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## Modelling of Electric Power Subsystem for a Weather Balloon Microsatellite

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### Key words:

Balloon,  
Microsatellite,  
Photovoltaic,  
Radiation and  
Temperature

### A B S T R A C T

*This paper examines monocrystalline PV cell Electric Power Subsystem (EPS) for a Weather Balloon microsatellite. The study deployed initial knowledge on power system and energy conversion to simulate electric power subsystem model in MATLAB Simulink 2013b environment through mathematical equations. The research investigated atmospheric conditions with respect to P-V and I-V characteristics on photovoltaic cells initiatives. The study adopted characteristic effect of solar energy radiation from 1367W/m<sup>2</sup> to 767W/m<sup>2</sup> with respect to low orbit temperature. The study has shown that photovoltaic devices could be considered for generation of electric power energy for spacecraft and microsatellite stations due to its efficiency and ability for thermal cycles in lower orbit with respect to limited time-varying degradation.*

### 1. Introduction

Power management and system availability has also been concern for weather balloon microsatellite. The study investigated electric power subsystem (EPS) for a weather balloon microsatellite is a standalone photovoltaic system, which requires a continuous power supply output for its loads. Hence, the microsatellite could be equipped with solar cell modules with a long life rechargeable batteries as a power source and energy storage respectively. Chuang-Shian (2012) explained that Photonic Devices Re-chargeable Unit (PDRU) is used to distribute electrical energy according to the power needs and the switching functionality of the different loads, regulate voltage, measure the status, and protect against anomalous conditions.

Marco (2006) claimed that, PDRU could comprise automated storage system such as Battery Discharge Regulator (BDR), DC/DC converter sub-unit, Battery Charge Regulator (BCR) and a current regulator sub-unit with main affinity to sense battery energy level for the efficient system charging.

Pastena (2006) described PDRU as switching unit for the BDR for the effective solar array absorptions. This is to support energy-load supply system and aiding the supply line to BCR for effective and robust charging network as revealed in Figure 1.

### 2.0 Modeling and Simulation of the Photovoltaic Module

The study models photovoltaic module in MATLAB/Simulink 2013b environment. The model is based on basic equivalent circuit of PV solar cell based with consideration of diode behavior as shown in Figure 2, Salmi et al. (2012).

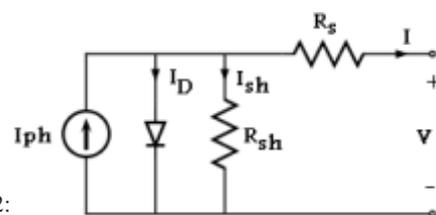
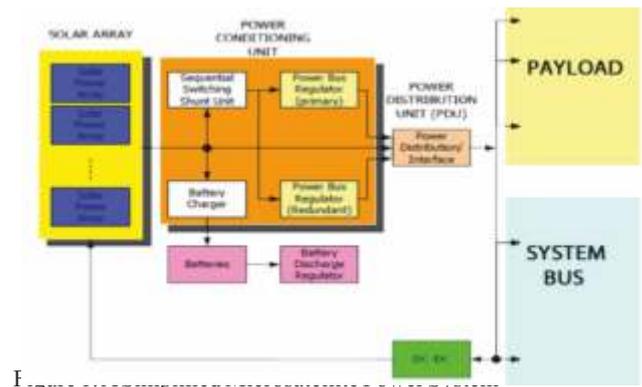


Figure 2:

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where,  $I_{ph}$  is the photocurrent,  $V$  is the voltage across the diode,  $I_{sh}$  is shunt current,  $R_{sh}$  is shunt resistor and  $R_s$  is resistor in series.

