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Design of MPPT charge controller using zeta converter for battery integrated with solar Photovoltaic (PV) system

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Design of MPPT charge controller using zeta converter for battery integrated with solar Photovoltaic (PV) system

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Abstract: In this work, the advantage of using Maximum Power Point Tracking (MPPT) algorithm in solar Photovoltaic (PV) system was investigated. By simulation, the performance and efficiency of the system with and without the tracking algorithm was analyzed. By using MATLAB's SimPower System block set, a model compromised of KC130TM solar panel powering a Zeta converter controlled by MPPT algorithm driving a lead acid battery as a load was designed. The main objective was to track the Maximum Power Point (MPP) of the solar PV module by modulating the zeta converter's duty cycle, thereby, optimizing the power output of the panel. The Perturb and Observe (P&O) algorithm preformed with higher overall efficiency compared with the system without MPPT. Additionally, the tracking algorithm was able to track the MPP quickly. The analysis of the algorithm led to a greater understanding of where the inefficiencies of this type of system are located, allowing improvement in future work on this field.

1. Introduction

Renewable Energy (RE) resources are being progressively integrated in power systems to support continuous increase in power generation due to limitation of fossil fuels supply and to reduce negative environmental impact [1]. Among the RE resources, the energy through the solar Photovoltaic (PV) effect can be considered the most necessary and sustainable resource due to its ubiquity, large quantity and sustainability of solar energy [2].

However, PV system is very sensitive where it requires a contentious improvement to its performance if its desired to achieve much more performance and cost-effective solar energy system. Maximum Power Point Tracking (MPPT) is an algorithm which can be implemented in the system to make it possible for the PV system to regularly supply the load with the maximum power. Due to the regular changes in the weather condition, under the existence of the MPPT algorithm, the PV system will be able to utilize and adapt to the changing of the temperature and irradiance [3,4]. MPPT algorithm main objective is to use the PV module ripple voltage or current to determine the deference in the output power. The output voltage from the PV module is fluctuated, due to the changes in its temperature and the irradiation projected from the sun. In order to adjust the voltage so that the maximum power is maintained, a DC-DC converter integrated with the MPPT algorithm is needed to be employed as charge controller in the PV system [4].

There are wide literatures and numerous types of research works have been conducted in the aspect of solar PV system charge controller over the years to increase the efficiency of the PV system. Hussein and Fardoun proposed a new MPPT controller based on genetic neural algorithm (GA) to resolves the drawbacks and limitations of traditional controller. The designed controller is using DC-DC converter and capable of charging different types of battery but the system is costly due to using many circuit breakers [5]. While, Lokeshreddy et al. presented a solar PV charge controller which contains series, shunt charge controller that improved the efficiency and charging period. However, there is no MPPT algorithm in the design and the output of PV panel is not regulated or utilized for the battery and the load [6].

Moreover, a fuzzy controller with adaptive output scaling factor as a maximum power point tracker of PV system was proposed by Guenounou et al. The system that consists of a PV panel, a DC-DC boost converter, a maximum power point tracker controller and a resistive load able to improve the PV performance by using incremental conductance algorithm to track the MPPT. However, due to the usage of many switches and passive components, the proposed system cost is high to implement [7]. Meanwhile, Rizzo and Scelba presented a novel MPPT method based on Artificial Neural Network (ANN) that provides an accurate and fast estimation of the Global Maximum Power Point (GMPP) in a PV system subjected to continuous and rapidly changing shadowing patterns but the drawback of the system was a low tracking speed [8].

Consequently, in this work, a MPPT charge controller will be designed for battery integrated with solar PV system. The zeta dc-dc converter is to be designed and implemented with the MPPT algorithm to serve as a charge controller for the system. The full model will be developed using MATLAB Simulink software to analyze the performance of the PV module and the zeta DC-DC converter.

