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Design and Simulation of an Efficient Solar-Energy Harvesting Testbed for Remote Sensor Node

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Abstract

Intelligent infrastructure mandates continuous sensing, monitoring, and assessment operations. However, this brings a critical challenge of electrical power supply. For remote infrastructure where electrical supply is scarce, power supply alternatives become the necessity. The ever increasing use of fossil energy, and scarcity of transmission and distribution of electricity to remote areas have led to the alternative energy sources with off-the-grid applications. Solar is a cheap and readily available energy source, and suitable for off-the-grid applications. To study the performance of an isolated solar energy generation and storage unit, a readily deployable simulation platform is demonstrated in this work. A MATLAB-Simulink interface is utilized to simulate solar panel, power converter with maximum power point tracking (MPPT) algorithm, and the energy storage unit. Two major contributing factors - Irradiation and temperature, and perturbation and observation based MPPT algorithm is demonstrated to maximize the solar energy generation. A buck-boost regulator with proportional-integral (PI) controller is demonstrated to recharge a battery module. In this paper, we use the AleoSolar S16.185 as PV module with 1000 W/m^2 at 25 ^{0}C. The work provided detail design and calculation of MPPT algorithm, buck-boost converter, and battery charging unit to recharge a battery of 1.108kWh. Simulation results successfully demonstrate the performance of the software platform. The proposed solar unit simulation platform shows great potential for integration with other functional units and control scheme by interfacing with actual hardware units. In future, the platform will be extended by including other functional blocks such as transmission and distribution lines, transformers, etc.

1. Introduction

Photovoltaic solar energy is electricity produced by transforming part of the solar radiation with a photovoltaic cell. It is definitely a non-polluting energy produced without fuel supply, thermodynamic machinery, Atmosphere warming and waste. However, in 2014, this source of energy represented only 3% of the world electricity generation [Stallon, Kumar and Baby (2013)]. This is due to its low efficiency of solar panels (researches are still conducting for improvement), as well as the close dependence on weather conditions of solar energy. During the winter, night or rain for example, the power provided by the panels is significantly reduced.

As the panels' efficiency is not high, the maximum power of them has to be harvest at any time. This is the role of a boost converter allowing, with the aid of a command, a tracking of the maximum power point. The command itself is called MPPT (Maximum Power Point Tracking) Algorithm. In the same way, the weather impact can be overcome by installing of a storage device which will have the role of supplying the network during sunless periods.

We first model the photovoltaic generator. Then, we design a converter downstream the photovoltaic module commanded by a MPPT algorithm. The last part is reserved to the energy storage. All design and simulation of this paper are done with Simulink.

2. Modeling Of A Photovoltaic (Pv) Generator

2.1. Implementing the PV generator on Simulink

The characteristic equation of voltage-current of the solar panel is given by (1).

$$I = N_p I_{ph} - N_p I_s \left(\exp\left(\frac{V + \left(\frac{R_s N_s}{N_p}\right) I}{V_t a} \right) - 1 \right) - \frac{V + \left(\frac{R_s N_s}{N_p}\right) I}{\frac{R_p N_s}{N_p}} \quad (1)$$

Where Np and Ns are respectively the number of cells in parallel and in series, I_{ph} is the photo-current; I_s the saturation current, R_s the series resistance of the cell, R_p the parallel resistance of the cell; a the ideality factor of the diode and V_t is the thermal voltage. Based on the voltage-current characteristic equation of the PV generator given by (1), some models have been developed by the National Renewable Energy Laboratory (NREL) and integrated in Simulink library. In this paper, we will use the module AleoSolar S16.185.
The parameter of the selected PV module at 1000 W/m^2 and 25^{0}C is shown in the table 1.

Table 1
Characteristics Of The Module Aleosolar S16.185

Model	AleoSolar S16.185
V at Maximum Power Point (V_{MPP})	24V
I at Maximum Power Point (I_{MPP})	7.7A
Vsc	30.4V
Isc	8.2A
P at Maximum Power Point (P_{MPP})	184.8

The P-V curves of the selected module are shown by Fig. 1 and Fig. 2. In Fig. 2, the irradiation (Irr.) is stable at 1000W/m^2 and the temperature (T) decreases from 55^{0}C to 25^{0}C. We notice that the maximum power, represented by the circle on each line, evolves in the opposite direction. However, in the Fig. 3, the temperature is stable at 25^{0}C while the irradiation increases from 200W/m^2 to 1000W/m^2 the maximum power increases as well.