The study mimic single exponential equation that models a PV cell from the Figure 2.  $I_{sh}$  is equal to the raw current output of the cell. The dark current in the diode 'ID', and the shunt current is 'IRSH'. The resultant current relationships in Figure 2 is revealed by Kirchoff's current law as stated in equation (1).

$$I = I_{PH} - I_D - I_{RSH} \tag{1}$$

where  $I$  is the current flowing out of the cell's terminal and  $V$  is the voltage across cell terminal. The current passing through diode could be represented by equation (2), as illustrated by Salmi et al. (2012).

$$I_{diode} = I_s (\exp^{Vq/NKT} - 1) \tag{2}$$

where,  $I_s$  is the reverse saturation current of the diode and is dictated by the shape of the diode,  $V$  is the voltage across the diode. Where,  $q$  is the electron charge given as  $1.602 \times 10^{-19}$  (C),  $K$  is the Boltzmann's constant ( $1.381 \times 10^{-23}$  (J/K)),  $N$  is the ideality factor of the diode,  $T$  is the Ambient temperature of the PV cell.

However, equation 2 is a function of voltage across the diode and voltage the cell. This require modification in order to prioritize dark current value ' $I_D$ ' in terms diode's current as equation 3 revealed; and this is referred to as Shockley equation for an ideal diode recall,  $V = V + R_s I$

$$I_n = I_c (\exp^{q(V + R_s I)/NKT} - 1) \tag{3}$$

In order to solve for  $I_{RSH}$ , as applied by kirchoff's voltage law and this could be resolved to equation (4), (Makarov et al., 2016).

$$I_{RSH} = (V + R_s I) / R_{SH} \tag{4}$$

Hence, equation 1 could be substituted for parameters of  $I_{PH}$ ,  $I_{RSH}$  and  $I_D$  as stated above to derive equation 5 (Salmi et al., 2012

$$I = I_{PH} - I_s \left( \exp^{\frac{q(V + R_s I)}{NKT}} - 1 \right) - \frac{V + R_s I}{R_{SH}} \tag{5}$$

The study mimic two physical conditions of solar insolation and temperature govern the output of a PV cell. The Simulink model demonstrates PV cell behavior under varying solar insolation and temperature.

### 2.1 Solar Insolation

Figure 4 models PV cell photocurrent subsystem; also considered generated current  $I_{PH}$ . This mainly depends on solar insolation  $\beta$  and the cell's working temperature  $T$  as revealed in equation 6.

$$I_{PH} = \frac{[I_{SC} + K_i(T - T_{ref})]\beta}{1000} \tag{6}$$

where  $K_i = 0.0017A/^{\circ}C$  is the cell's short circuit current temperature coefficient,  $\beta$  is the solar insolation in kW/m<sup>2</sup>,  $I_{SC}$  is the cell's short circuit current at 25°C,  $T$  is cell's temperature and  $T_{ref}$  is the cell's reference temperature which is usually 298K.