2. MPPT algorithm

The output power generated by the solar cell is described as the product of the measured voltage and current. As shown in figure 1, the red curve represents the I-V curve while the blue curve represents the output power curve. The maximum power generated by the cell is when the current equals to Imp and the voltage equals to Vmp. It is also known that the output power is zero at either Isc or at Voc point. Furthermore, the output power curve will increase and fall in between the two points and the highest value of the power on the curve between Isc and Voc is called Maximum Power Point (MPP) [9]. Thus, it is important to make sure the solar power output is operating near the maximum point for an efficient operation.

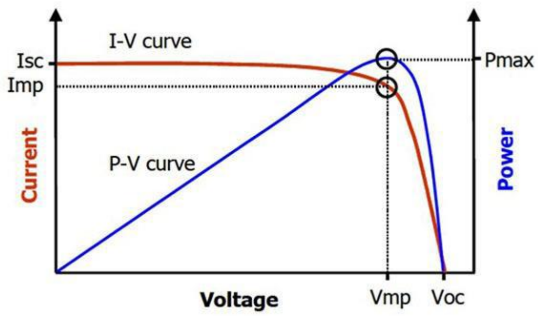

Figure 1. Maximum Power Point (MPP) curve [9]

However, this I-V curve of PV array relies on irradiance and temperature condition. When the irradiance increases with constant temperature, the PV current also increases in direct proportion with negligible effect on PV voltage. Similarly, if the temperature increases with constant irradiance, the PV voltage decreases substantially while the PV current increases slightly [10]. Hence, a tracking algorithm known as MPPT is needed to regulate the PV panel output that varies non-linearly with irradiance, temperature and load.

MPPT is based on PV power measurement and regulation of PV voltage. By varying the duty cycle of the converter, the ratio of the input and output voltages can be adjusted appropriately [11]. There are large number of MPPT techniques have been developed to increase the efficiency of PV system such as fractional open circuit voltage, fractional short circuit current, Perturb and Observe (P&O), incremental conductance, fuzzy logic, neural network and Particle Swarm Optimization (PSO) [3]. Out of all these techniques, P&O MPPT algorithm is used widely due to its easiness of implementation [3,12].

P&O algorithm also known as hill climbing method is based on the output current and voltage of the PV panel. The perturbation indicates the changing in the output power of the system. However, based on figure 2, when the perturbation increases toward the MPP, the voltage needs to be increased. On the other hand, if the perturbation decreases away from the MPP, the voltage needs to be decreased. Practically, the voltage change is controlled by the duty cycle of the DC-DC controller. This process of changing the duty cycle will keep operating until the MPP is achieved. This method is considered simple and efficient comparing with the other methods implemented in MPPT. However, the only downside of this method is that it takes time to achieve the MPP if the duty cycle deference value is assumed to be too low and the exact MPP is difficult to be achieved. Thus, the power will be fluctuating between point A and B as shown in figure 2 [3,13].

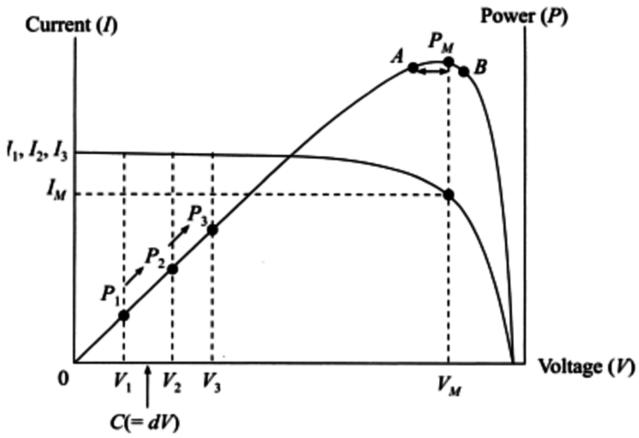

Figure 2. P&O technique for MPPT [14]

3. MPPT charge controller design using zeta converter

The MPPT algorithm implemented in this work is P&O to extract the MPP from the solar PV module. Figure 3 presents the essential components of the overall system block diagram. PV module is used to supply the converter with energy. At the same time, the PV module current and voltage will be measured and fed to the MPPT algorithm. The duty cycle will be set to achieve the MPP from the PV power input once the input parameters are measured. From the duty cycle, a Pulse Width Modulation (PWM) will be generated to be fed to the zeta converter to control the switching time. Finally, the output of the converter will be fed to the load the desired voltage.

