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FPGA Based Maximum Power Point Tracking of Photovoltaic System using Perturb and Observe Method during Shading Condition

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Nowadays, PV cell which is known as a photovoltaic is one of the most important parts in electrical field to convert photo light to voltage and current at the desired output voltage and frequency by using varies control techniques. This project presents design and implementation of FPGA Based Maximum Power Point Tracking (MPPT) Controller for Photovoltaic system using Perturb and Observed method (P&O). The MPPT controller is employed to control and get Maximum Power Point (MPP) from the source. Altera DE1 board is used as a controller for the implementation of the MPPT system. The simulation of this FPGA based MPPT controller is designed and implemented using Quartus II VHDL software tools. The results shown, the same signal obtained from Matlab simulink software as compared with Quartus II. It has been observed that the designed system has been successfully extracting the MPP during partially shading condition as in the simulations.

Keywords: FPGA, MPPT, Photovoltaic, Perturb and Observe, Shading Condition.

1. INTRODUCTION

Photovoltaic (PV) offers an environmentally friendly source of electricity since it is clean, pollution free and inexhaustible. However, the output from a PV solar cell alone is not good enough to input into an electricity bank or in to the main grid because its output is not constant in terms of voltage. This raises a need to design a controller which can calculate and extract the maximum power point (MPP) at any instant from the solar cells.

Maximum Power Point Tracking, frequently referred as MPPT, is an electronic system that operates the Photovoltaic (PV) modules in a manner that allow the modules to produce all the power they are capable of on that time. MPPT is not a mechanical tracking system that "physically moves" the module to make them point more directly at the sun. MPPT is a fully electronic system that varies the electrical operating point of the module so that modules are able to deliver maximum available power.

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By looking at the MPPT tracking algorithm point of view there are various methods of MPPT. These methods are implemented by designing various algorithms like Perturb-and-observe (P&O) method, Open- and Short-circuit method, Incremental Conductance algorithm, and other algorithms[1-4]. The best MPPT technique base on cost versus energy generation is the P&O[5,6]. Since fast tracking response and accuracy conflict one from other, the mentioned tracking methods cannot satisfy, simultaneously, both of them. In place of the traditional and spread methods, some authors have proposed complex MPPT algorithms, based on fuzzy logic and neural network, in order to accomplish fast tracking response and accuracy in a single system. These proposals, nevertheless, present some disadvantageous: needed for high processing capacity, complexity, cost elevation and, in some cases, employment of extra sensors.

To implement the purpose MPPT algorithm, there are many technologies that available now days. The following is a commonly used controller; Microcontroller base implementation[7,8], Digital Signal Processing (DSP) base implementation[9], and FPGA base implementation[10] work of this paper is summarized in the last section.

2. PHOTOVOLTAIC MODEL

To model solar cell, the one-diode model has been proposed[12], and some researchers have studies how to extract parameters for the model[13]. Figure 1 shows the single-diode model.

In this project, a PV module, MSX-60, produce by Solarex's Megamodule™ series is chosen. In the next chapter, the mathematical modeling will be deriving according to single-diode model and parameter from MSX-60 module. The electrical characteristic of MSX-60 is described in Table 1.

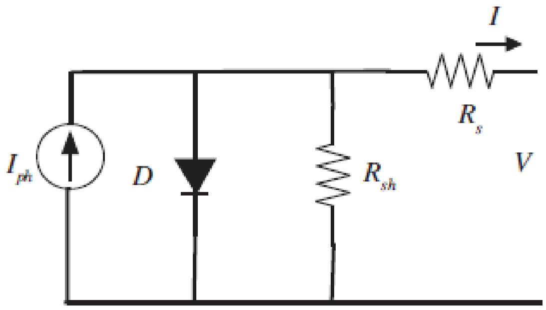


Fig. 1. The single-diode model of a practical photovoltaic device.

Table 1. Electrical Characteristics of MSX-60

Parameter	Variable	Value
Maximum power	P_{MPP}	60W
Voltage at Pmax	V_{MPP}	17.1V
Current at Pmax	I_{MPP}	3.5A
Short circuit current	I_{SC}	3.8A
Open circuit voltage	V_{OC}	21.1V
Temperature coefficient of I_{SC}	α	$(0.065 \pm 0.015)\% / ^{o}C$
Temperature coefficient of V_{OC}	β	$(-0.5 \pm 0.05)\% / ^{o}C$

3. PERTURB AND OBSERVE

The concept behind the "perturb and observe" (P&O) method is to modify the operating voltage or current of the photovoltaic panel until obtain the maximum power from it. For example, if increasing the voltage to a panel increases the power output of the panel, the system continues increasing the operating voltage until the power output begins to decrease. Once this happens, the voltage is decreased to get back towards the maximum power point. This perturbation continues indefinitely. Thus, the power output value oscillates around a maximum power point and never stabilizes[11].

Figure 2 shows the flow chart of P&O method where (k) is current state of value, ($k-1$) is previous state value, and C is step size. After one perturbs operation, the current power is calculated and compared with previous value to determine the change of power ΔP. If $\Delta P > 0$, then the operation continues in the same direction of perturbation. Otherwise, the operation reverses the perturbation direction.

