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Solar powered water pumping system with MPPT

Nighil N.* and K. Vijith**

ABSTRACT

This paper presents the simulation and analysis of Solar powered water pumping system with maximum power point tracking (MPPT).The system consist of PV panel, converter battery and pump load.Thesystem is able to perform MPPT, battery charging and driving the pump with single transistor. To tap maximum power from the panel, an algorithm based on Perturb and Observe (P&O) methodis used.The battery in the converter will discharge and run the pump during night and low irradiance time. The model is simple and easily adoptable. The effectiveness of system is studied with simulation results.

Index Terms: Maximum power point tracking (MPPT), Continuous conduction mode (CCM), Photovoltaic (PV), Single switch converter (SCC), State of charge (SOC), Perturb and observe method (P&O method)

1. INTRODUCTION

To overcome the energy crisis and prompt consumption of conventional fossil fuel energy resources. The solar energy is the most desirable alternate among the all renewable energy resources. The photovoltaic array converts solar energy into electricity based on irradiance and temperature level. Mainly photovoltaic systems are classified as standalone system and grid connected system. A standalone photovoltaic pumping system is nothing but the system which works independently without the support from grid. The most important application of standalone PV system is for water pumping, mainly in rural areas where there will be huge amount of solar irradiation and system is not connected to grid system. Thecharacteristic of photovoltaic array is non-linear in nature which produces only a single MPP, at which the PV array gives maximum output power. As theoutput power from the photovoltaic array is proportional to the irradiance and temperature, it is necessary to design a control mechanism has to acquire maximum power from the PV panel. Thephotovoltaic array uses a charge controller[DC-DC converter]. The maximum power point tracking (MPPT)[1] algorithm controls the converter and it is used between the photovoltaic array and PMDC motor-pump.

The conventional design uses cascaded converter topology for pumping, charging/discharging the battery and maximum power point tracking. In cascaded converter power is repetitivelyprocessed and high number of switches increases converter physical size and cost. Therefore integrated buck and buck-boost converter with single switch [2] is used here for pumping.

The proposed system consist of solar PV panel, integrated buck and buck-boost converter with single switch and a battery, as shown in Fig. 2. The system is able to perform MPPTand run the permanent magnet DC motor pump load at different modes mentioned below. If maximum power from the panel is not utilized for pumping, then the extra power from the PV input is used to charge the battery. When PV panel is shaded

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or during night, battery will discharge and supply power to the pump load. The PV panel charges the battery when pumping is not done.

Various MPPT algorithms have been proposed and implemented which includes Perturb and Observe method [3], neural network control method [4], incremental conductance method [5], and fractional Open Circuit Voltage algorithm [6]. All these control methodology differ in their cost, efficiency and complexity. In this paper, Perturb and Observe method is used to model the maximum power point tracking(MPPT).

2. SYSTEM OVERVIEW

2.1. Solar Panel

Permanent magnet DC motor pump loadrated power is 373W, so solar panel array should supply a minimum power of 380W for charging the battery and pumping operation. In this paper, solar panel having open

