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Simple Simulation of Perturb and Observe MPPT Algorithm on Synchronous Buck Converter

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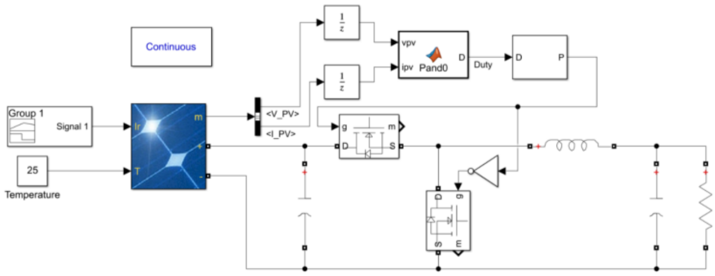
ABSTRACT



The efficiency of the PV system can be improved by operating the solar panel on its Maximum Power Point (MPP). However, variations in irradiance and temperature will lead to the shifting of solar panel MPP. To continuously operate the solar panel near its MPP, a tracking algorithm is needed. In this research, a model consisting of a synchronous buck converter and a Maximum Power Point Tracking (MPPT) algorithm will be designed as a MATLAB/Simulink model. The simulation was run in Standard Test Condition (25°C, 1000 W/m^2) in five irradiance variations (200 W/m^2, 600 W/m^2, 1000 W/m^2, 800 W/m^2, and 400 W/m^2). Perturb and Observe technique was used to implement the algorithm into the synchronous buck converter, which will control a 10 W solar panel load so it will operate near its MPP. Low power solar panel, 10 W, was used for low energy power applications such as IoT sensors, solar street lights, and wireless communication nodes. Results show that the proposed algorithm can track solar panel MPP with an average efficiency of 98.24%.

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1. INTRODUCTION

Solar panel Maximum Power Point (MPP) will vary depending on two environmental conditions, the amount of irradiance that illuminates the solar panel and the solar panel working temperature [1]. Due to the variations of those two factors in real-life solar panel operation and in order to maximize the solar panel power output, load characteristics must be continuously adjusted so that the solar panel constantly operates at or near its MPP [2][3].

The Maximum Power Point Tracking (MPPT) algorithm can be used for tracking solar panel MPP in varying environmental conditions [4]. MPPT algorithm will adjust the PWM signal duty cycle that controls the switching mechanism on a DC-DC converter connected to the solar panel so that the solar panel load characteristics will constantly be adapted in such a way that the solar panel will always operate at or near its MPP. Previous research has proposed various MPPT techniques such as Constant Voltage, the perturb and observe (P&O), Incremental Conductance, and Fuzzy Logic Control [5]-[9]. Of the several MPPT algorithms, the perturb and observe algorithm is most widely used because of its easy implementation. However, the disadvantage of this algorithm is that its efficiency is still low.

Therefore, in this research, the MPPT algorithm was designed with Perturb and Observe technique for controlling a 10 W solar panel. The algorithm was applied to a synchronous buck converter model in MATLAB/SIMULINK in which the solar panel load characteristics will be adjusted. The simulation was run in Standard Test Condition (25°C, 1000 W/m^2) in five irradiance variations (200 W/m^2, 600 W/m^2, 1000 W/m^2, 800 W/m^2, and 400 W/m^2). The main results show that the proposed algorithm can track solar panel MPP with an average efficiency of 98.24%.

2. METHODS

2.1. Topology Synchronous Buck Converter

A buck converter is a DC-DC Converter that steps down an input DC voltage of a certain level to a lower-level output DC voltage [10]-[15]. The step-down in voltage is the result of the inductor and the switches in a buck converter that allows two states of operation in the buck converter, the ON state and the OFF state [16].

Buck Converters generally have two switches for controlling the switching mechanism, a high-side switch and a low-side switch [17]-[21]. An asynchronous buck converter will use a MOSFET as a high-side switch and a diode as a low-side switch. An asynchronous buck converter will only need a single PWM signal for controlling the switching mechanism. In this research, a MOSFET will be used for both switches, and two PWM signals will be generated alternately to allow the ON-state and the OFF-state operation, hence the name synchronous buck converter [22].

2.2. Design Parameters Synchronous Buck Converter

The specification of synchronous buck converters is shown in Table 1.

