Design & Analysis of PWM & MPPT Power Converters for Energy Harvesting IoT Nodes

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***Abstract*— This paper focus on the design of efficient circuit and systems for low power (< 1 W) energy harvesting wireless sensor network (WSN) nodes. We investigated various topologies of solar battery charging systems. We designed a 3.6 volts battery charging circuit in MATLAB/Simulink for IoT nodes. We observed that using pulse width modulation (PWM) control techniques the battery charges up to 30% only for 500 seconds of simulation time. On another hand, using Perturb & Observation (P&O) maximum power point tracking (MPPT) techniques the battery charges up to 95 % within 200 seconds of simulation time only. Thus, as shown by our simulation results the P&O MPPT is more efficient as compared to PWM technique for battery charging of IoT nodes.**

Keywords- Solar Panel, Voltage Regulation, Battery, PWM, MPPT, WSN, IoT.

1. INTRODUCTION

The internet of things (IoT) nodes are used temperature monitoring, light monitoring, pressure monitoring, and humidity measurement applications in smart cities, smart agriculture, and industrial plants[1], etc. The IoT infrastructure consists of wireless sensor networks (WSN) nodes to perform the sensing, computation & communication tasks [2]. The WSN nodes are powered by finite battery supply which gets consumed at a very high rate. Thus the alternate source of energy should be provided to increase the battery lifetime of WSN nodes used in IoT applications [3]. In this paper, we have addressed the issue of designing efficient power supply circuits & systems for energy harvesting IoT nodes.

The Simple Basic Solar Energy Harvesting Battery charger circuit has a direct connection between solar panel and battery is shown in fig.1 (a). The Fig. 1(b) shows reverse charging protection using a diode Fig.1 (c) shows the Transistor Linear Voltage Regulators.

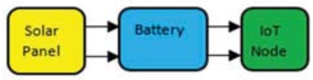

Fig.1(a) Direct connection between Solar panel & IoT node battery

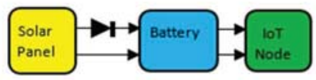

Fig.1(b) Connection using reverse current protection diode

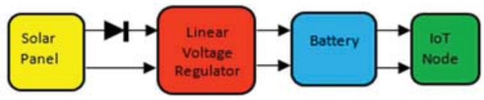

Fig.1(c) Connection using Linear Voltage Regulator

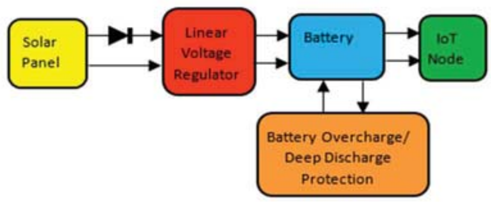

Fig.1 (d) Connection using Linear Voltage Regulator & Overcharge/deep discharge protection circuit

3. VARIOUS POWER CONVERTER TOPOLOGIES

The function of any voltage regulator is to provide overvoltage and under-voltage protection, short circuit or

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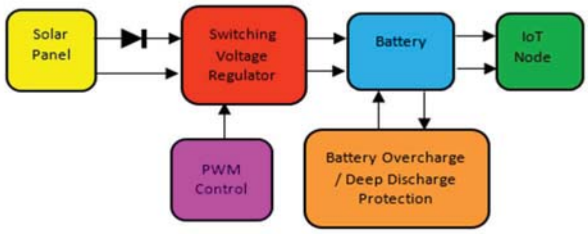

Fig.2 (a) Solar Battery Charger using Switching Voltage Regulator and PWM Control

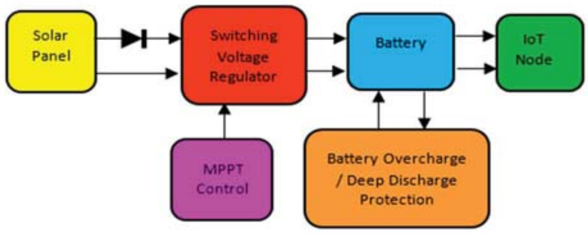

Fig.2 (b) Solar Battery Charger using Switching Voltage Regulator and MPPT Control

The advantages of a transistor voltage regulator are Simple Circuit, low cost, Less Noise, and ripple at low voltages. The disadvantages are high power dissipation, Poor efficiency at High output voltages (30% -60% only). This paper is organized as: Section 2 explaind efficiency of a power converter, section 3 describes various DC-DC power converter topologies, section 4 shows the simulation results, and finally, section 5 shows the conclusion.