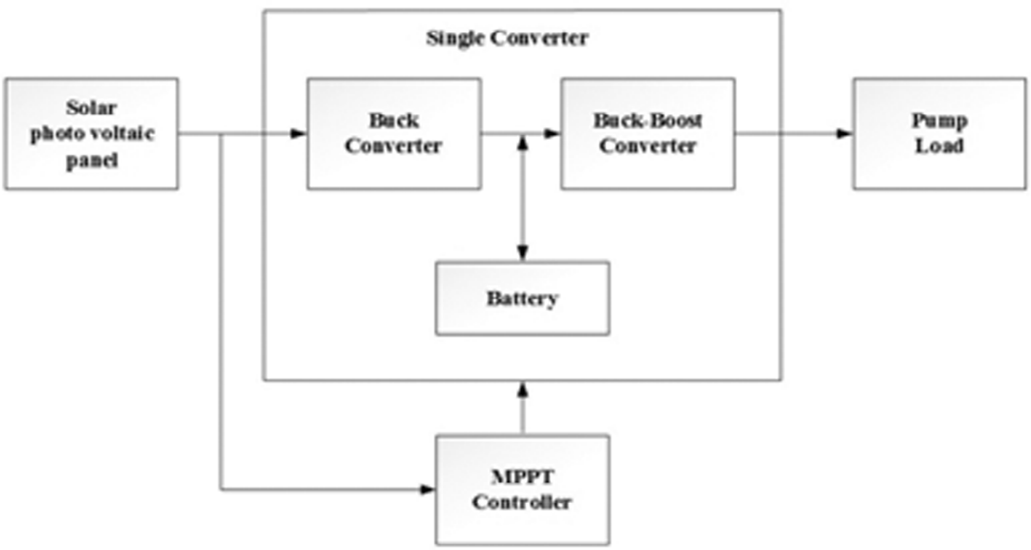

Figure 1: Block diagram of proposed system

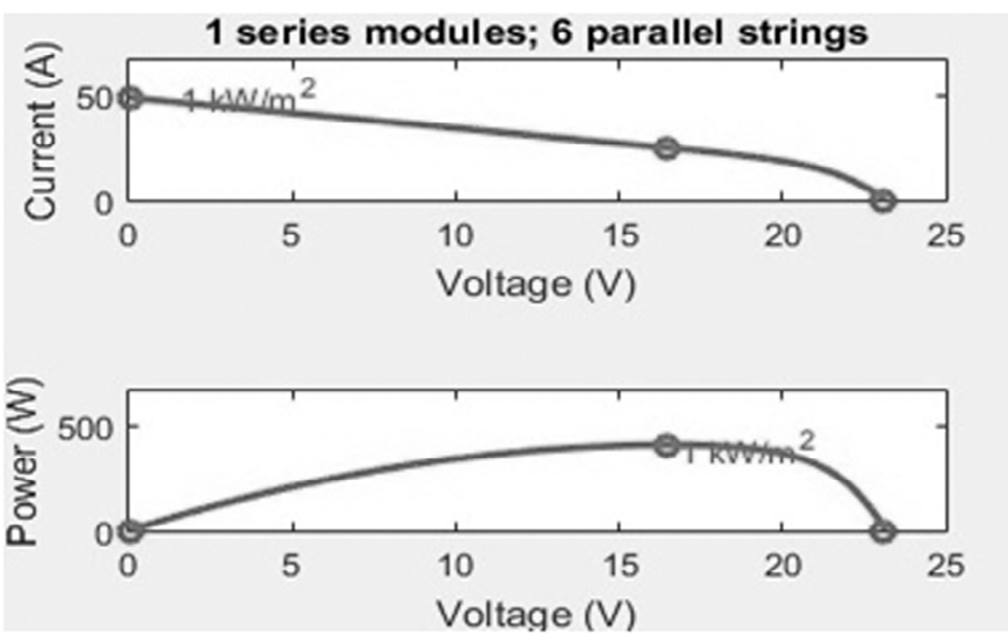

Figure 2: I-V and P-V characteristics of solar panel at irradiance of 1000W/m^2 and 25° C

circuit voltage (V_{oc}) = 23.1V and short circuit current (I_{sc}) = 5.1A are connected into modules with 36 cells in series. The output power of solar panel is 68W with maximum voltage (V_{mpp}) = 16.4V and maximum current (I_{mpp}) = 4.1A at rated sun irradiance of 1000W/m^{2}and the temperature of 25°C, so total 6 solar panel array of above specification are parallely connected. The Solar panel array was modeled using MATLAB/ SIMULINK 2015 model .The I-V and P-V characteristics of solar panelobtained for a solar irradiation of 1000W/m^2 at 25° Cis given in Fig. 2.

