A RELIABLE AND EFFICIENT CIRCUITRY FOR PHOTOVOLTAIC ENERGY HARVESTIN FOR POWERING MARINE INSTRUMENTATIONS

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Abstract

This paper presents and demonstrates a simple and reliable electronic circuitry for photovoltaic energy harvesting which best suited for powering marine instrumentations. The main functions of the designed circuitry are: i) tracking the maximum power point of the photovoltaic cells which are subject to continuous movements due to sea waves, ii) power conversion and management of energy storages with a high efficiency; and iii) achieving a high level of reliability for operation of circuit in a harsh marine environment. The proposed circuitry is designed based on an analog controller which implements a sensor-less algorithm for maximum power point tracking. The power converter unit includes a simple buck converter with minimum electronic components. Compared with DSP-based digital controllers, the simplicity of the proposed analog controller highly improves reliability of the power conversion unit. The total power consumption of the electronic circuit is in the range of a few milliwatts. This enhances the overall efficiency of power conversion especially in low power (a few watt) applications such as powering of marine and metrological sensors. The circuitry also includes a control unit for battery charging to protect batteries against overcharging. The performance of the designed circuitry is experimentally demonstrated using a test setup for power management unit of an ocean-graphical buoy.

1 Introduction

Maximum power point tracking of photovoltaic (PV) cells have been widely investigated in academia to improve the captured energy from a PV cell [1-3]. Most of the suggested algorithms have been experimentally tested using a DSP-based electronic setup with a fixed PV cell in a calm condition of a Lab. The main criteria in theses researches involve the characteristics of a PV cells and less attention have been paid to the user-end system and outdoor conditions. On the other hand, industrial applications demand more attentions on sound operation of power conversion and control circuitry under harsh environmental conditions.

Oceanographic buoys are good examples in which floating marine/metrological instruments installed in distant offshore locations. In such an application, PV energy system is the only reliable and available source of energy for supplying low power dc instrumentations. The harsh environment of sea causes a buoy and its equipments expose to high level humidity, continuous mechanical stresses and vibrations. From electrical aspects, due to frequently occurring lighting discharge between clouds, all electronic circuitries are highly expose to electromagnetic interferences (EMI). These condition demands a highly reliable structure and circuit for all equipments including power conversion units for PV cells.

Existing buoys which uses DSP-based power conversion and managements for PV cells, usually improves the reliability by using redundant units in a master/slave schemes. This approach requires over designs in electronic circuits which reduces overall efficiency of the system especially in low power (a few watt) applications.

Herein, we propose a simple and robust analog circuitry which is highly reliable against EMI due to eliminating DSP-processing units and efficient due using to minimum electronic components. The simplicity of the circuit also allows integration of individual identical modules for PV panels which also increases the reliability of power supply units. The circuitry includes a dc/dc buck converter which is controlled with a gated pulse generator with a fixed duty cycle. To follow the maximum power point of a PV cell, a tracking scheme based on estimation of the fixed open circuit voltage of a cell is used which is only requires the terminal voltage of a PV cell as a feedback. Therefore, no external sensor or extra PV panel are required for implementation of this algorithm. Batteries storages are also protected against overcharging by using a hysteresis control loop. To verify the performance and capabilities of the design electronics, the circuitry has been implemented and successfully tested on the prototype of “Mowj-negar”, the metrological and oceanographical buoy which is developed at Subsea R&D center, Isfahan University of Technology.

2 Modeling and control algorithm of stand-alone PV energy systems

2.1 Model of a PV cell

The model of a semiconductor-based PV cell is:

$$i = I_l - I_0\left(e^{\frac{qv}{nkT}} - 1\right) \qquad (1)$$

where I_l ideally equals short circuit current of the PV cell which is proportional to the solar irradiation, I_0 is the dark saturation current, v is the terminal voltage of the cell, q=1.6×10^{-19} is the electron charge, k=$i = 1.38\times10^{-23}$ is Boltzmann's constant, T is absolute temperature in Kelvin and n is the ideality factor which is defined a number between 1 and 2. Base on Equation (1) the output power of a PV cell is given by:

$$P = vi = v(I_l - I_0\left(e^{\frac{qv}{nkT}} - 1\right) \qquad (2)$$

Using Equation (2) and by applying different values for I_l the effect of solar irradiance on P-V characteristics of a PV cell is shown in Figure 1. For maximum power point tracking (MPPT), the operating point of the PV cell (output voltage) must be maintained within optimal zone depicted on Figure 1.

2.2 Fixed voltage algorithm for MPPT

From Figure 1, the maximum power can be achieved in a narrow zone of the output voltage. Therefore, if the control circuit maintains PV output voltage within optimal zone, maximum power tracking will be achieved. This control algorithm is called fixed voltage as it uses a fixed reference voltage within the optimal zone for PV terminal voltage.