Tabel 1. Synchronous Buck Converter Specification

Component	Specification
Inductor	100 uH
Input Capacitor	470 µF
Output Capacitor	470 µF

The specification mentioned was calculated according to the formula from Texas Instruments [23].

$$L > \frac{V_{Output}\,(V_{Input} - V_{Output})}{\Delta I_{Inductor} \times f_s \times V_{Input}} \tag{1}$$

$$C_{Input} > \frac{(I_{out} - I_{Minimum})}{8 \times f_s \times V_{InputRipple}} \tag{2}$$

$$C_{Output} > \frac{\Delta I_{Inductor}}{8 \times f_s \times \Delta V_{Output}} \tag{3}$$

In this research, the simulation was conducted in MATLAB/Simulink software. Firstly, for validating the algorithm's ability in tracking the MPP, the simulation will be run with variations in irradiance with 200 W/m^2, 600 W/m^2, 1000 W/m^2, 800 W/m^2, and 400 W/m^2 simultaneously. Each variation of irradiance will be applied to the solar panel for 1 second in simulation. The solar panel temperature will be set constant at 25°C.

The simulation model of the synchronous buck converter is presented in Figure 1. For simulation, we utilized Standard Test Condition (25°C and 1000 W/m^2). In the DC-DC converter circuit, there are two MOSFET for synchronize the buck-converter. The inductor, input capacitor, and output capacitor value are 100 µH, 470 µH, and 470 µH, respectively. MPPT controller is a box to put Perturb and Observe algorithm.

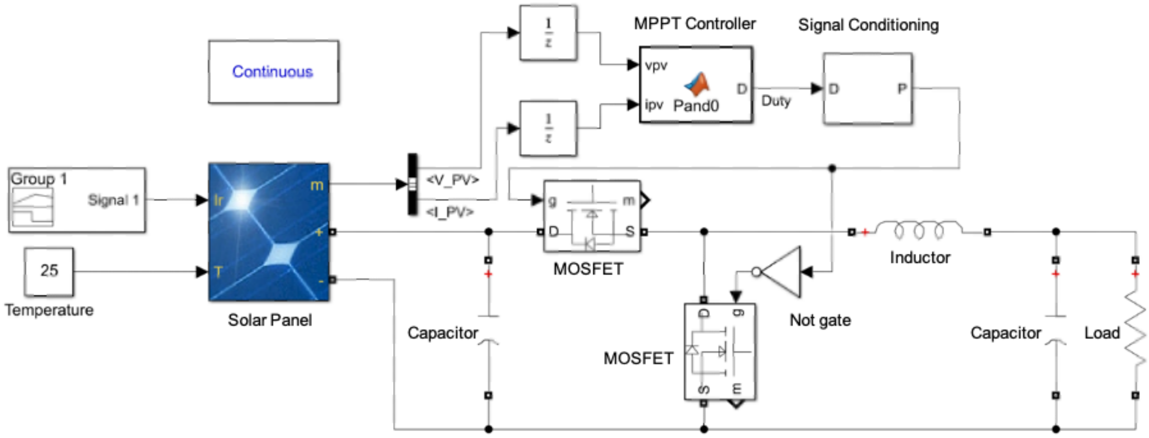

Figure 1. Synchronous buck converter model

2.3. MPPT Pertub and Observe Technique

Perturb and Observe (P&O) technique is the most commonly used MPPT algorithm because of its accuracy and relatively easy implementation [24]-[27]. This method will operate by continuously measuring the voltage and current of solar panel output and recording the measurement of the previous iteration. Firstly, there will be a perturbation to the load characteristic of a solar panel and then the voltage and power output will be observed by comparing it to the previous measurement iteration. The algorithm will decide the action needed, whether increasing or reducing the voltage by controlling the duty cycle so that the solar panel operating condition will move towards its MPP. In this research, the P&O technique will be executed in the Simulink model and there will be some restrictions made in order to constrain the duty cycle so that the duty cycle value will not drop below zero or raise above 100% can be seen in Figure 2.