2.2. Converter

Circuit diagram of the whole system is shown in Fig. 3. It consist of input inductor and output inductor, capacitor is used to absorb the ac current ripple of the battery and an output capacitor. To run thepump in different modes mentioned above, integrated buck and buck-boost converter with single switch is used. The input inductance and output inductance are operated in continuous conduction mode (CCM) shown in Fig.4.The input inductancecharged up by Photo voltaicSource with a slope of

$$\frac{di_{L1}}{dt} = \frac{V_{in} - V_B}{L_1} \tag{1}$$

The output inductance charges with a slope of

$$\frac{di_{L2}}{dt} = \frac{V_0}{L_2} \tag{2}$$

Where V_B is battery voltage and $V_0$is output voltage

The peak current values of the two inductors are shown in equation (3) and (4).

$$i_{L1,\,peak} = i_{L1} + \frac{(V_{in} - V_B)DT_S}{2L_1} \tag{3}$$

$$i_{L2,\,peak} = i_{L2} + \frac{V_0 DT_S}{2L_1} \tag{4}$$

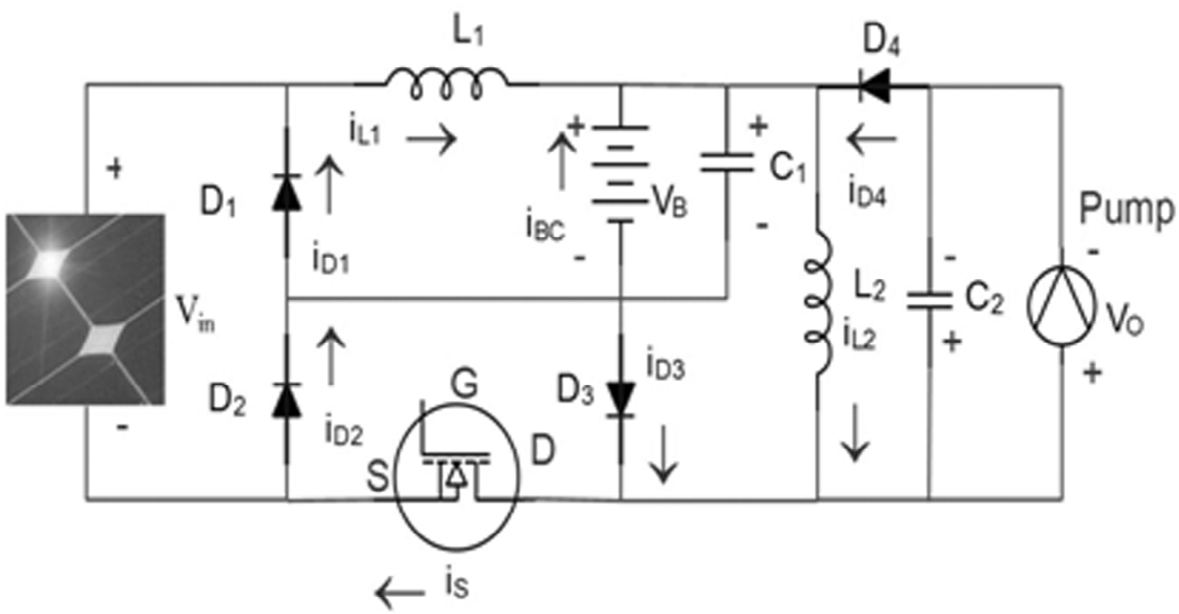

Figure 3: Circuit diagram

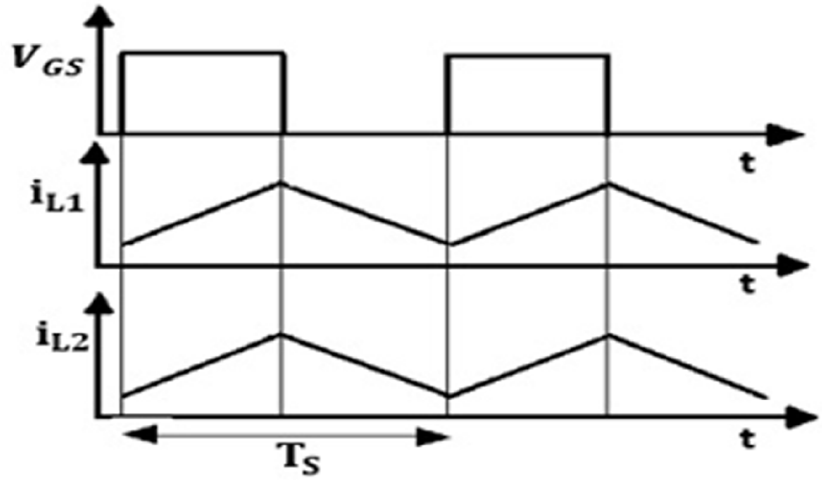

Figure 4: Waveform of input inductor current i_{L1} and output inductor current i_{L2}.

2.3. Battery

The proposed system uses 12V, 31Ah battery torun the pump, when PV panel is shaded or during night.If maximum power from the panel is not utilized for pumping, then battery is charged. During night and low irradiance time, battery will discharge and run the pump. Battery capacity is designed based on equation (5) with 12V, 373W and 50% DOD (Depth of discharge) [8].

$$Total\ Ah\ capacity = \frac{power\ required\ by\ pump\ load}{DOD\ \times\ system\ voltage} \tag{5}$$

