Modeling of Maximum Power Point Tracking Controller for Solar Power System

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Abstrak

Pada makalah ini, sebuah pengendali penjejakan titik maksimum daya (MPPT) untuk sistem pembangkit tenaga surya dimodelkan menggunakan MATLAB Simulink. Model yang dikembangkan dibangun dari modul PV, konverter buck, dan pengendali MPPT. Kontribusi dari makalah ini adalah pada pemodelan konverter buck yang menggunakan pendekatan model persamaan, tidak dengan pendekatan model rangkaian. Model konverter buck yang dikembangkan ini mengijinkan tegangan input konverter, yaitu tegangan keluaran PV, berubah sesuai dengan perubahan siklus kerja, sehingga pada saat terjadi perubahan lingkungan, titik daya maksimum tetap dapat dicapai. Dari hasil percobaan, model yang dikembangkan menghasilkan sifat yang sama dengan model dengan pendekatan rangkaian. Hasil simulasi menunjukkan bahwa model yang dikembangkan dapat mengikuti titik daya maksimum menggunakan algoritma Perturb dan Observe.

Kata kunci: *algoritma Perturb dan Observe, fotovoltaik, konverter buck, Model Simulink, MPPT*

Abstract

In this paper, a Maximum Power Point Tracking (MPPT) controller for solar power system is modeled using MATLAB Simulink. The model consists of PV module, buck converter, and MPPT controller. The contribution of the work is in the modeling of buck converter using equation model approach rather than circuit model one. The buck converter model is developed using equation model that allowing the input voltage of the converter, i.e. output voltage of PV is changed by varying the duty cycle, so that the maximum power point could be tracked when the environmental changes. From the experiment, the developed model comforms with the circuit model provided by MATLAB Simulink Power Simulation. Furher, the simulation results show that the developed model performs well in tracking the maximum power point (MPP) of the PV module using Perturb and Observe (P&O) Algorithm.

Keywords: *buck converter, MPPT, model Simulink, Perturb dan Observe algorithm, photovoltaic*

1. Introduction

Recently, the needs of renewable energy resources increase due to the fuel energy crisis and the global warming issue. Solar energy is one of the most important renewable energy. Solar energy using photovoltaic (PV) offers several advantages such as clean, no noise, and free. The conversion efficiency of electric power generation is about 27% as reported in [1]. Naturally, the problem of PV is the electric power generated depends on the weather condition. To increase the reliability of the power generation, solar energy is combined with other renewable energy resources such as wind energy system [2].

The PV module has a non-linear characteristic of the current-voltage (I-V) relationship. In the I-V curve, there is a point which the power is maximum for a particular irradiation condition. The similar characteristic also occurs in the wind energy system, in the sense that there is a point which a maximum power is achieved for a particular wind speed [3]. Therefore, to achieve the maximum efficiency, it is necessary to track this maximum power point (MPP) called as MPPT (Maximum Power Point Tracking).

There are many MPPT techniques could be found in literatures: Perturb and Observe (P & O) [4-6]; Incremental Conductance (IC) [7]; Fuzzy Logic [8], [9]; and Artificial Neural Network [10], [11]. The P&O method is widely used because of the simplicity and easy to be implemented. The method perturbs the PV operation point by increasing or decreasing the PV

voltage to find the maximum power point (MPP).

Commonly, researches developed MPPT techniques in two ways: hardware implementation and software modeling. In [4] and [6], they implemented the hardware of MPPT controller based on a microcontroller system. A Digital Signal Processor (DSP) module was employed in [5] and [9]. Software modeling was used in [7], [8], [10], [11]. There are two different approaches on software modeling: circuit model and equation model. In the first approach, the built in electrical components such as resistor, inductor, capacitor, etc. are used in the modeling. This approach is supported by software tools such as PSPICE, PSCAD, MATLAB Simulink (PowerSimulation). The second approach model is the system using a block or sub-system to represent the system's equation. This model could be implemented on the most popular software (C++, Java, MATLAB, etc).

The circuit modeling is easy to use, but there are several drawbacks: a) It is supported by the limited software; b) It is difficult to modify the model; c) It avoids for creating the new model. On the contrary, the equation modeling is rather difficult and complex to develop. However, it allows to modifying the model and creating the new model.

The common implementation of MPPT algorithm is by employing DC-DC converter between PV module and load/battery, and a MPPT controller to control the duty cycle of the converter. By varying the duty cyle of converter, the ratio of input and output voltage could be adjusted appropriately. Thus the input voltage of converter, i.e. output voltage of PV might be changed by changing the duty cyle. In other words, the control objective is to change the input of converter. This behaviour creates a problem when modeling the DC-DC converter using equation model approach, due to fact that in the equation modeling, the model is representated by the rule of "changing the input to change the output". Therefore, researchers prefer to employ circuit model for modeling the DC-DC converter modeling [7], [12-14].

This paper describes a MPPT controller using a buck converter to track the MPP of PV module. The main contribution of the paper is the modeling of buck converter using equation modeling, which allows the input voltage of the buck converter to be controlled by MPPT algorithm. PV module, buck converter and MPPT (P&O algorithm) are modeled using MATLAB Simulink. Since the main consideration is on tracking the MPP by adjusting the duty cyle of buck converter, output of the buck converter is considered as the general load. It could be a battery or electrical load.