2. Efficiency of a Power Converter:

The efficiency of a linear voltage regulator is given as [7]:

$$\text{Efficiency}(\eta) = \frac{P_o}{P_o + P_{loss}} \qquad (1)$$

Or,

$$\eta = \frac{V_o I_o}{V_o I_o + (V_{in} - V_o) I_o} = \frac{V_o}{V_{in}} \qquad (2)$$

Where, the output power is given as:

$$P_0 = V_0 . I_0 \qquad (3)$$

over-heating protection [4-7]. Here, the battery may get damaged due to overcharge or deep discharge [8]. Therefore, fig.1 (d) provides a more efficient system which includes overvoltage protection also. The advantages are a Very simple circuit, less number of components [9]. The disadvantages are very poor output voltage, current from the battery may return to solar panels, improper load matching, etc.

And the power loss is given as:

$$P_{loss} = (V_{in} - V_o) I_o \qquad (4)$$

The Fig. 2(a) shows a pulse width modulation (PWM) controlled switching voltage regulator with battery overcharge & deep discharge protection features [10]. The advantages of switching regulators are small size, high efficiency (80-90%) and multiple output range. The disadvantages of switching voltage regulators are as: [11]

- Buck-Boost Switching regulators uses inductor coils, which may cause EMI interface.
- Complex design
- High-Frequency Noise
- Higher Cost

Table 1: Comparison of Linear & Switching regulators

Comparison Parameters	Linear	Switch Mode
Size	Large	Small
Weight	Large	Small
Efficiency	40%-60%	70%-85%
Electromagnetic Interference	Low	High
Number of Components	Less	More

Table 1 shows a comparison of linear & switching regulators. The fig. 2(b) shows the P&O MPPT controlled voltage regulator with battery overcharge & deep discharge protection features. Theoretically, the MPPT controlled power converters are better than PWM controlled converters.

Fig.3 shows MATLAB / Simulink implementation of DC-DC boost converter for battery charging of IoT node using PWM Control method.