3. CONVERTER DESIGN

The design of integrated buck and buck-boost converter is discussed in this section [7]. The inductance value is chosen such that the input and output stages are worked in continuous conduction mode (CCM). The minimum value of L_1 is given by

$$L_1 > \frac{[V_{in} - V_B]^D}{F * \Delta i_L} \tag{6}$$

For the output stage inductor, the minimum value of L_2 is given by equation (7) and (8). Where V_{in} is the input voltage to the converter and V_B is the battery voltage and F is the operating frequency and D is the duty ratio and Δi_L is the ripple in inductor current.

$$L_2 > \frac{[V_{in}] * D}{F * \Delta i_L} \tag{7}$$

$$L_2 > \frac{[V_b] * D}{F * \Delta i_L} \tag{8}$$

The inductance values used in Fig. 6 are 230μH and 270μH.

Capacitor C_1 is used to absorb AC current ripple of battery. Capacitor value is designed based on equation (7) with output voltage ripple 1%.

$$C_1 > \frac{[1 - D] * V_0}{8 * F^2 * \Delta V_0} \tag{9}$$

Output capacitance C_2 is used to reduce output voltage rippleand it will maintain constant output voltage across pump load.

The minimum value of C_2 is given by

$$C_2 > \frac{D*T*V_0}{R*\Delta V_0} \tag{10}$$

Where V_0 is the output voltage and ΔV_0 is the ripple in output voltage.

The capacitance values used in Fig. 6 are 52μF and 3*m*F.

4. DESIGN OF MPPT CONTROL

There are different methods of MPPT such as Perturb and Observe method, Incremental conductance method, Fuzzy Control, Fractional Open Circuit Voltage, Neural Network algorithm etc. The perturb and observe