2. Research Method
2.1 PV Modeling
The simple model of PV consists of a current source, a diode, and a resistor as shown in Figure 1. Output current of the photocell (I_L) is directly proportional to the irradiation level of the light falls on the solar cell.
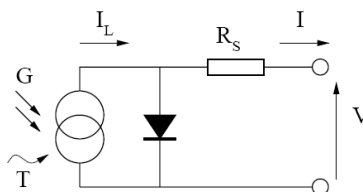

Figure 1. Equivalent model of PV [15].

The I-V characteristic of PV is expressed by the following equation [15]:

$$I = I_L - I_0(e^{q(V+IR_S)/nkT} - 1) \tag{1}$$
$$I_{L(T_1)} = G * I_{SC(T_1,nom)}/G_{(nom)} \tag{2}$$
$$K_0 = (I_{SC(T_2)} - I_{SC(T_1)})/(T_2 - T_1) \tag{3}$$
$$I_L = I_{L(T_1)}(1 + K_0(T - T_1)) \tag{4}$$

$$I_0 = I_{0(T_1)} * (T/T_1)^{3/n}$$
$$* e^{-qV_g/nk*(1/T-1/T_1)} \tag{5}$$

$$I_{0(T_1)} = I_{SC(T_1)}/(e^{qV_{OC(T_1)}/nkT_1} - 1) \tag{6}$$

$$R_S = -dV/dI_{V_{OC}} - 1/X_V \tag{7}$$

$$X_V = I_{0(T_1)} * q/nkT_1 * e^{qV_{OC(T_1)}/nkT_1} \tag{8}$$

where,

I_0 : saturation current for diode [A]
q : electronic charging [1.6e-19 C]
n : quality factor of diode
k : Boltzman's constant [1.38e-23 JK^{-1}]
T : temperature [^{o}C]
T_1 : reference temperature-1 [^{o}C]
T_2 : reference temperature-2 [^{o}C]
G : irradiance [W/m^2]
I_{sc} : short circuit current [A]
V_{oc} : open circuit voltage [V]
V_g : gap voltage band [V]

Figure 2 and 3 show the I-V and P-V characteristics of the typical 50 Watt PV module, respectively. The electrical characteristic of PV module considered in the experiment is described in Table 1.

Table 1. Electrical characteristic of PV module (Standard radiance level of 1000 W/m^2).

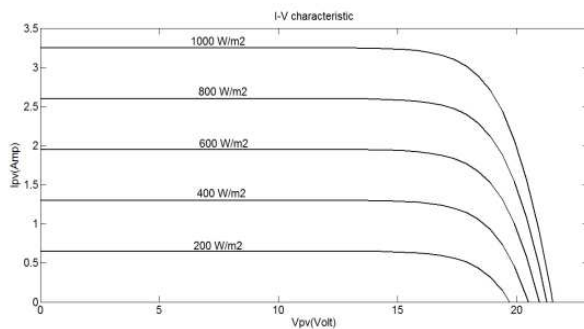| Variable	Level
Pmax (W)	50 ± 5%
Vpm (V)	17.5 ± 5%
Ipm (A)	2.86 ± 5%
Voc (V)	21.5 ± 5%
Isc (A)	3.25 ± 5%

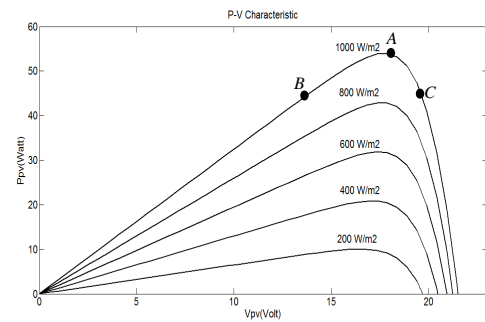Figure 2. I-V characteristic of PV module.

Figure 3. P-V characteristic of PV module

Observing Figure 3, for a particular solar irradiation level (for instance 1000 Watt/m^2), the point A is the maximum power point (MPP). At this point, it yields an equation

$$\frac{dP}{dV} = 0 \tag{9}$$

When the operation point changes to B or C, the equations are expressed in Eqs. (10) and (11) respectively.

$$\frac{dP}{dV} > 0 \tag{10}$$

$$\frac{dP}{dV} < 0 \tag{11}$$

The objective of MPPT technique is to track the operation point to the maximum one (point *A*).

2.2 Buck Converter Modeling

Buck converter is one of DC-DC converter type which is used to convert down the input voltage of the converter. Figure 4 shows the topology of buck converter which consists of power switch *S*, freewheeling diode *D*, inductor *L*, and capacitor *C*. MOSFET (Metal-Oxide-Semiconductor Field Effect) is selected as power switch *S*, rather than IGBT (Insulated Gate Bipolar Transistor), due to high frequency and low voltage application.