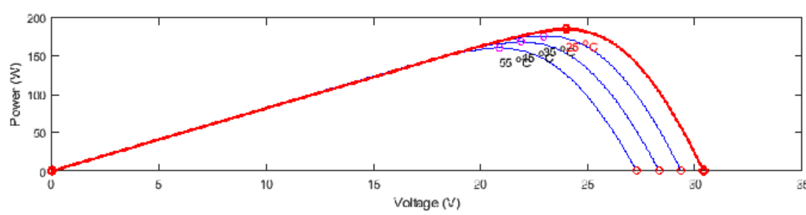

Fig. 1: P-V curves with T=55^{0}C, T=45^{0}C, T=35^{0}C, T=25^{0}C.

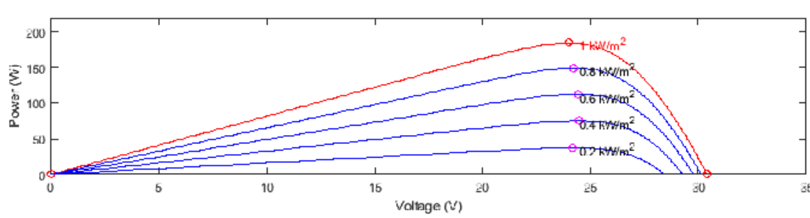

Fig. 2: P-V curves with Irr=1000W/m^2 to Irr=200W/m^2

The PV system under study is composed of 3 strings with 2 units for each string. At 1000 W/m^2 and 25^{0}C,

$$V = 2 * V_{MPP} = 2 * 24 = 48V \tag{2}$$
$$P = 2 * 3 * P_{MPP} = 2 * 3 * 184.8 = 1108.8W \tag{3}$$

3. Modeling Of The Boost Converter With Mppt Algorithm

3.1. The Boost converter

The boost converter is also known as step-up converter. It is generally used in the conversion of a low input voltage into a high output voltage. It consists of a continuous input voltage source V_{in}, an inductor L, a switch S, a diode, and a capacitor C [Agarwal (2014) - Umashankar, Aparna, Priya, and Suryanarayanan (2015)].

Fig. 3 shows the electrical diagram of the proposed boost converter.

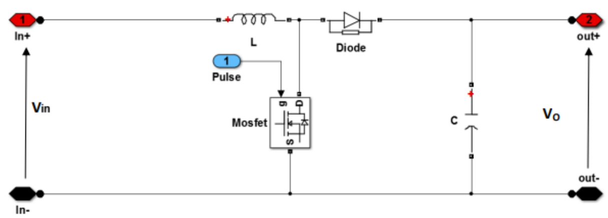

Fig. 3: Diagram of the proposed boost converter

The relationship between the V_{in} input voltage and V_0 output of the converter is given by (4) [Kahoul and Mekki (2015)].

$$V_{in} = \frac{V_0}{1-D} \tag{4}$$

Where D is the duty cycle $0 \leq D \leq 1$

The equations (5) and (6) respectively express the capacitance and inductance of the filter [Stallon, Kumar, and Baby (2013)].

$$C = \frac{DV_0}{f_s R \Delta V} \tag{5}$$
$$L = \frac{V_{in} D}{f_s \Delta I} \tag{6}$$

In these relationships, D is the duty cycle, fs is the mosfet frequency, ΔV is the tolerable voltage limit, ΔI is the tolerable current limit, and R is the load resistance. At 1000 W/m^2 and 25^{0}C, when V_{in} = 48 V and Vo = 130 V, we have: D = 0.63, P=1108.3W and I=8.5A. We choose fs = 50 kHz, ΔV= 5 and ΔI=30 the calculations of R, L and C give: R=16.9Ω, L=2*10^{-4} H and C=1.9x10^{-5}F.

3.2. The MPPT algorithm (Perturb and Observe)

The Perturbation and Observation (P & O) method is a widely used approach in MPPT research because it is simple and requires only voltage and current measurements of the PV field V and I, respectively. This method operates by periodically disturbing the voltage of the PV generator, and comparing the previously supplied power with the new one after disturbance.