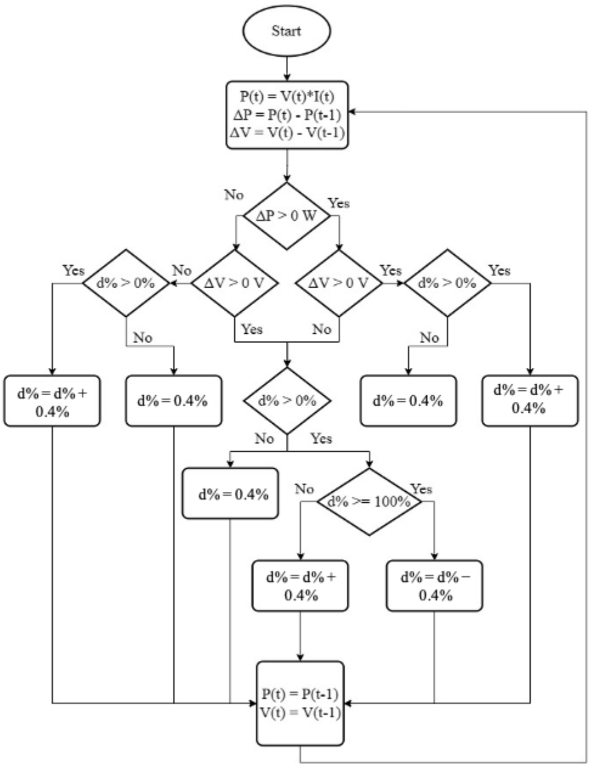

Figure 2. Perturb and observe flowchart

Figure 2 shows that there are two main conditions in the algorithm, an increase or a decrease in duty cycle by 0.4%. Delta duty cycle (d%) is set to 0.4% to increase resolution of the DC-DC converter voltage. A decrease in the duty cycle will happen if the delta power (ΔP) and delta voltage (ΔV) are both positive or both negative, whereas the duty cycle will increase if ΔP is negative and ΔV is positive or vice versa.

2.4. Solar panel specification

Solar panel model specification was adapted to the specification of a commercial 10 W solar panel in Standard Test Condition (25°C, 1000 W/m^2) by SUNLITE according to Table 2. Based on the specification, the solar panel model will output a maximum power of 9.91 W for 1000 W/m^2 , 7.91 W for 800 W/m^2 , 5.91 W for 600 W/m^2 , 3.89 W for 400 W/m^2 , and 1.90 W for 200 W/m^2 . The maximum power mentioned is under the condition of a constant 25°C temperature.

Tabel 2. Solar Panel Specification

Parameters	Value
Peak Power (W_p)	10 W
Maximum Power Current (I_{mp})	0.54 A
Maximum Power Voltage (V_{mp})	18.36 V
Short Circuit Current (I_{sc})	0.58 A
Open Circuit Voltage (V_{oc})	22 V

3. Simulation Results

Figure 3 shows the simulation results of the solar panel system with Perturb and Observe technique. Figure 3 shows that the output power will follow the irradiance variations and output a higher power when a higher irradiance was applied. The average output power in each irradiance variation is as follows: 9.77 W for 1000 W/m^2, 7.82 W for 800 W/m^2, 5.84 W for 600 W/m^2, 3.87 W for 400 W/m^2, and 1.82 W for 200 W/m^2.

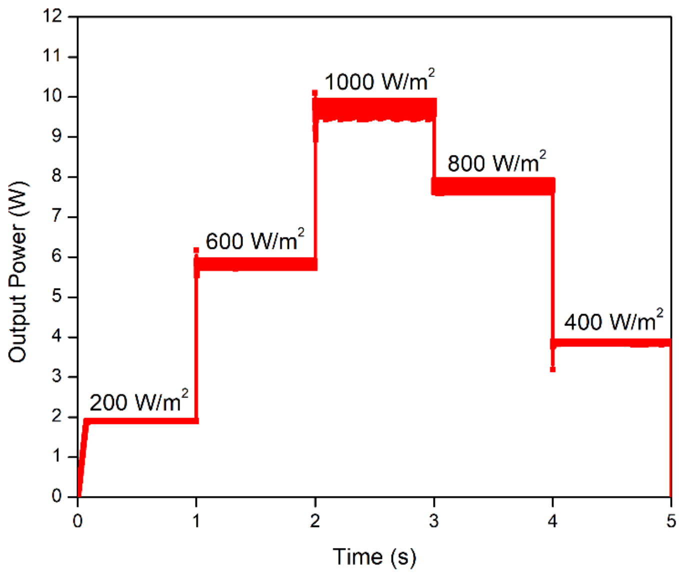

Figure 3. Simulation results with irradiance variations

The efficiency was obtained by dividing the average output power and the solar panel's maximum output. The efficiency value obtained in each irradiance is shown in Table 3. Based on the table it can be seen that the algorithm can track solar panel MPPT accurately with an overall efficiency of 98.24% in all irradiance variations. It also can be seen that the first irradiance interval shows the lowest efficiency at 95.75%. This can be analyzed because the initial duty cycle value was set at 90%. Because of that, the algorithm needed some time to adjust the duty cycle to reach MPP.