In the continuous conduction mode (CCM), the buck converter could be in two different states: ON state and OFF state. In the ON state, power MOSFET S is on and diode *D* is off. The corresponding circuit is shown in Figure 5, where R_S is the on-resistance of the MOSFET, R_L is the resistance of inductor, i_S is the current flows through the MOSFET, and i_L is the current through inductor *L*. The system equation is expressed as:

$$L\frac{di_L}{dt} = v_{in} - i_L R_L - v_{out} \tag{12}$$

$$i_S = i_L \tag{13}$$

$$C\frac{dv_{out}}{dt} = i_L - i_{load} \tag{14}$$

In the OFF state, MOSFET *S* is off, diode *D* is on. The corresponding circuit is shown in Figure 6. In this state, since the current flowing in the inductor could not change instantly, the current flows to the diode. The current in the inductor will decrease and cause the voltage across the conductor in reverse polarity. The system equation is expressed as:

$$L\frac{di_L}{dt} = -(i_L R_L + v_{out}) \tag{15}$$

$$i_S = 0 \tag{16}$$

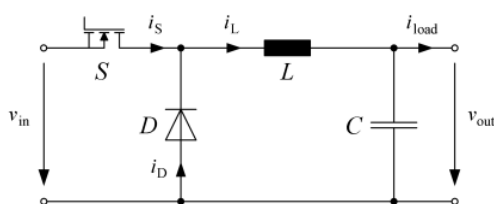$$C\frac{dv_{out}}{dt} = i_L - i_{load} \tag{17}$$
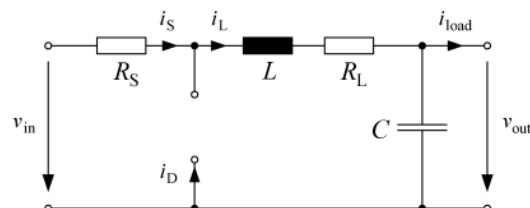

Figure 4. Buck converter circuit [16]

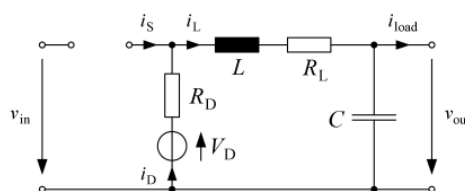Figure 5. Equivalent circuit in the ON state [16]

Figure 6. Equivalent circuit in the OFF state [16]

In the steady state condition, the average inductor voltage is the summation of Eqs. (12) and (15), and yields:

$$L\frac{di_L}{dt} = d(v_{in} - i_L R_L - v_{out}) + (1-d)(-i_L R_L - v_{out}) \tag{18}$$

$$= dv_{in} - i_L R_L - v_{out}$$

where d is the period of the ON state. The average capacitor current is the summation of Eqs. (14) and (17), and yields:

$$C\frac{dv_{out}}{dt} = d(i_L - i_{load}) + (1-d)(i_L - i_{load}) \tag{19}$$

$$= i_L - i_{load}$$

The average input current i_s is given as

$$i_S = di_L \tag{20}$$

2.3 Perturb and Observe Algorithm

The Perturb and Observe (P&O) algorithm ~~operates~~ perturbs the PV voltage periodically by varying the duty cycle, and observes the PV power to increase or decrease PV voltage in the next cycle. If the perturbation voltage produces an increase of the power, then the direction or slope of perturbation voltage (duty cycle) is the same as the previous cycle. On the contrary, if the perturbation voltage produces a decrease of the power, then the direction or slope of perturbation voltage (duty cycle) is the opposite from the previous cycle. Figure 7 shows the flowchart of the algorithm.
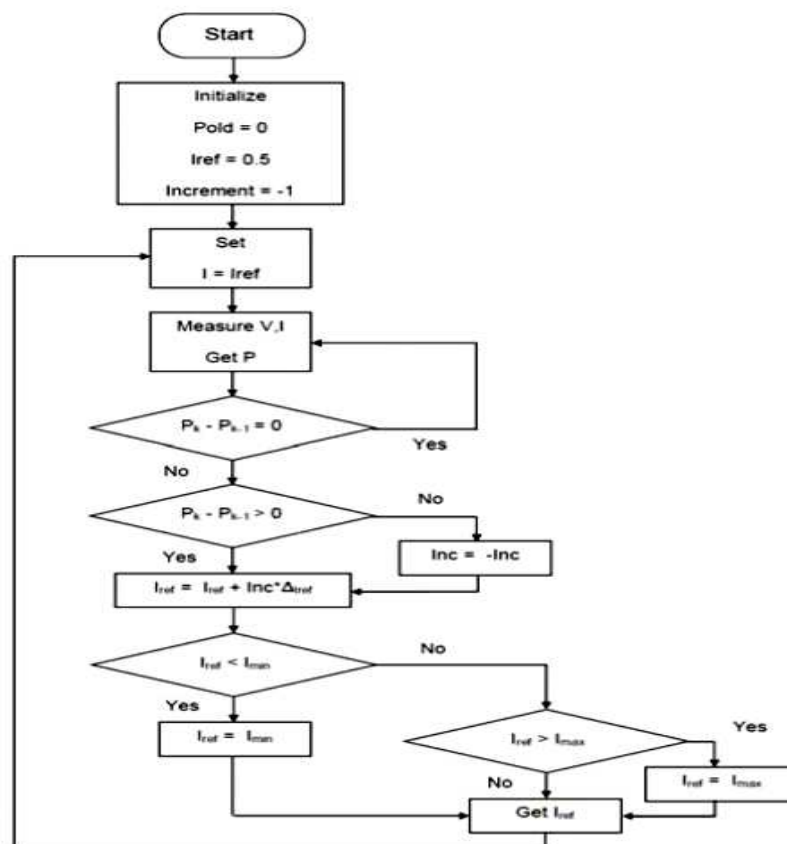

Figure 7. Flowchart of P&O algorithm [8].