The MPPT charge controller designed in this work compromised of Kyocera KC130TM solar module from the MATLAB's SimPowerSystem block set. With maximum power of 130 W and maximum output voltage of 17.6 V, the PV module will be able to supply lead acid battery with nominal voltage of 12 V and 6 cells connected in series. Figure 4 shows the built in PV module in Simulink SEMSCAPE library where the model represents the solar panel equivalent circuit. In this design, the controlled current source value is adjusted based on the irradiance and the temperature of the module while, the shunt and series resistors are determined based on the model number of the PV module.

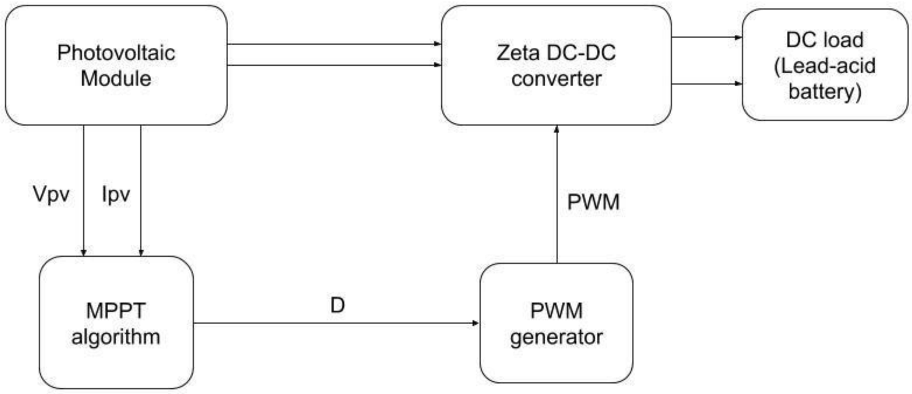

Figure 3. MPPT charge controller overall block diagram

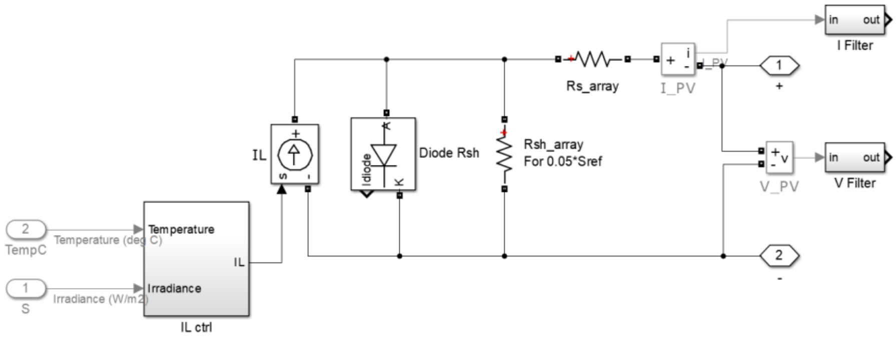

Figure 4. Solar module equivalent circuit in Simulink

The zeta converter consists of two inductors, two capacitors and a diode. It is a fourth order converter, configured based on buck converter which can operate in step-up or step-down mode depending on the duty cycle of the switch used in the circuit. Figure 5 shows the equivalent circuit of zeta converter. The switching frequency in the design is assumed to be 50 kHz.