This method makes possible to find the MPP even during the variations of the illumination and the temperature. The flowchart of this method is given by Fig. 4 [Sholapur,Mohan and Narsimhegowda (2014)].

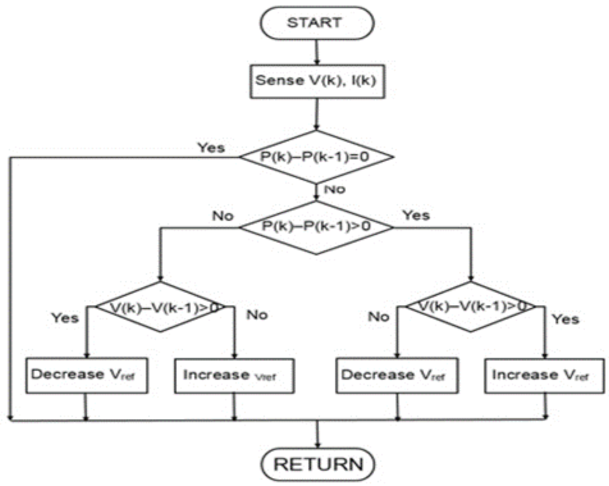

Fig. 4: Flowchart of perturb and observe algorithm

3.3.Simulation

After having modelled the PV generator and connected it to the boost converter, we performed the simulation of its operation. An MPPT command was inserted using a programmed block on Simulink as shown by the Fig. 5 (blue rectangle).

The result of the simulation is shown by the Fig. 6 (PV directly connected to the load) and Fig. 7 (PV connected to the load through boost converter equipped with a MPPT command).

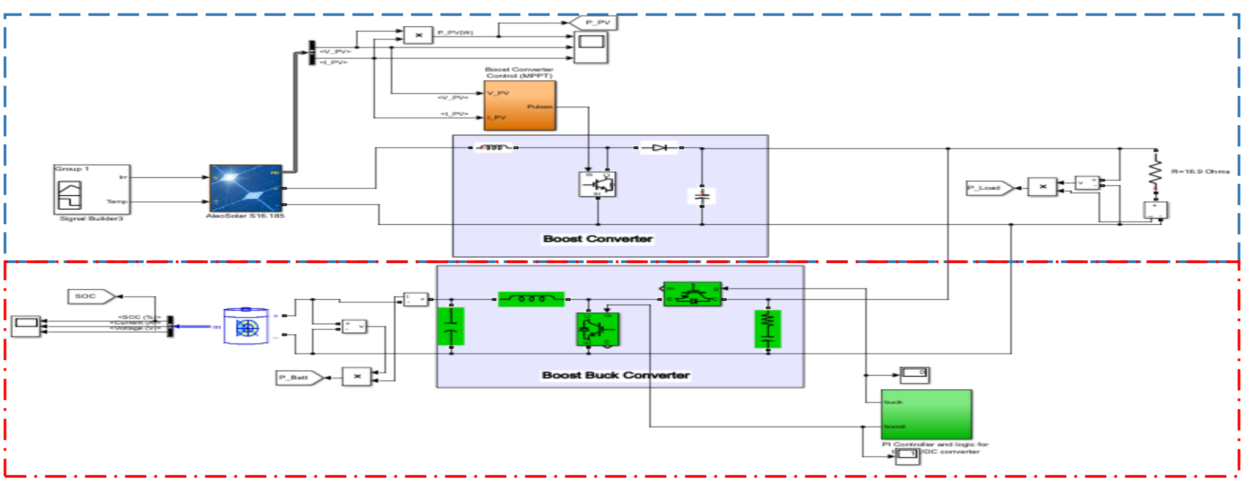

Fig. 5: PV system connected to the load through a Boost converter (blue rectangle). Battery and charge controller will be discussed later (red rectangle)