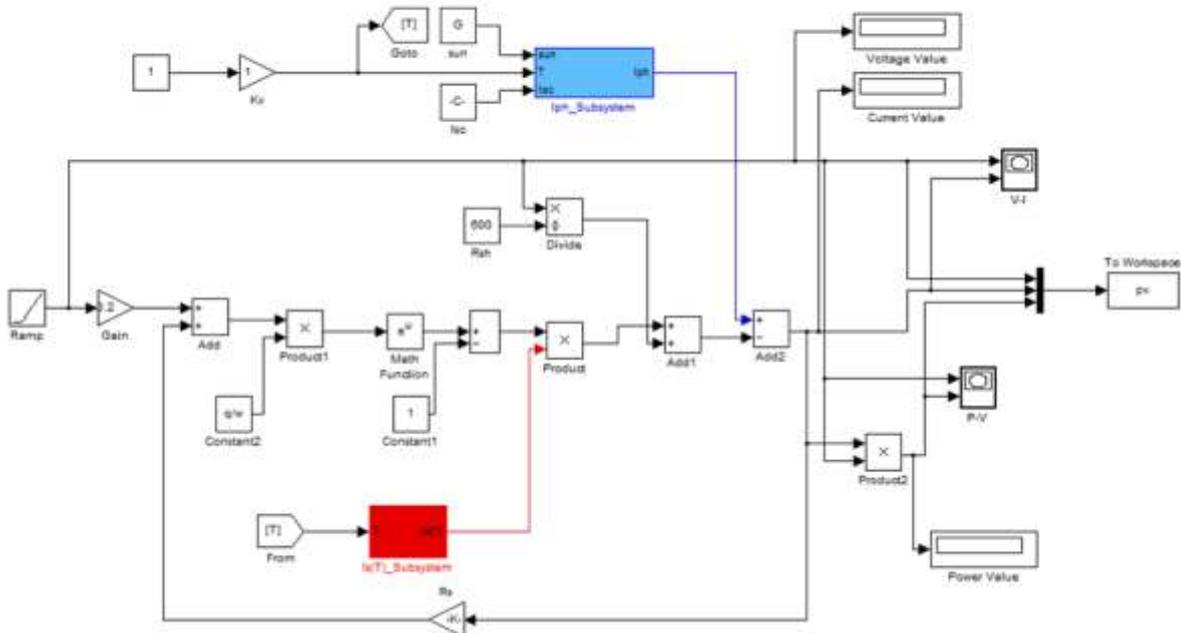


Figure 3: A Photovoltaic Cell Simulink Model

2.2 Temperature Variation

Figure 5, revealed second subsystem developed for the simulation temperature variation on diode reverse and PV cell saturation current. The effect of temperature variation on PV cell output is considered in two pattern:

- (i) the short circuit current 'Isc' of PV cell and;
- (ii) change of diode's PV cell saturation current (cubic power) and is given by equation 7.

$$I_s(T) = I_s \left( \frac{T}{T_{nom}} \right)^3 \exp \left[ \left( \frac{T}{T_{nom}} - 1 \right) \frac{E_g}{N \cdot V_t} \right] \quad (7)$$

where Tnom is the nominal temperature at 273K, Is is the diode reverse saturation current, Eg is the band gap energy of the semiconductor and Vt is the thermal voltage at room temperature as developed in MATLAB Simulink model, Figure 5.

3.0 Result and Discussion

3.1 Variation in Solar Radiation

Sun irradiance on the outer atmosphere and the earth are spaced at 1AU. The mean earth/sun distance of 149,597,890 km, this is called the solar constant (Kalidindi et al., 2015). Currently accepted values are about 1360 Wm<sup>-2</sup> (NASA given value is 1353 ± 21Wm<sup>-2</sup>). The World Metrological Organization (WMO) promotes a value of 1367 Wm<sup>-2</sup> (Mohammadia et al; 2015). The study adopted solar radiation variation range from 1367W/m<sup>2</sup> to 767W/m<sup>2</sup> as revealed in Figure 6 at low Earth Orbit (EO)

Figure 6 revealed the significance of light incident to solar cell. The study unveiled changes in solar cell parameters, these includes the ISC, the VOC and fill factor (FF).