Practically, a reference voltage in the range of 62 to 80% of Voc (open circuit voltage) can provide maximum power point tracking at different irradiations [4-5].As Figure 2 shows Voc can be estimated by a fix value. Therefore, fixed voltage algorithm does not need disconnection of PV or using any extra PV cell to measure the open circuit voltage. The fixed voltage algorithm can be readily implemented based on discrete and analog electronic components. Thus, the fixed voltage algorithm can be considered as a robust and reliable MPPT algorithm.

3 Power conversion and control circuitries

The heart of MPPT circuit is a switch-mode DC/DC converter. MPPT uses the converter to regulate the PV terminal voltage at the PV maximum power point. Figure 2 illustrates the block diagram of a simple converter feedback system.

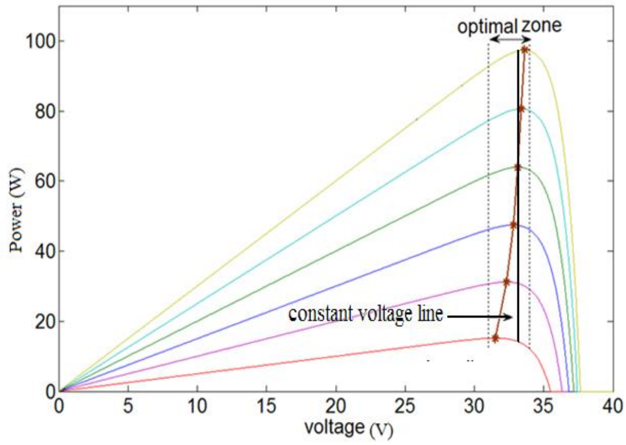


Figure 1: Power-voltage curves for a PV cell.

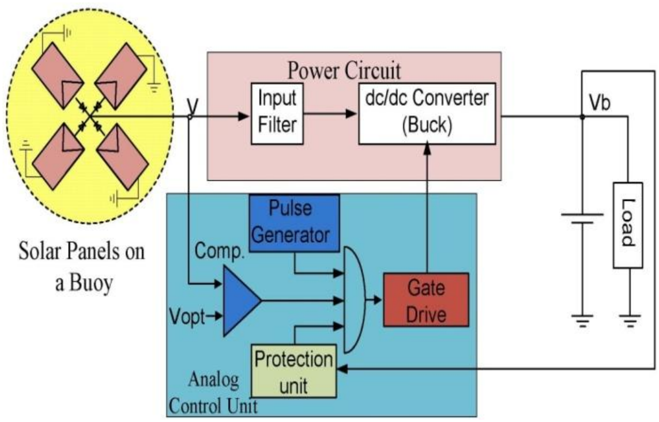


Figure 2: Power convertor with feedback system.

The control system compares PV terminal voltage with a dc reference voltage to generate a gating pulse. The gating pulse equals 0 (1) when input voltage is less (higher) than reference voltage. A fixed frequency converter pulse with a pre-specified duty cycle is applied to the switching converter.

This pulse is enabled / disabled by the gating pulse using a simple AND gate (Figure 2). In this algorithm, the duty cycle of converter pulses should set at a value that whenever the pulses are applied to the converter, the terminal voltage becomes less than the reference voltage. It is possible since we have a fix voltage (battery) as output voltage of converter. Based on this algorithm, when the input voltage is higher than the reference voltage, the gating pulse is 1 which allows converter pulses force the PV terminal voltage to decrease. When the terminal voltage becomes less than the reference voltage, the gating pulse is 0 which disable the converter pulses. Thus, the PV terminal voltage will increase again. This on/off control procedure regulates the PV terminal voltage at the desired dc reference voltage. A detailed design of buck converter component can be found in several references (e.g. [6]). When the battery is fully charged, it should be protected against overcharging. A simple hysteresis circuit for protection of battery (Figure 3) can be used. This circuit uses comparator with positive feedback to make a hysteresis loop with adjustable upper and lower thresholds. Using this circuit, as the voltage of battery reaches to a pre-specified upper threshold, output value of the comparator becomes low. This control signal can be used to turn off the converter or disconnecting the battery from the cells. Then, battery supplies power and as the voltage of battery reaches to its pre-specified lower level, output value of the comparator becomes high and charging of the battery starts again. To add this function of charging protection to the fixed voltage control strategy, the output signal of the comparator is connected in parallel with gating signal of the converter unit.

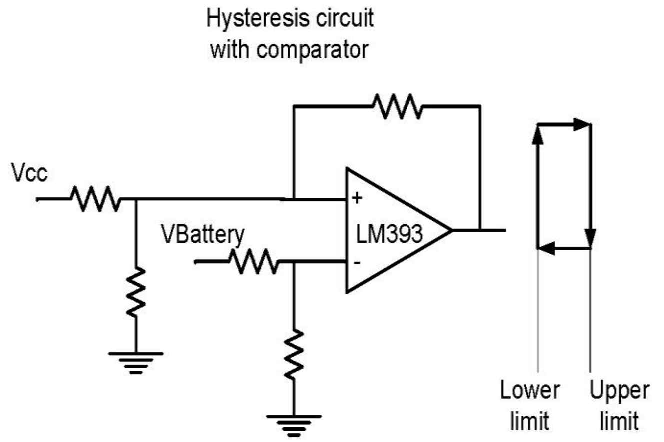


Figure 3: A hysteresis loop for battery protection.