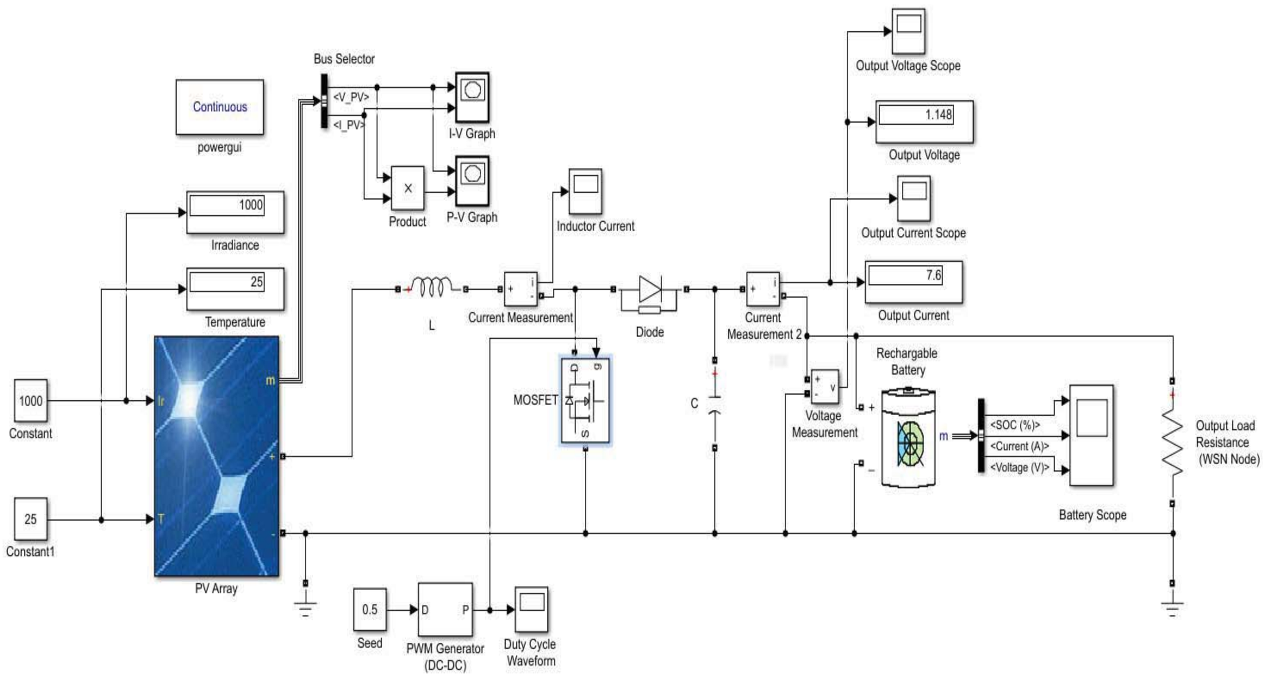

Fig.3 PWM controlled Buck converter for battery charging of IoT node

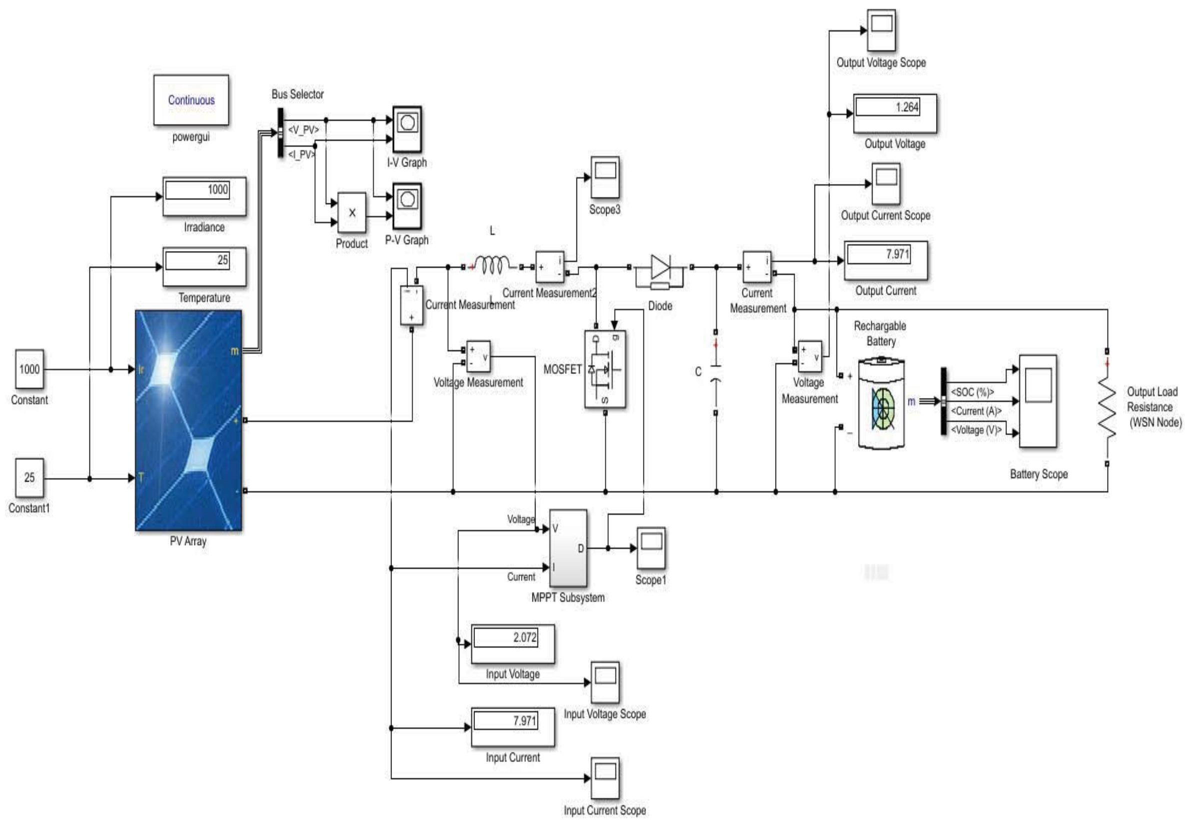

Fig. 4 P&O MPPT controlled Buck converter for battery charging of IoT node

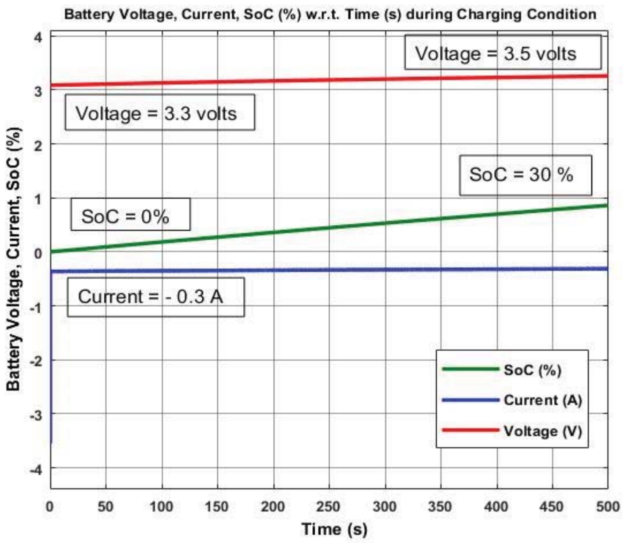

Fig.5 Simulation results for Battery charging using PWM control technique

Similarly, fig.4 shows the MATLAB / Simulink implementation of DC-DC boost Converter for battery charging of IoT node using P&O MPPT Control method. The solar panel Irradiance level is 1000 W/m^2 and the temperature is 25 Degree Celsius.

4. SIMULATION RESULTS

In fig.5, the simulation results for battery charging using PWM control is shown. Here, the battery SoC reaches only 30 % after 500 seconds. In fig. 6, the simulation results for battery charging using P&O MPPT control is shown. Here, the battery SoC reaches 95% after 200 seconds only. Thus from our simulation results, it is shown that the MPPT technique is better than PWM control technique for battery charging of IoT nodes.