The advantage of P&O algorithm is simple and easy to be implemented, especially using the low cost microcontrontroller system. However, the main drawback of the algorithm is that it oscillates around the maximum power point, due the perturbing process to find the maximum power point.

2.4 System Modeling

The configuration of MPPT controller is shown in Figure 8. The inputs of MPPT controller are voltage and current of the PV module, while the output is PWM (pulse width modulation) for controlling the duty cycle of the buck converter. The system is simulated using MATLAB SIMULINK.

The Simulink model of the PV-module is shown in Figure 9. The input of PV-module block is *Va* (PV voltage), *Suns* (irradiation), and *TaC* (operating temperature). The output of the PV-module block is *Ia* (PV current). The PV-module uses the electrical parameter as listed in Table 1. Equatins (1)-(8) are adopted to model the I-V characteristics of the PV.
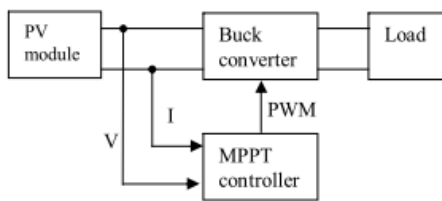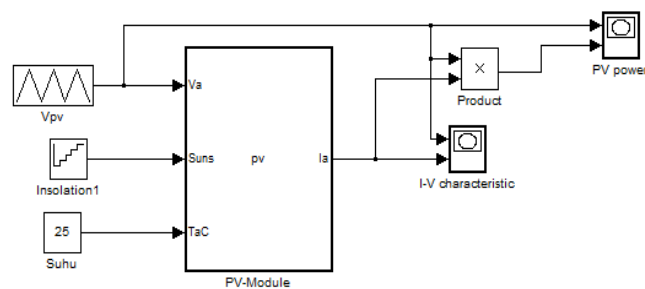

Figure 8. Configuration of MPPT controller.

Figure 9. Simulink model of the PV-module

The Simulink model of the buck converter is shown in Figure 10. The model input consists of i_g (input current of the converter), i_{load} (load current of the converter), d (duty cycle), and f_s (frequency of PWM signal). The model output consists of v_g (input voltage of the converter) and v_{out} (output voltage of the converter).
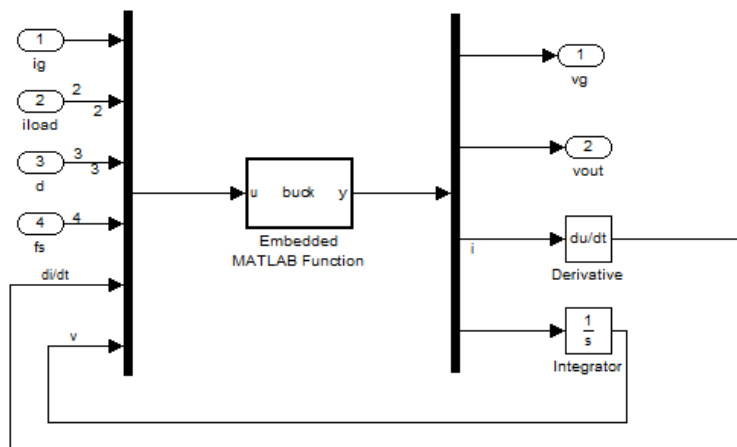

Figure 10. Simulink model of the buck converter.

It is noted here that the input voltage of the converter (v_g) is considered as output, because in the MPPT technique, the changes on the duty cycle is used to change the PV voltage or the input voltage of the converter (v_g). It is different from the real hardware implementation or circuit model approach, when the duty cycle is changed, the ratio between input and output voltages follows accordingly. Therefore, the input voltage might change due to

the changes of the duty cycle. But in the equation modeling, if v_g is considered as input of the model, then it is not possible to change v_g by varying the duty cycle. Thus, v_g should be output of the model as shown in Figure 10. Fortunately, from Eqs. (18)-(20), such model could be constructed easily.