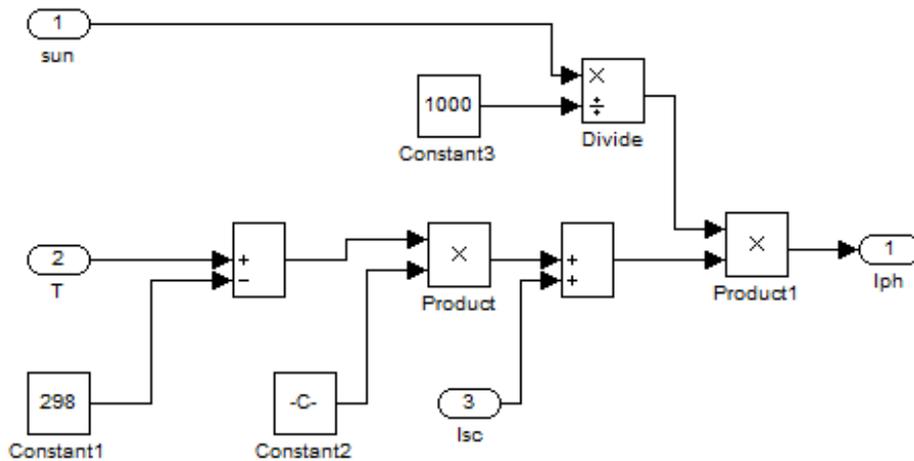


Figure 4: Varying Solar Irradiance Sub-system Simulink Model

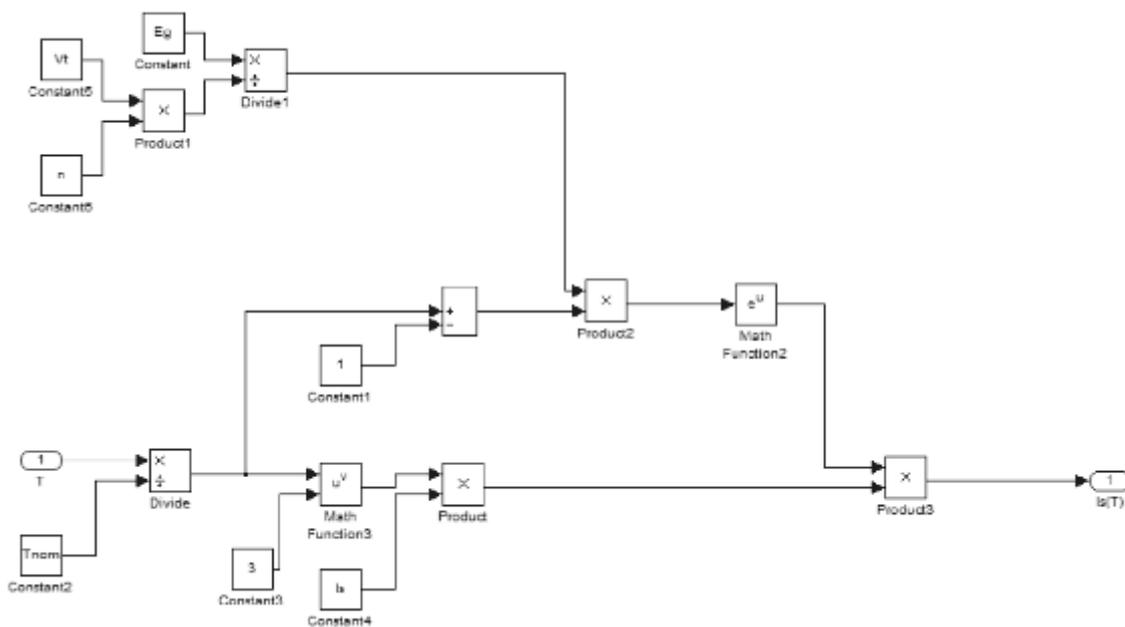


Figure 5: PV Cell Temperature Sub-system Simulink Model

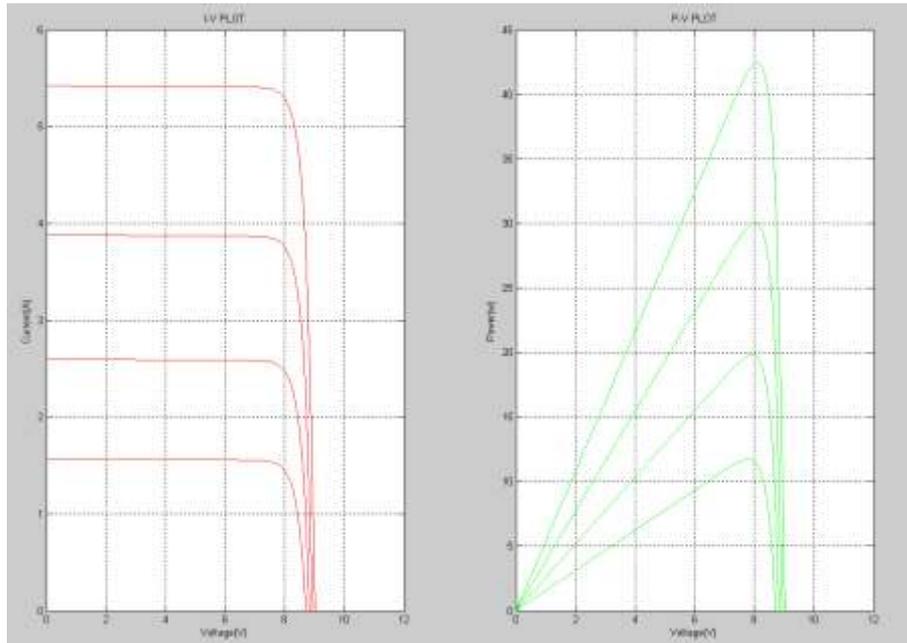


Figure 6: Effect of Solar Irradiance Variation on I-V and P-V Characteristics

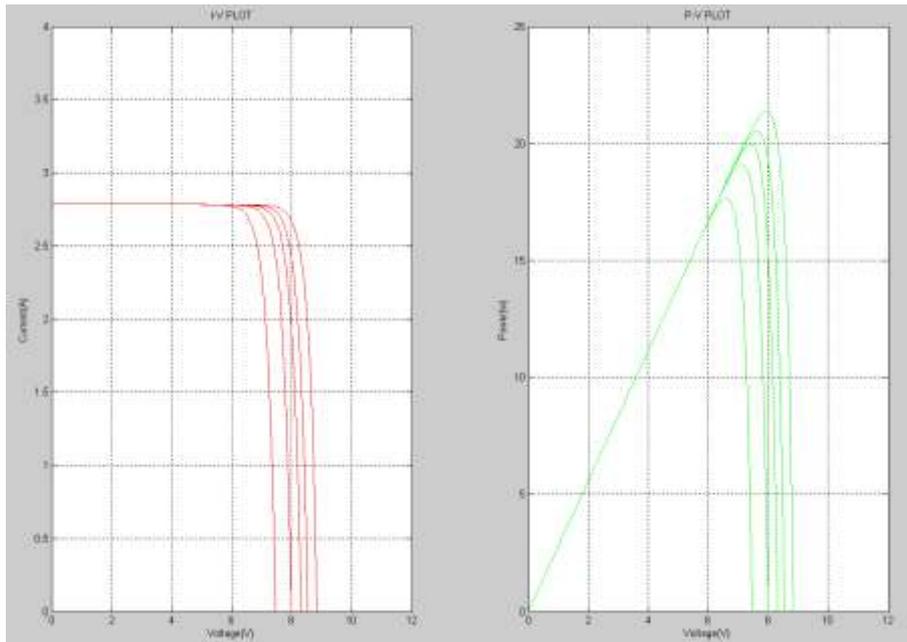


Figure 7: Effect of Temperature Variation on I-V and P-V Characteristics

It can be seen that, as solar radiation array drops, the study unveiled corresponding large drop in the power output and short-circuit current of the solar array. This established that, the efficiency of a solar array used in space application greatly depends on the solar radiation.

### 3.2 Temperature Variation

Increase in altitude thus contribute to corresponding decreases in temperature. The average adiabatic lapse rate (how cold it gets with altitude) is 0.65 Celsius per 100 meters (Amendt et al;

2012). The study considered adiabatic temperature range of 75°C to 0°C. It was revealed that changes in temperature with respect to adiabatic condition on VOC and P<sub>MAX</sub> can be clearly seen in figure 7 at low Earth Orbit (EO).

Figure 8, established that the shunt resistance of any photovoltaic cell should be large enough for better power output and fill factor. Furthermore, it can also be seen that at low shunt resistance, the PV cell current collapses more steeply. This means that; the higher the power loss; the lower the fill factor.

### 3.4 Series Resistance Variation

Series resistance presents internal resistive characteristic of the cell, which controls internal losses within the cell. The effect of variation in series resistance from  $10\text{m}\Omega$  to  $100\text{m}\Omega$  is revealed by Figure 9 at low Earth Orbit (EO)

It can be observed as series resistance increases, power output of the photovoltaic characteristic drop at the maximum power point voltage. Furthermore, it was noted that increase in series resistance could lead to reduction of fill factor (FF). Although, excessive high values could be investigated in the study of short-circuit current.