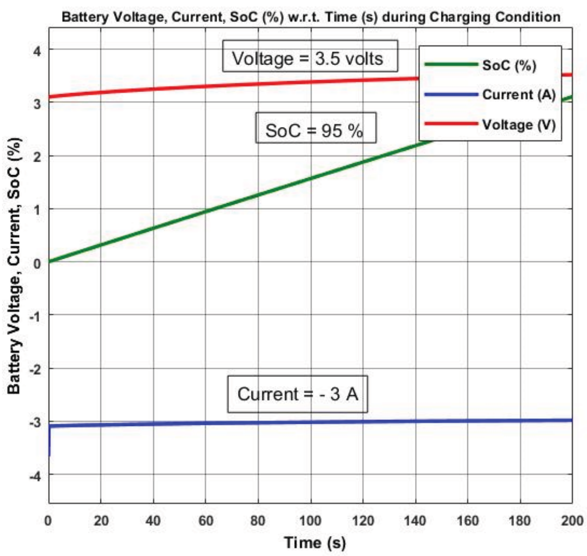

Fig.6 Simulation results using P&O MPPT control technique

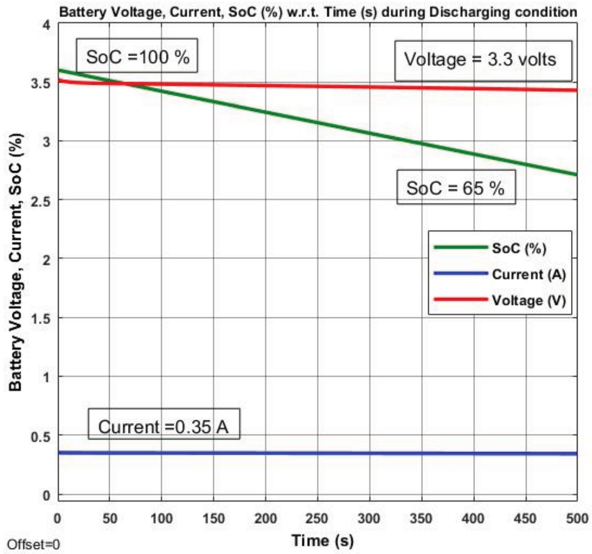

Fig. 7 Simulation results for battery discharging

Fig.7 shows the battery discharging curve for 500 seconds of IoT node operation. The battery energy is consumed in transmission, reception, and idle listening of the data & control packets of IoT node. The discharging rate depends upon the duty cycle of the operation of the IoT node.

5. CONCLUSION

In this research paper, the comparisons of various power converters system have been outlined. From our MATLAB/Simulink simulation results, it is shown that the MPPT technique is better than PWM control technique for battery charging of IoT nodes. In future, this work can be extended to various advanced MPPT algorithms like Incremental conductance, fractional over voltage (FOV), Artificial Neural Networks (ANN), and machine learning algorithms for battery charging of EH-IoT nodes.

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