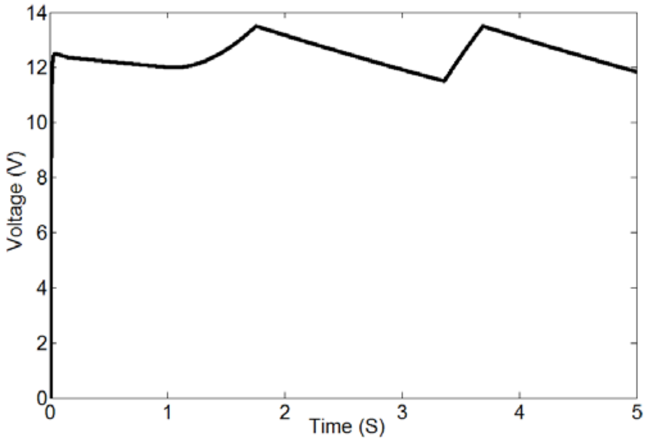
4 Design verifications

4.1 Simulation

To investigate performance of the suggested algorithm for MPPT in buoy PV energy system, the PV cell model (with its parasitic capacitance), dc/dc converter and control loops were simulated using PSCAD/EMTDC software tool. The simulation results for MPPT at different sunlight irradiance and battery charging control are shown on Figure 4. It shows that the converter controller tracks maximum power via regulating and maintaining the terminal voltage of PV at its reference level with protecting the battery from over/under charging.

4.2 Experimental measurements and tests

Figure 5 shows the picture of "Mowj-Negar" the oceanographic buoy which is designed and developed in Subsea R&D Center at Isfahan University of Technology. To improve the PV energy system for this buoy, a prototype of 4 multi-directional PV cells has been implemented as shown in Figure 6. Four sets of the designed analog controller and power converters were implemented on a single board (Figure7) which is used for experimental tests.



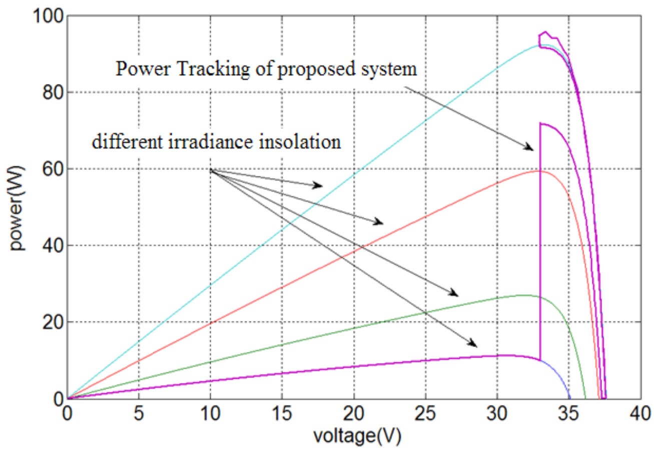


Figure 4: Simulation results of the design circuit.

To enhance overall reliability of system, we used an independent circuit for each panel. Different voltages were used as reference voltage for PV panels. At each voltage we measured extracted power from each PV cells. Table 1 summarizes the measured power of each panel at each reference voltage. The results show that the maximum output power of each panel occurs at terminal voltage close to 28 volt which is consistent with assumptions for designing the control circuit based on fixed voltage algorithm.

4 Conclusion

A simple yet accurate analog control circuit for maximum power point tracking of PV cells is designed and implemented. The control algorithm is based on a fixed voltage algorithm. The simplicity of circuit allows using individual controller for PV modules in a PV energy system which in turns enhanced the reliability of energy system. The proposed circuit has been designed for improving the robustness and efficiency of the PV energy system of a buoy. The performance of the designed circuit was successfully tested using a prototype for PV cells in a buoy.

Figure 5: “Mowj-Negar” the oceanographic buoy of Isfahan University of Technology.

Figure 6: Practical MPPT & battery charger circuit

Vref	Panel A	Panel B	Panel C	Panel D
(V)	Pin(W)	Pin(W)	Pin(W)	Pin(W)
25	23.7	19.5	13.5	12.75
25.5	23.7	19.9	13.77	13
26	24.18	19.76	13.78	13
26.5	24.6	19.87	14	13.25
27	24.84	19.98	14.04	13.23
27.5	25	20.35	14.02	13.2
28	25.2	20.44	14	13.16
28.5	24.8	19.95	13.96	13.11
29	24.9	19.86	13.92	13.05
29.5	24.78	19.76	13.86	12.68
30	24.6	19.5	13.8	12.6
30.5	24.1	18.91	13.42	12.5
31	23.56	18	13	12.1
31.5	22.68	17.64	12.9	11.5

Table 1: practical results of proposed system

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