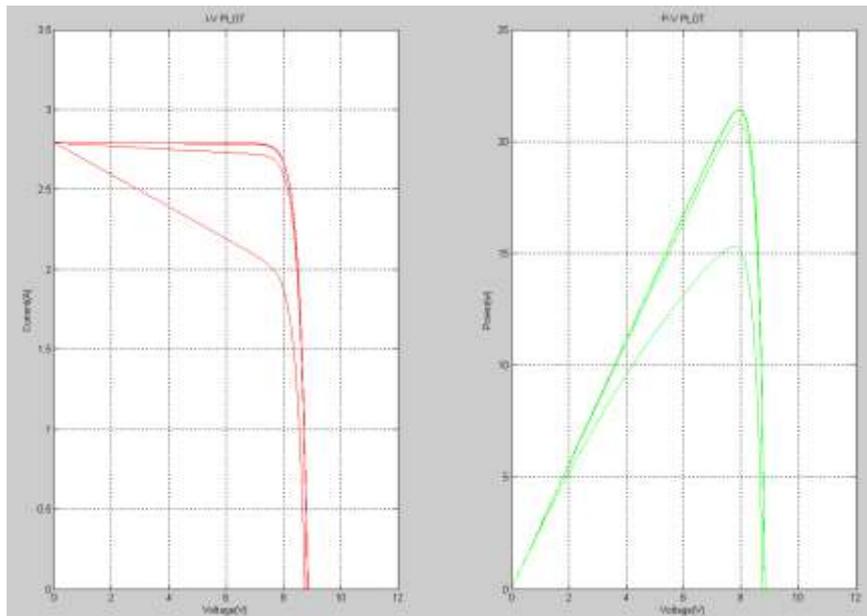


Figure 8: Effect of Shunt Resistance Variation on I-V and P-V Characteristics

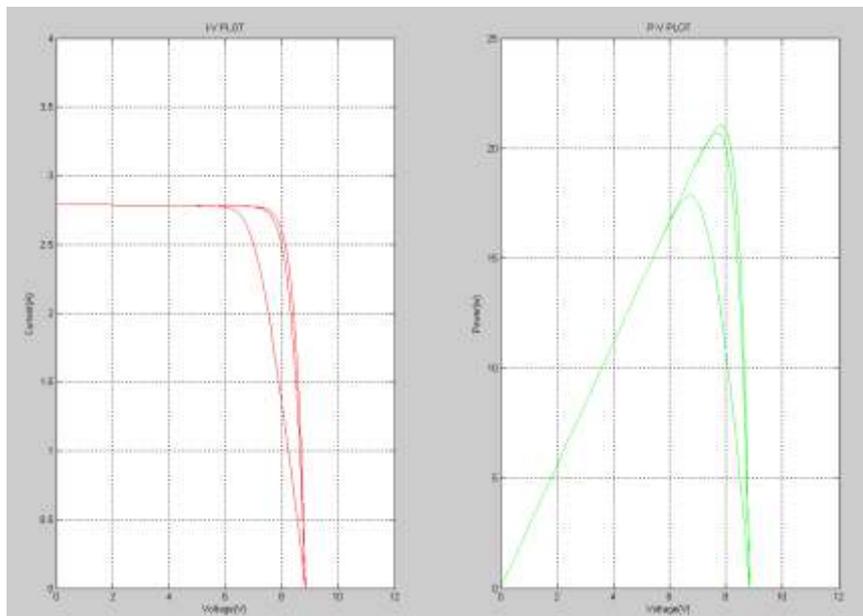


Figure 9: Effect of Series Resistance Variation on I-V and P-V Characteristics

#### 4.0 Conclusion

Power management has also been challenge of weather balloon microsatellite. In designing the Electric Power Subsystem for a weather balloon microsatellite, more attention and consideration needs to be given to power output with respect to adiabatic lapse rate and temperature. Photovoltaic devices has affinity and potential of electrical power generation for onboard spacecraft. Due to its power delivery efficacy and ability to withstand hundreds of thermal cycles in orbit, this make PV devices to be available as source of energy in adiabatic conditions. It has limited degradation with time due to cosmic radiations, resistance to mechanical solicitations during orbital movement, absence of moving parts and zero production of vibrations or noise. This study investigated atmospheric conditions with respect to P-V and I-V characteristics on photovoltaic cells initiatives taking solar energy radiation from 1367W/m<sup>2</sup> to 767W/m<sup>2</sup> in its low orbital temperature as revealed above. Although, natural phenomena such as eclipse of the moon could distort system availability. The study revealed that, monocrystalline PV cell could be a source of Electric Power Subsystem (EPS) for a Weather Balloon Microsatellite.

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