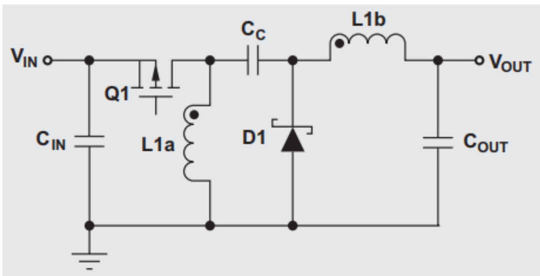

Figure 5. Zeta converter equivalent circuit [15]

The value of each inductor is described as in Equation (1).

$$L_{1a\,min} = L_{1b\,min} = V_{in}\left(\frac{D}{f_{sw} \times \Delta I_{L1a}}\right) \tag{1}$$

The input capacitor and series capacitor ripple voltage are assumed to be 10% of the input voltage from the PV panel. Hence, the capacitance is described as in Equation (2).

$$C_{in} = C_c = \frac{D \times I_{out}}{\Delta V \times f_{sw}} \tag{2}$$

While, the output capacitor capacitance is determined by Equation (3).

$$C_{out} = \frac{\Delta I_{L1b}}{8 \times \Delta V_{Cout} \times f_{sw}} \quad (3)$$

where, D is the duty cycle, ΔI_{L1a} and ΔI_{L1b} is the ripple current of the inductor, $f_{sw} = \frac{1}{T}$ is the switching frequency, C is the capacitance of the capacitor and ΔV is the ripple voltage across the capacitor. Besides, $\Delta VCout$ is the output ripple voltage and it is assumed to be 25 mV and Vin will be 17.6 V. In addition, the resistive load is assumed to be 3 ohms to achieve an output voltage from the converter of 19 V, so that the converter can supply the lead acid battery.

Figure 6 shows the equivalent model of MPPT algorithm designed using Simulink blocks. The input from the PV module will be measured and compared with the previous measurement using the sum blocks. After measuring the input power and compare it with the previous or reference power, three switch cases will control the duty cycle by either increasing or decreasing it to achieve the MPP desired. If the initial power value is greater than the one measured and the measured voltage is greater than the initial voltage, the duty cycle will be increased. However, if the voltage measured is less than the initial voltage, the duty cycle will decrease. At the same time, if the power measured is less than the initial power and the measured voltage is less than the initial voltage, the duty cycle will increase. Whereas, the duty cycle will decrease if the measured voltage is greater than the initial voltage. This tracking is a continuous operation where the measured values will be the initial values for the next looping process. In this design, the D-sample block will eliminate any fluctuation in the duty cycle signal, while the saturation block will limit the value of the duty cycle from 0 to 0.9.