       The Simulink model of the overall system is shown in Figure 11. In the model, six PV modules are connected in parallel. The current output of the PV is fed to the buck converter, while the PV voltage input is come from the output of buck converter. MPPT block read the PV power and generate the corresponding duty cycle to the buck converter.
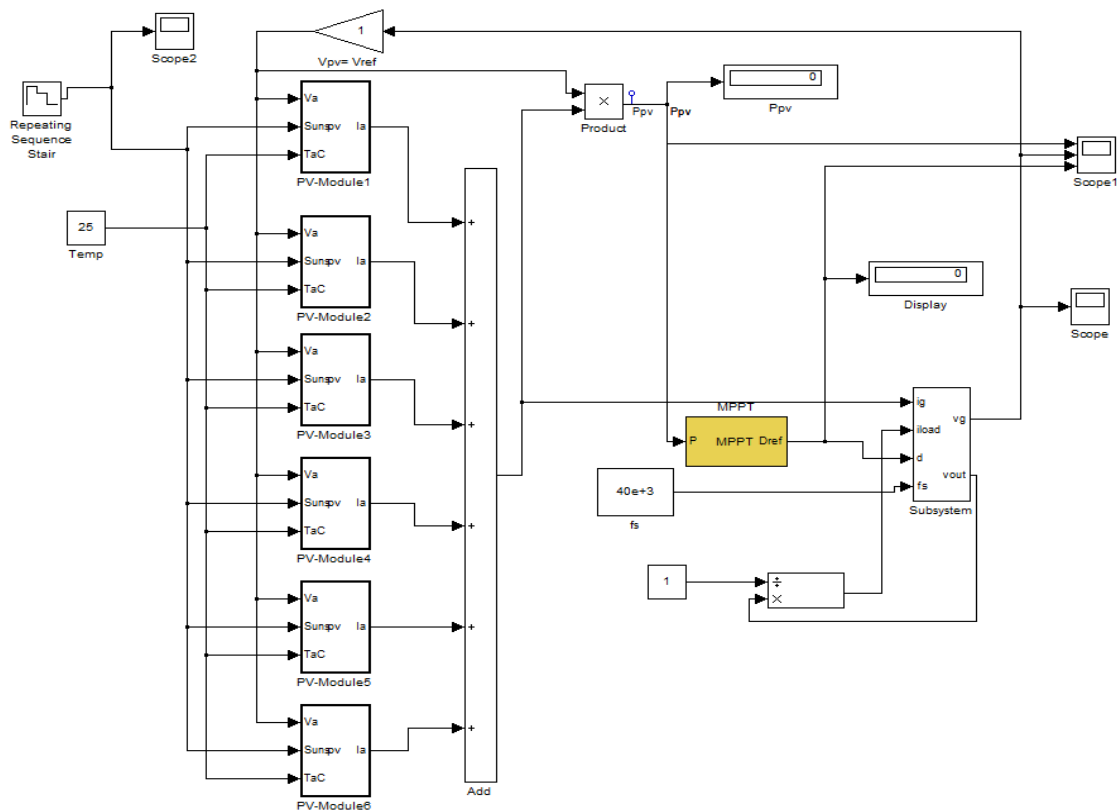

Figure 11. Simulink model of MPPT control system

3. Results and Analysis

       To verify the developed model, several experiments are conducted as discussed belows. In the first experiment, buck converter model is compared to the one of circuit model provided by MATLAB/Simulink Power Simulation. Figure 12 shows the Simulink model of both models, where the upper part is the circuit model and the lower part is the developed equation model. The parameters of buck converter are shown in Table 2. In the experiment, the same PV model is used for both models, where the solar irradiation level is 0.6 Suns = 600 Watt/m^2 and ambient temperature is 25 ^{0}C. The voltage outputs of both models are shown in Figure 13, where the dash line and solid line represent the responses of circuit model and the developed model respectively. From the figure, it is clear that the output of the developed buck converter model (equation model approach) is almost similar to the one of circuit model approach.

Table 2. Parameters of buck converter

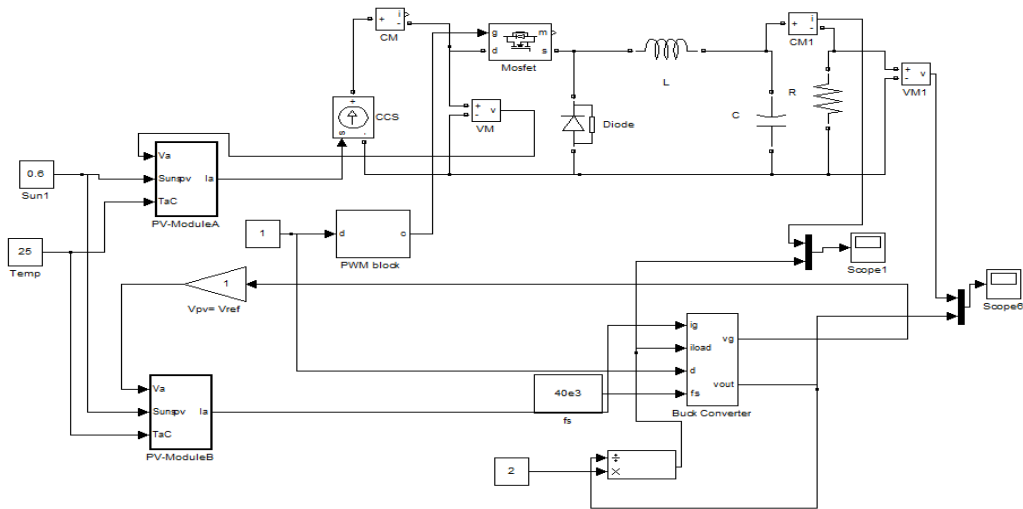| Variable	Value
L	100 µH
C	50 µF
R (load)	2 Ohm
PWM frequency	40 Khz

Figure 12. Simulink model for comparison of the buck converter (circuit model and proposed equation model).
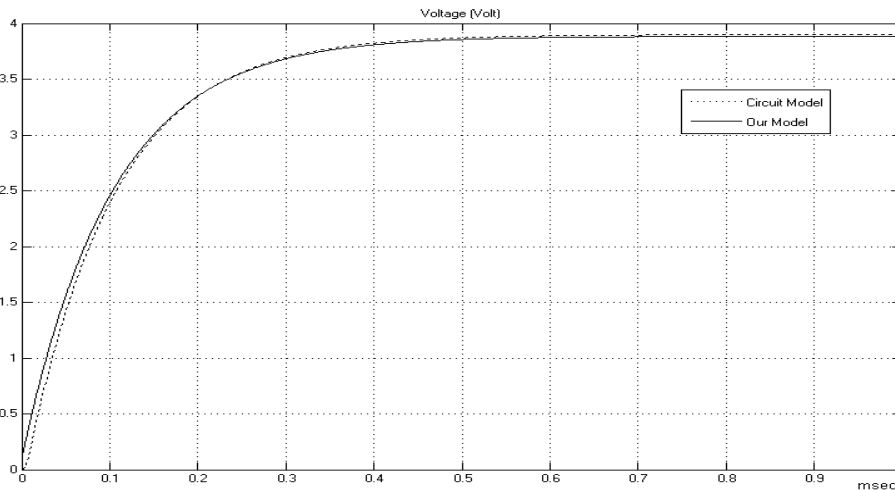

Figure 13. Voltage output of the buck converter (circuit model and proposed equation model).