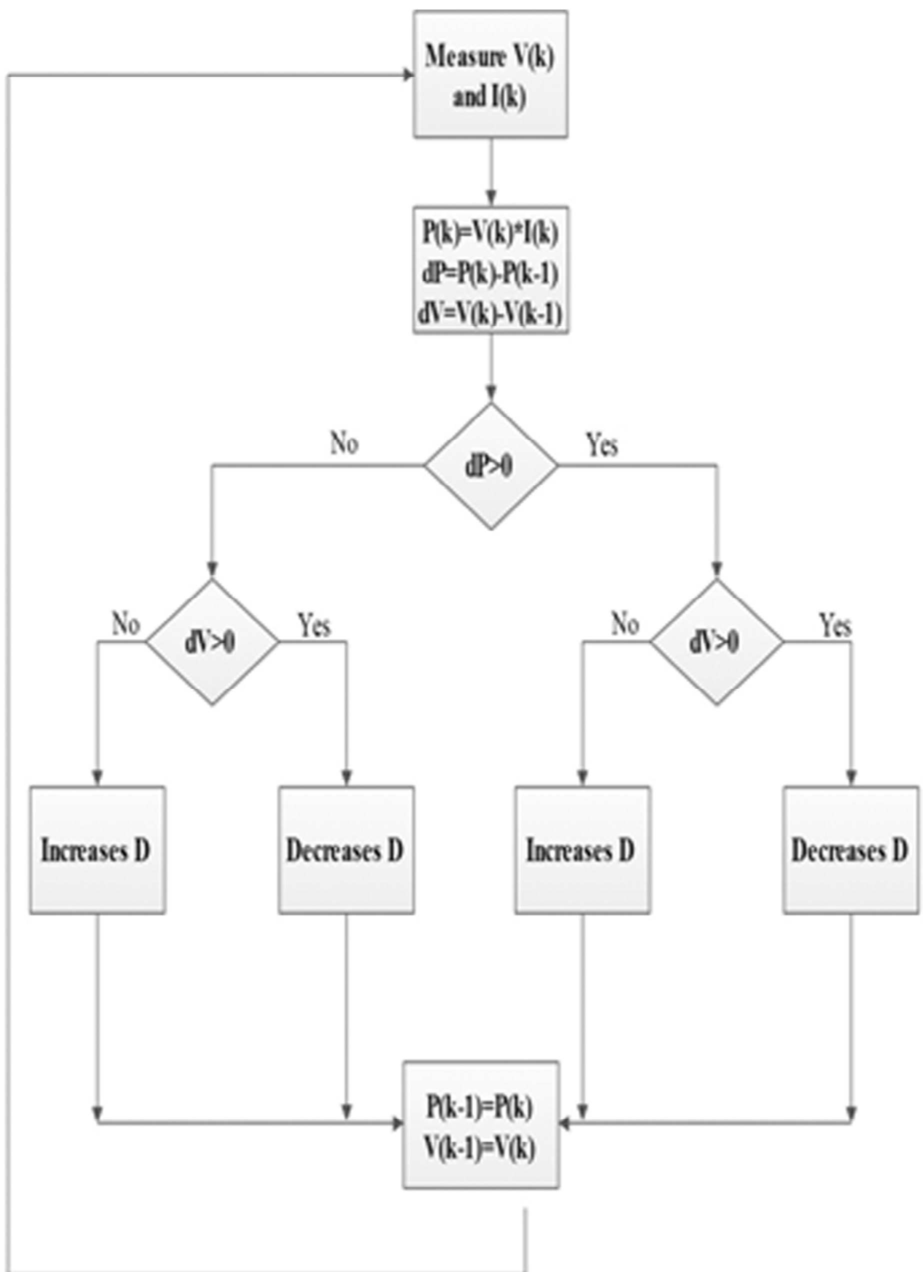

Figure 5: The flow chart of perturb and observe method

algorithm is one of the easiest and commercially used algorithm to implement the Maximum Power Point Tracking due to its easiness of hardware implementation.The P&O algorithms function by intermittently changing (i.e. increasing or decreasing) output voltage of the photovoltaic array and matching theoutput power of photovoltaic array with that of the prior perturbation cycle. If the solar PV array output voltage changes and solar PV output power increases, the control algorithm moves the photovoltaic array working point in that direction, else the working point moves in the reverse direction. The algorithm continues in the same way for next perturbation cycle.

The proposed system uses perturb and observe method for maximum power point tracking. Simultaneously PV array output voltage and solar PV array output current are sensed and solar output power is calculated. If voltage increases and power decreases, then duty ratio is increased. If voltage increases and power also increases, then duty ratio is decreased. If voltage decreases and power increases, then duty ratio is increased. If power and voltage decreases, then duty ratio is decreased. If duty ratio is increased, which in turn decreases array terminal voltage and vice versa. The algorithm continues for next cycle also in the same way as shown in Fig. 5.