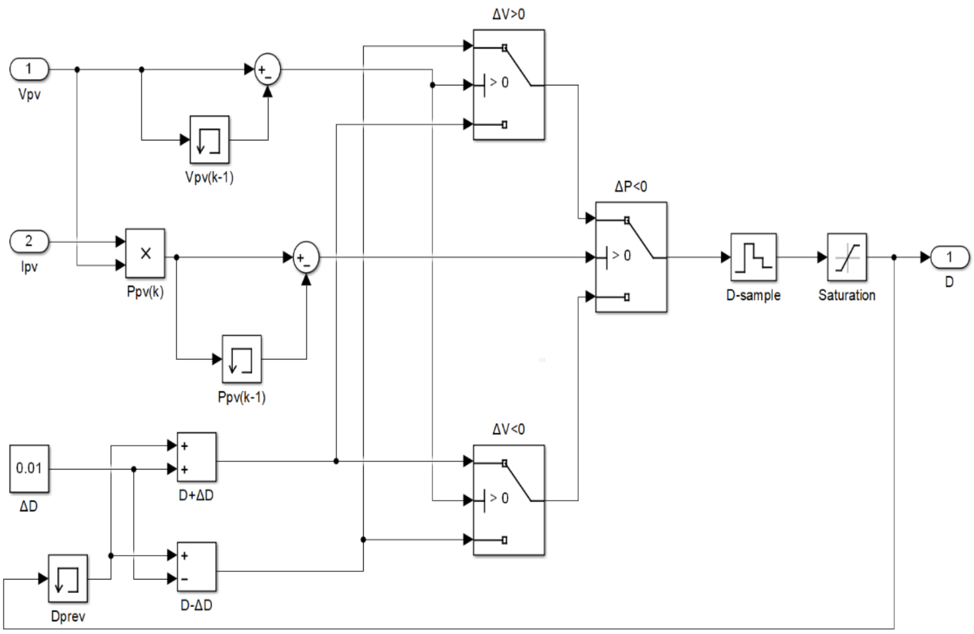

Figure 6. Designed MPPT algorithm based on P&O

4. Results and discussion

The designed MPPT charge controller need to be validated first before proceeding to the performance simulation. Thus, validation was performed by comparing the MPP obtained from the designed system with MPP from the Kyocera Solar KC130TM PV module datasheet at different level of irradiance. Table 1 presents the MPP comparison data where it can be seen clearly that the designed MPPT charge controller is reliable for further engineering analysis.

Table 1. MPP at each irradiance level.

Irradiance (w/m^2)	MPP from KC130TM datasheet (Watt)	MPP from simulation (Watt)
1000	130.1	130
600	78.96	79
200	25.87	25.9

In general, the simulation results contain the compression of two systems with variance of irradiance changes. The first system is with MPPT algorithm implemented and the second one is without the tracking algorithm. Both results for the two systems will be compared in order to determine and identify the effect that can be established with implementing MPPT algorithm.

Figure 7 presents the simulation results with a constant irradiance for both MPPT and without MPPT algorithm system. There are three types of results in the figure which are the irradiance, duty cycle and efficiency versus time. From Figure 7, it can be seen clearly that the charge controller without tracking algorithm was not able to maintain the maximum efficiency with the time and the efficiency decreased from 88% to 77% due to the absence of power tracking algorithm. While, the design with MPPT able to maintain the efficiency by adjusting the duty cycle to track the MPP. However, the variation of the efficiency between 82% to 84 % was due to the P&O tracking method weakness, where the system will not be able to track the exact MPP. Instead it will fluctuate around the MPP within the three steps as can be seen in Figure 7.

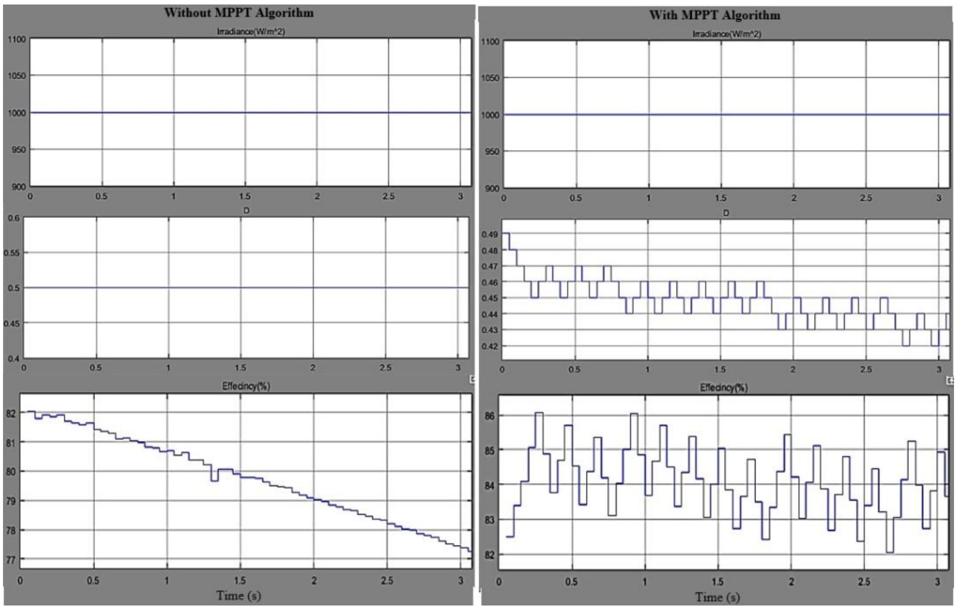

Figure 7. Simulation results with a constant irradiance for both MPPT and without MPPT algorithm.