In the second experiment, the performance of buck converter with MPPT is compared to the traditional one. In the experiment, the irradiation level varies from 1000, 500, 200, 300, and 400 Watt/m^2. Figure 14 shows the experimental result. Comparing the PV power outputs in the figure, it is obtained that the PV power outputs of the model without MPPT control are not always the maximum ones for the particular irradiation level compared to the model with MPPT control. When irradiation level is 1000 and 500 Watt/m^2, both models show the same PV power outputs. When irradiation level changes to 200, 300, and 400 Watt/m^2, the PV power output of the model with MPPT control is greater than the one of the model without MPPT control.

In the experiment, the initial value of duty cycle is 0.5, thus at the beginning the response of the MPPT control is slow to reach the maximum power point, in this case the duty cycle of the maximum power point should be reached is 1.0. From the figure, it is observed that when the irradiance level changes, the MPPT control shows a slow response to reach the new maximum power point. This response depends on the step value of perturbing duty cycle. The step value used in the experiment where the result is shown in Figure 14 is 0.007. To observe the effect of the step value, the value is increased to 0.05, and the result is shown in Figure 15. By increasing the step value, the response is faster as shown in the figure. However the amplitude of oscillation around the maximum power point increases.
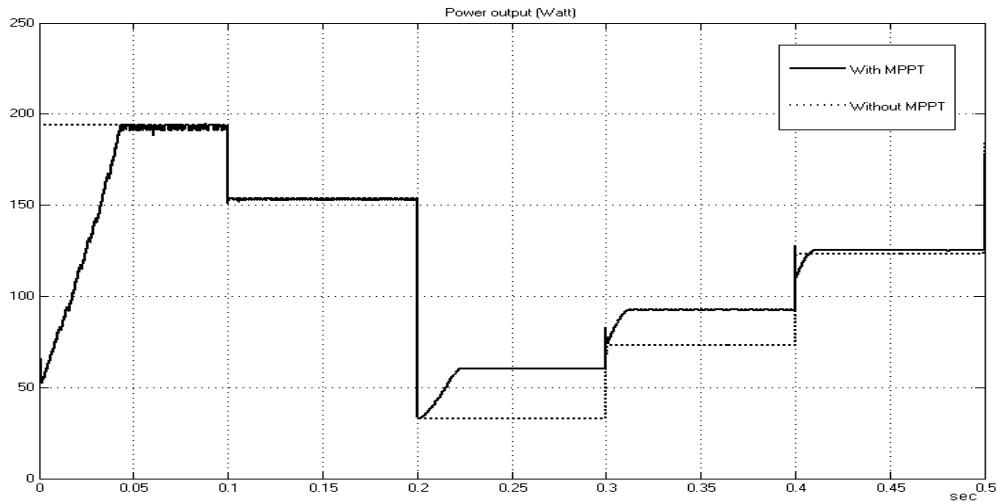
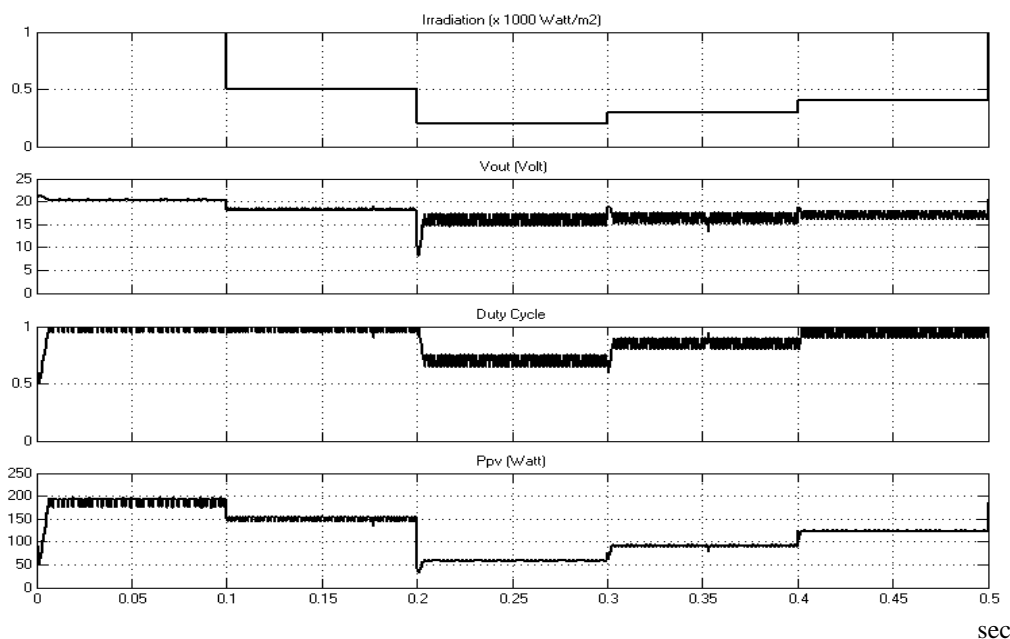Figure 14. The experiment result of the model with and without MPPT control

Figure 15. The experiment result of the model with MPPT control with greater step value (step value 0.05).