5. SIMULATION MODEL

Table 1
Matlab Simulation Parameter

	RATINGS
SOLAR PHOTOVOLTAICPANEL	Rated Power/panel = 68W, V_{mpp} = 16.5A, I_{mpp} = 4.13, V_{oc} = 23.1V, I_{sc} = 8.1A, F_S = 20KHz.
CONVERTER	$L_1 = 252\mu H$, $L_2 = 270\mu H$, $C_1 = 52mF$, $C_2 = 2.6mf$
BATTERY	Voltage = 12V, Rated Capacity = 31Ah.
PUMP LOAD	Rated Power = 0.5 HP, Rated voltage = 24V, Rated Current = 19A.

6. SIMULATION RESULT

Simulation results for a runtime of 2 seconds for pumping and battery charging mode is shown below. The output voltage is 15V till 0.3 seconds. At 0.3 seconds, the maximum power point tracking is enabled which then boosts the output voltage to 23V as shown in Fig. 7.

Figure 8 shows the power consumed by the pump. The power consumed by the pump is 100W until it reaches 0.3 seconds. The maximum power point tracking is enabled at 0.3 seconds and as a result the output power increases to 240 W.

Figure 9 shows the SOC percentage of battery. The simulation is started with a 50% SOC. Figure 10 shows the battery power. The battery discharges with a power of 50W until it reaches simulation time of 0.3 seconds. At 0.3 seconds, the maximum power point tracking is enabled and the battery starts charging with aoutput power of 110W.This paper discusses briefly about the pumping and battery charging mode, other modes of operation results also analyzedand verified.

Simulation of solar powered water pumping system was done in MATLAB/ SIMULINK -2015 MODEL is shown in Fig. 6

7. CONCLUSION

In this paper, solar powered water pumping system with MPPTis simulated. A single switch converter with battery is designed for this purpose. The model has been proved efficient in different modes of operation with MPPT. The MPPT was implemented using MATLAB\SIMULINK model. The proposed system with MPPT can be implemented practically using microprocessor or DSP with less cost.

