibility to generate the daily solar radiation ($G_{TH_{clc}}$) from the monthly average daily solar radiation data (G_{H_m}) and to estimate the daily temperature profile ($T_{a_{cal}}$) from the irradiance profile and the monthly mean daily minimum and maximum hourly temperatures ($\overline{T_{a_{d,max}}}$ and $\overline{T_{a_{d,min}}}$).

All the solar radiation data are relative to the horizontal plane. Anyhow, the angle of incidence of solar radiation on PV panels is variable due to the fact that the PV panel is not tracked and it is installed on a mobile system. If the trajectory (Cartesian coordinates: X, Y and Z) that the mobile system has to follow is known in advance, it is possible to calculate the tilt angle (β) and the azimuth angle (γ) that characterize the PV panel position. These two angles are useful not only to estimate the radiation on the inclined surface starting from the horizontal one, but also to evaluate the power consumption of the load. The electrical behavior of the photovoltaic panel used in the simulations has been modelled implementing the one diode model [8]. Mathematical models are implemented to correlate the PV cells temperature and irradiance to the environmental variables. Then, a MPPT regulator is implemented; it allows to optimize the output power (P_{MPP}). The available current depends on the voltage of the battery connected to the DC bus. The battery model receives the maximum current from the panel block and then this information is translated into an output voltage and SOC data. The logic controller decides the final level of the battery to stop the charge on the basis of the SOC parameters.

3. Generate daily radiation profile from monthly average daily solar radiation values on horizontal surface

In the case only the monthly average daily solar radiation data are available, an algorithm that allows to generate the daily radiation profile has been implemented. The flux diagram of the algorithm is shown in Fig. 2.

The goal of the algorithm here implemented is to generate the trend of the solar radiation of all the day of a specific month in such a way that the average daily solar radiation is equal (considering a tolerance) to the monthly average daily solar radiation value.

The steps of the algorithm are the following:

- generate for all days of a specific month a clear sky daily solar radiation profile;
- calculate the average daily solar radiation for that specific month;
- compare it with the monthly average daily solar radiation value given as input data: if it is greater, a random number (numRand1), between 1 and the number of days of the considered month, is generated;
- a random number between 0 and 2 is also generated (numRand2);
- the algorithm generates a solar radiation profile for the day correspondent to numRand1 that is variable if numRand2 $\leqslant 1$, cloudy otherwise;
- the average daily solar radiation is recalculated and compared again with the monthly average daily solar radiation value;
- the algorithm ends when the average daily solar radiation is equal (considering a tolerance) to the monthly average daily solar radiation value.

A variable solar radiation profile is generated adding to the clear sky solar radiation profile a Gaussian Noise and multiplying it for a random number between 0.5 and 1; while a cloudy solar radiation profile is generated multiplying the clear sky solar radiation profile for a random number between 0.2 and 0.4.

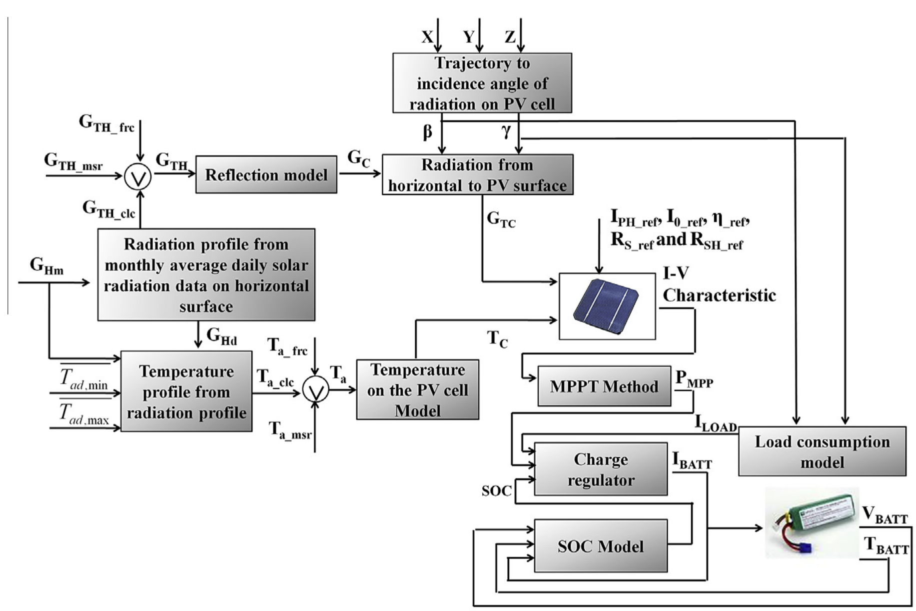

Fig. 1. Block diagram of the developed system.