In the third experiment, the perfomance of MPPT is tested under different patterns of irradiation changes, i.e when the irradiation level changes to the ramp function and the sinusoidal function. When the irradiation level changes to the ramp function, the MPPT control is able to track the maximum point properly as shown in Figure 16. When irradiation level changes to the sinusoidal, the MPPT control is unable to track the maximum point as shown in Figure 17. In the figure, the MPPT control could not adjust the duty cyle properly. The response of MPPT control is too slow to follow the fast changing of the irradiation level. According to the previous experiments, when the irradiation level is lower than 500 Watt/m^2, the duty cyle should be lower than 1.0 to reach the maximum power point. However as shown in Figure 17, when the irradiation level decreases below 500 Watt/m^2, the duty cycle is adjusted to the proper value lately. To overcome the problem, the step value is changed to the greater value, i.e. 0.03, and the experiment result is shown in Figure 18. From the figure, it is observed that by increasing the step value, the MPPT control could track the irradiation level changes properly, but the higher oscillation is produced.
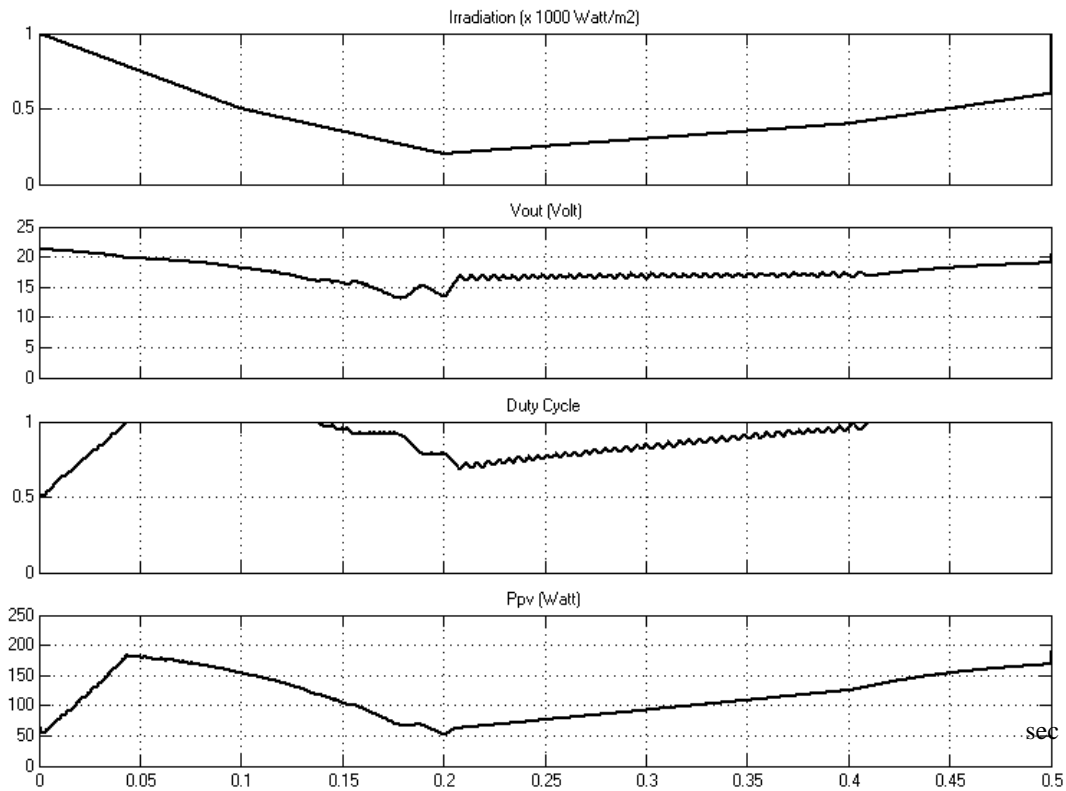
Figure 16. The experiment result of the model with MPPT control with the ramp function of the irradiation level changes (step value 0.007).
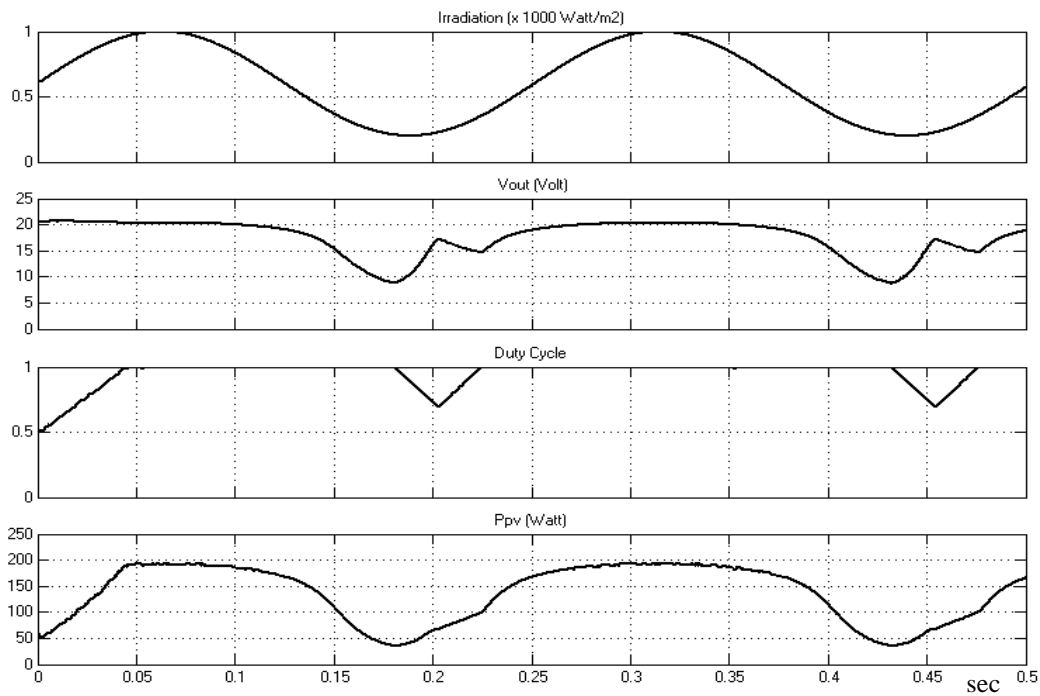