Table 3. Simulation Efficiency Results

Time Interval (s)	0-1	1-2	2-3	3-4	4-5
Irradiance (W/m^2)	200	600	1000	800	400
Efficiency (%)	95.75	98.88	98.51	98.78	99.26

Some of the factors that can influence efficiency in Perturb and Observe technique is the delta duty cycle. In P&O, the increase or decrease in the duty cycle is constant or it can be said that the delta duty cycle is fixed. The delta duty cycle in this research is set at 0.4%. The time needed for the algorithm to reach MPP will depend on this delta duty cycle. Other than that, because the P&O technique will constantly perturb the load characteristics of the solar panel, there will be oscillation in the steady-state condition. This study is comparable with other researchers [28][29] that also shows the oscillation in the steady-state condition. This oscillation will also contribute to efficiency and will be shown in Figure 4. The highest oscillation value is around 0.29 W peak-to-peak power. To recover this oscillation, other researchers improve other methods, such as adjust delta duty cycle and multilevel DC-DC converter [30][31].

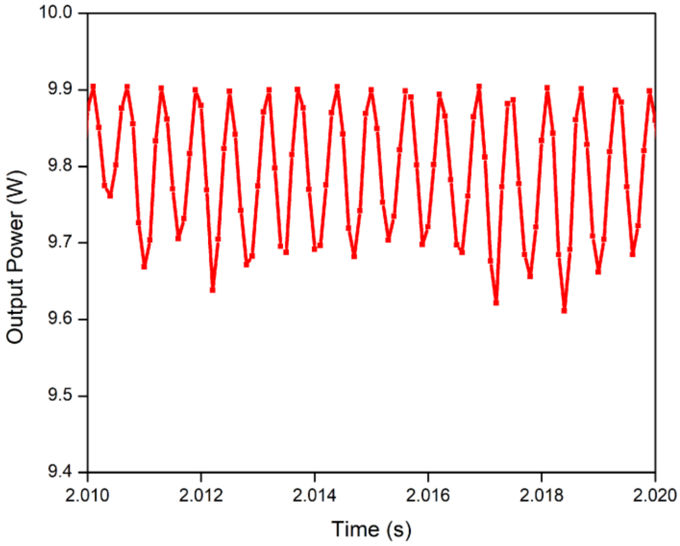

Figure 4. Sample of oscillation in power

Moreover, our simple P&O method successfully outcomes with 95%-99%. Table 4 lists a comparison between the proposed method and other hybrid P&O techniques introduced in the literature in terms of the algorithm, oscillation level and tracking efficiency. As presented, the proposed method is simpler with moderate oscillation level and high-power efficiency.

Table 4. Comparison between the other hybrid P&O algorithm and the proposed method

Methods	Algorithm	Power efficiency (%)	Oscillation
Proposed method (Simple P&O)	Simple	95-99	Moderate
ANN-PSO [32]	Complicated	92-98	Moderate
ANN-P&O [30]	Complicated	99.5-99.8	Low

4. CONCLUSIONS

In this research, Perturb and Observe technique with synchronous buck converter integration has been designed in MATLAB/Simulink. The designed converter and algorithm were integrated with a 10 W solar panel to investigate the ability of perturb and observe technique in tracking solar panel MPP. Based on the results obtained, the proposed algorithm can track solar panel MPP in various irradiance variations (200 W/m^2 , 600 W/m^2 , 1000 W/m^2 , 800 W/m^2 , and 400 W/m^2) with average efficiency of 98.24%. This research also shows some of the disadvantages of the Perturb and Observe technique, in which the delta duty cycle is constant and leads to oscillation in the steady state condition which can lead to a decrease in efficiency. To recover this oscillation, other techniques such as adjustable delta duty cycle or multilevel DC-DC converter is needed. Moreover, this research's contributions are applicable for low energy power applications such as IoT sensors, solar street lights, and wireless communication nodes.

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