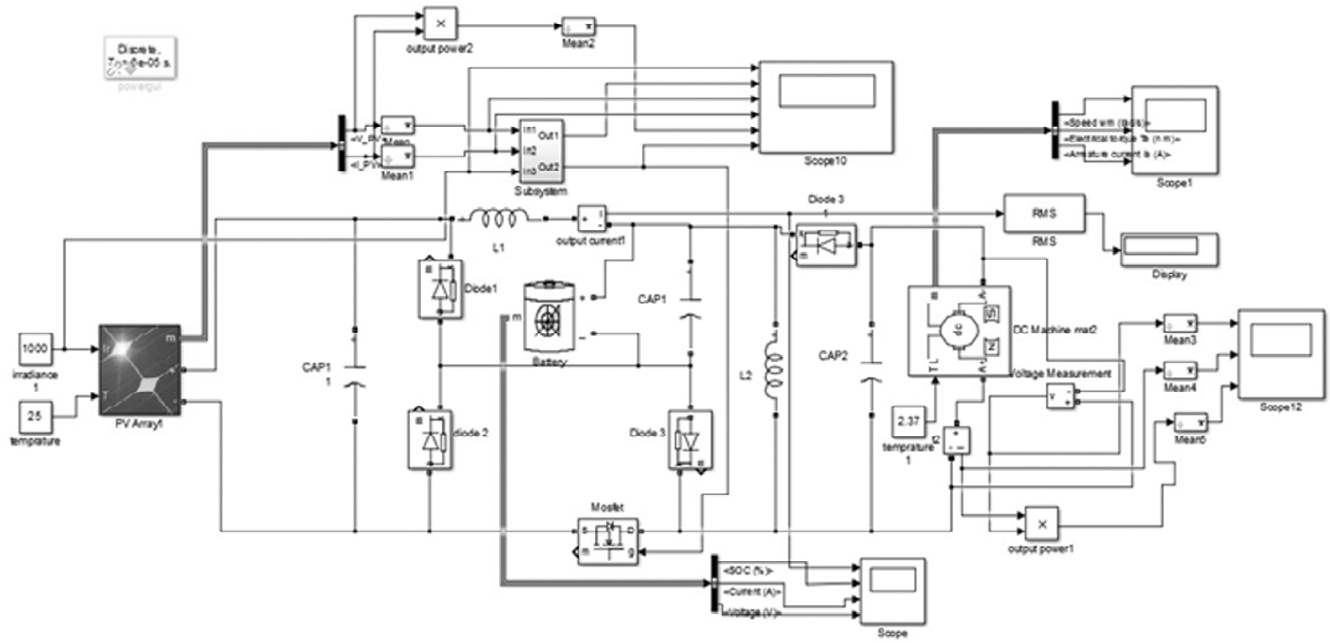

Figure 6: Matlab/Simulink Model

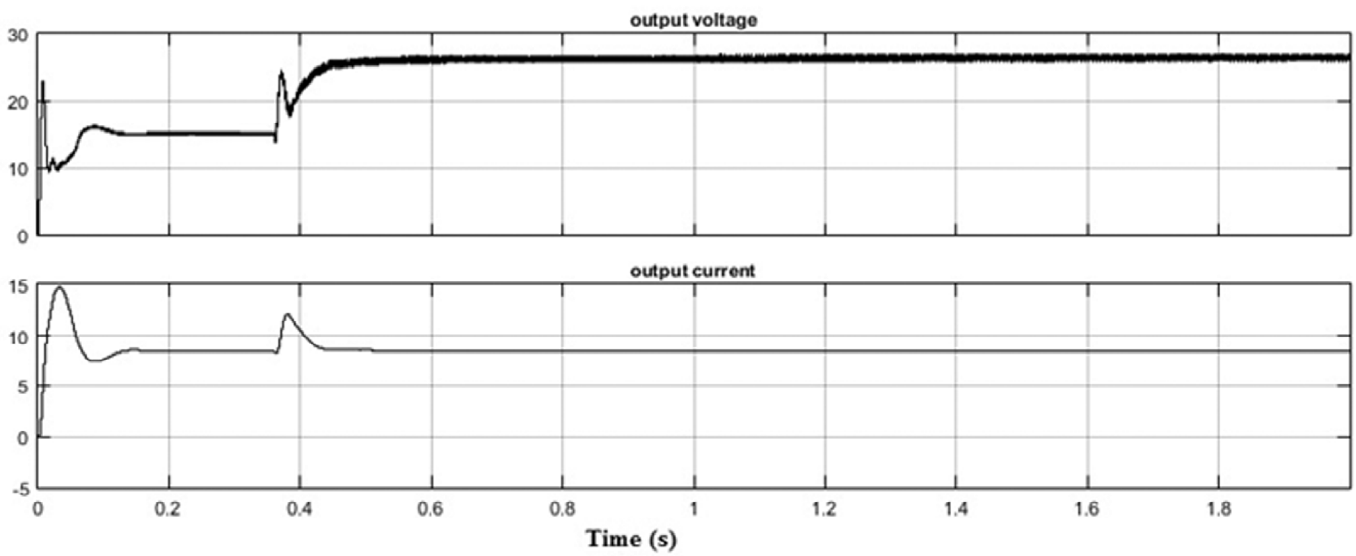

Figure 7: Output voltage and current

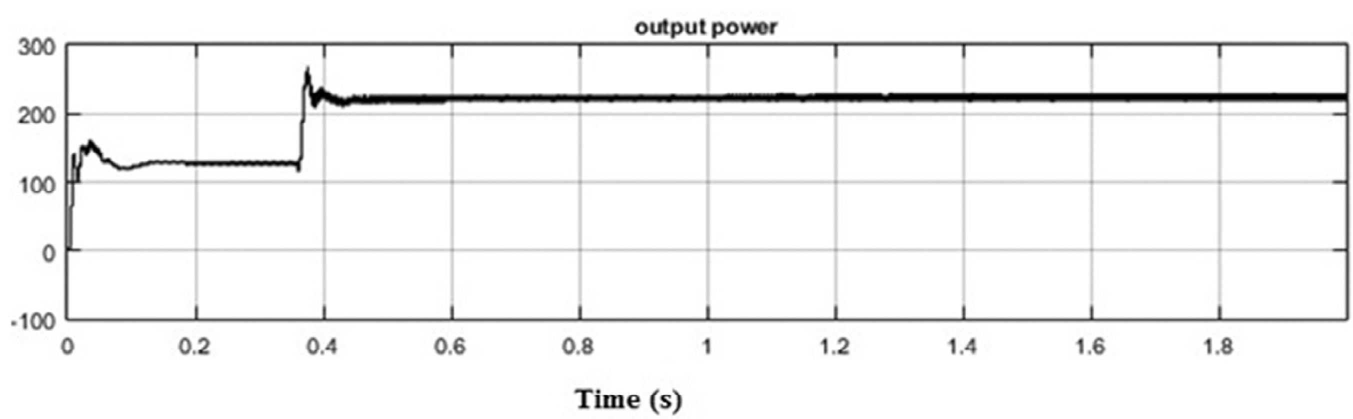

Figure 8: power consumed by pump