Next, the designed MPPT charge controller was simulated with step irradiance changes and the results was compared with the system without MPPT algorithm. The simulation results in Figure 8 shows that with constant duty cycle, the efficiency of the system decreased with the irradiance decrement. Hence, the system was not able to maintain its maximum efficiency at the MPP. The power of the system decreased with the decrement of the irradiance causing the output power of the converter to decrease, which explains the efficiency drop of the system. But, when MPPT algorithm were included in the designed charge controller, the system was able to maintain a nearly constant efficiency for the overall system as can be seen in Figure 8. With the adjustment of the duty cycle at each irradiance step, the efficiency is tracked using the tracking algorithm at every irradiance step. However, at 200 w/m^2 irradiance, the system takes time to maintain the efficiency of the system.

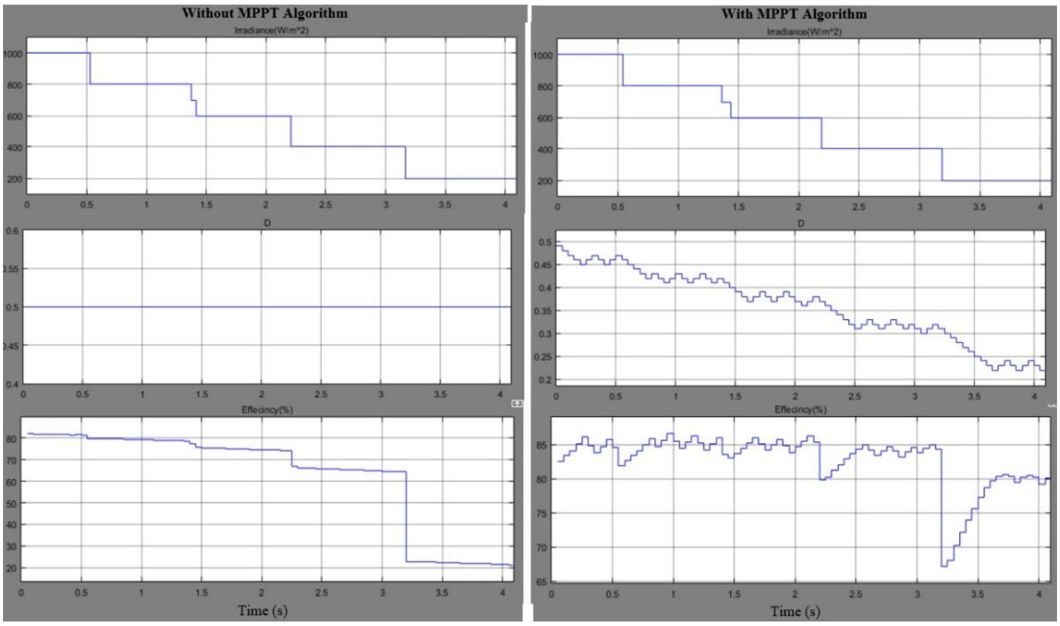

Figure 8. Simulation results with step irradiance for both MPPT and without MPPT algorithm.

5. Conclusion

In this work, MPPT charge controller based on P&O algorithm using zeta converter for battery integrated with solar PV system was designed successfully by using Matlab/Simulink. The implementation of MPPT algorithm and zeta converter has been verified to extract the MPP by adjusting the duty cycle. Based on the simulation results obtained, the system with MPPT algorithm has shown better performance compared with the system without MPPT algorithm with 10% more efficieny at initial operation. Besides that, when the amount of irradiance generated by the sun decreases, the PV module power also decrease. However, with the implementation of designed MPPT charge controller, the system was able to maintain the maximum efficiency under different irradiance levels.

Acknowledgments
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