Figure 17. The experiment result of the model with MPPT control with the sinusoidal function of the irradiation level changes (step value is 0.007).
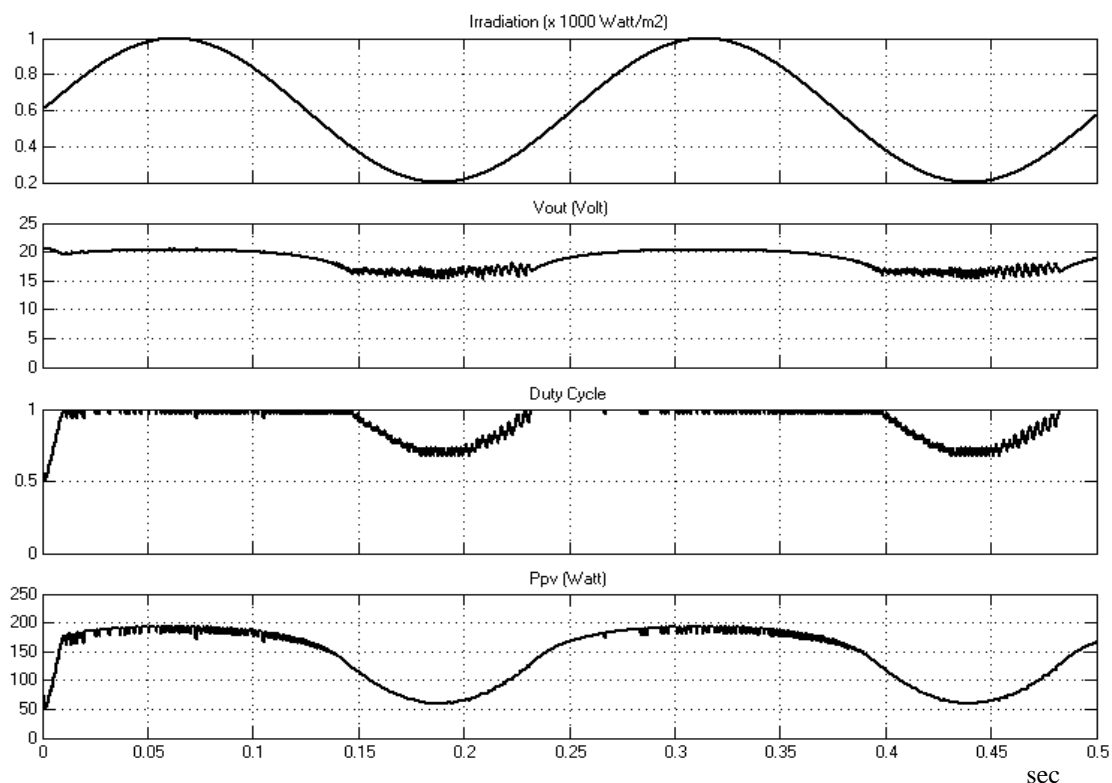
Figure 18. The experiment result of the model with MPPT control with the sinusoidal function of the irradiation level changes (step value is 0.03).

4. Conclusion

A MPPT controller for solar system is modeled in this paper. The buck converter is modeled using equation model approach, rather than circuit model approach. By developing model using equation modeling, the model could be modified or entendexd easily. To verify the developed equation model, the comparison to the existing circuilt model is done. The experiment result shows that the developed model is usited to the existing one. Moreover, a MPPT control model (P&O algorithm) is modeled and tested using several experiment data. The experiment results show that the overall model behaves like the real situation. Further, the properties of P&O algorithm such as the effect of the step value of perturbing duty cycle and the oscillation problem are well simulated.

In future, the different MPPT methods will be evaluated. Furthermore, the MPPT algorithm will be applied to the other renewable energy, such as the wind energy system.

Acknowledgment

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