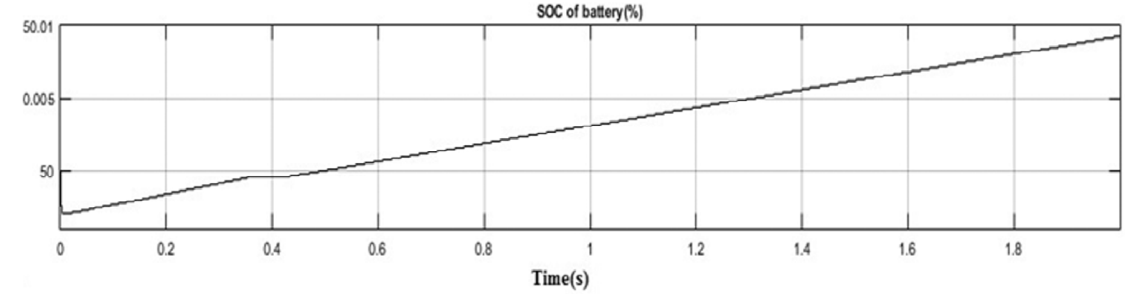

Figure 9: Battery SOC (simulation started with 50% SOC)

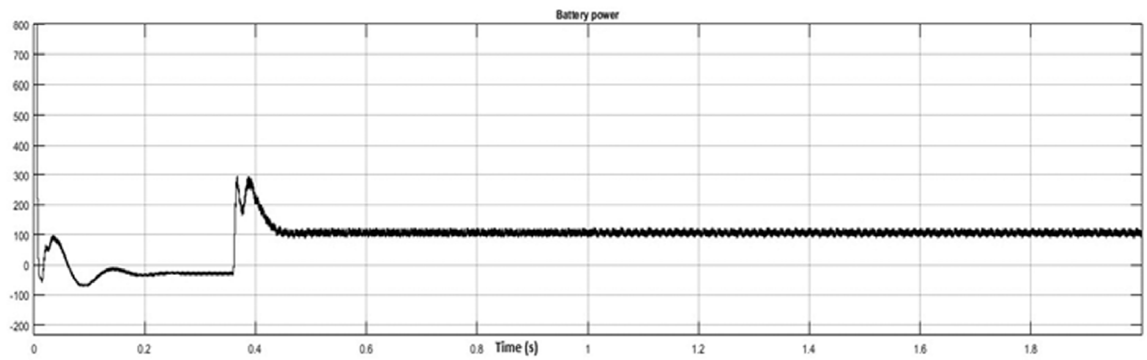

Figure 10: Power consumed by battery

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