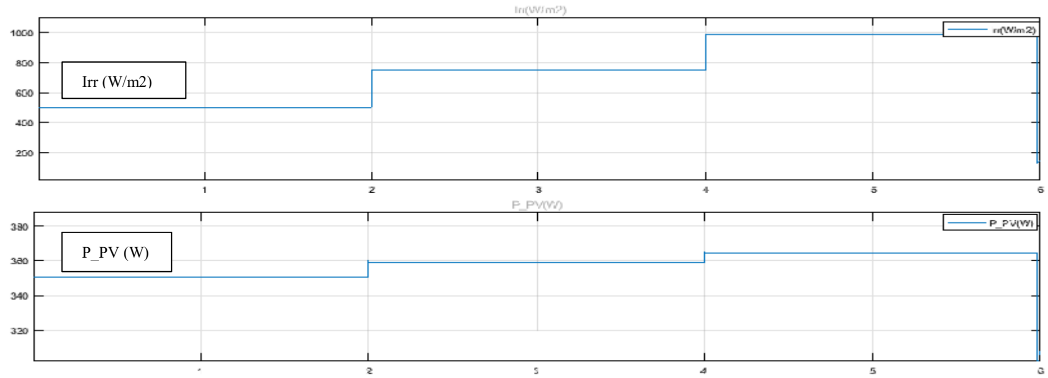

Fig. 6: Result of the simulation of a PV system directly connected to the load

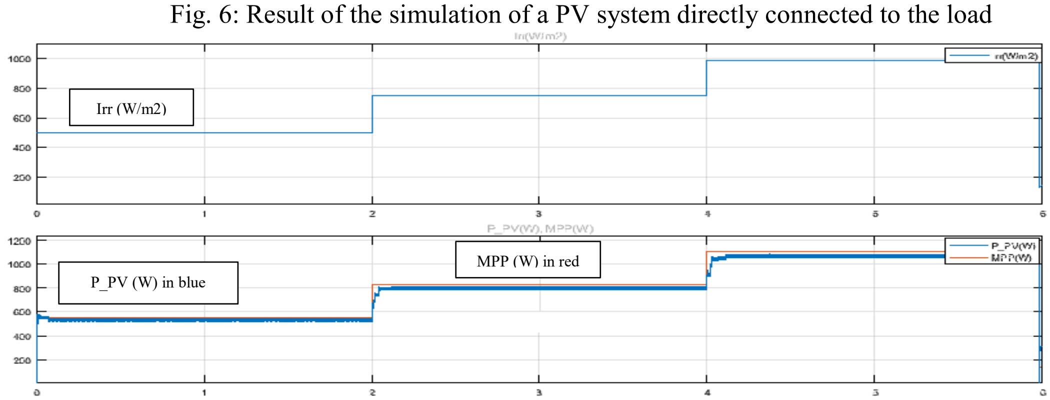

Fig. 7: Result of the simulation of a PV system connected to the load through a Boost converter equipped with a MPPT command

In the Fig. 6 at times t = [0 s - 2 s], t = [2 s - 4 s] and t = [4 s - 6 s], the powers consumed are respectively P_PV=350, 360 and 365 W, for respective irradiances G = 500, 750 and 1000 W / m^2, and for a constant temperature set at 25 ° C. The PV generator does not operate at its maximum power because at these times the MPPs are respectively equal to 554, 831 and 1108 W. The power consumed does not correspond to the maximum output. However, in Fig. 7 at time t = [0 s - 2 s], t = [2 s - 4 s] and t = [4 s - 6s], we find that the power is respectively equal to 545, 810 and 1100 W, for respective irradiances G = 500, 750 and 1000 W / m^2, and for a temperature set at 25 ° C.

4. Modelling Of The Energy Storage

We uses a Simulink component as a Battery with appropriate parameters. In fact, the load required a power of 1108W under a voltage of 130 V. We consider that the battery should be able to supply the load for a maximum of 1h. Then the battery's capacity should be equals to 1.108kWh. However, the battery has two functioning modes. While it is absorbing power, it operates as a load. So its voltage should be less than the network voltage. Contrarily, when the battery is injecting the power into the network, its voltage should be greater. So, we use a buck-boost converter to connect the battery to the network; the buck function being a voltage divider (battery charging) and the boost function being a voltage multiplier (battery discharging). A control philosophy has been implemented to activate or deactivate these two modes.

Conclusion

Due to of the energetic needs increase and the constraint to respect the environment, renewable energies is emerging. Solar energy is one of them. However, its dependence to weather conditions (temperature and solar irradiation) makes its less efficient. Technologies have been developed to overcome these issues. Boost converter is used to harvest the maximum power from solar panel at any time and within any weather conditions. Battery is used to store the exceeding energy during good weather conditions and return it during bad one.

Acknowledgment

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