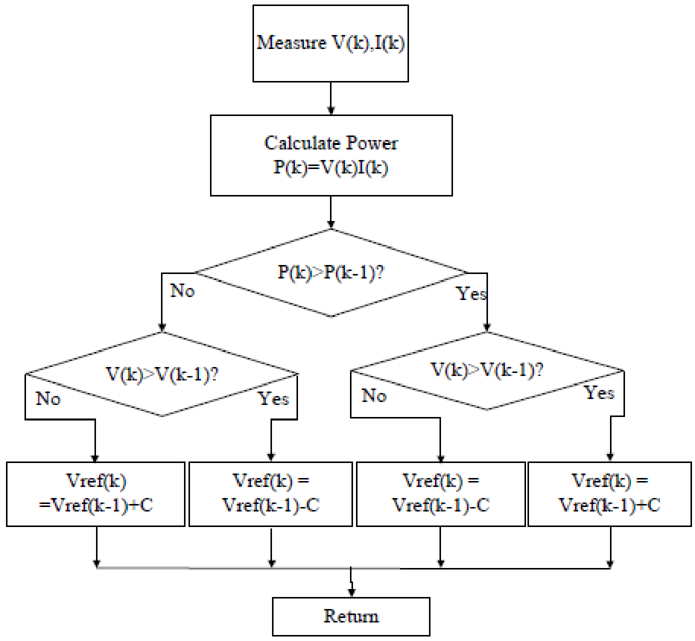


Fig. 2. Flow chart of P&O algorithm

4. INPUT GRAPH FOR PV MODULE

Figure 3 and Figure 4 show the graph for input variable of PV module which is irradiance and temperature. From Figure 5, the purple lines of the graph are representing switch 2 for both graph. On the other hand, switch 1 is representing in sunny day, whereas for switch 2 is representing partially shaded condition. For this simulation, the switch is turned on to switch 2, which to examine simulation during partially shading condition.

5. ANALYSIS OF MPPT PARAMETERS

Figure 6 shows the power delivered to the load under partially shaded condition. The irradiance various dynamically start from 12 pm until 14 pm. However, the perturb and observe algorithm can track correctly.

The fluctuation of the power and voltage in stable stage is due to the same reason in the previous testing. From the observation, the changes of V_{ref} is directly proportion to the input irradiance as depict in Figure 7. Figure 8 and 9 show the PV current and value of duty cycle for PWM for this simulation.

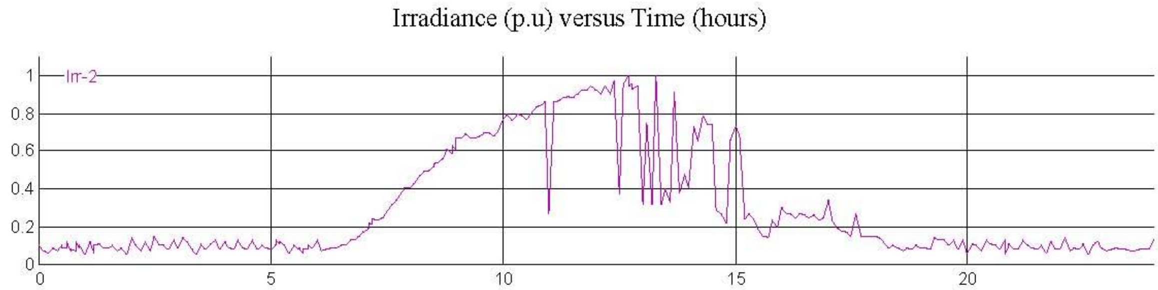


Fig. 3. Input irradiance for PV module

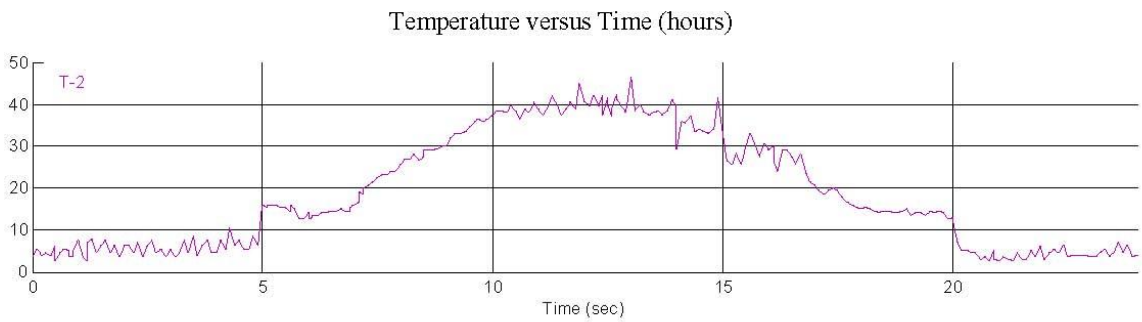


Fig. 4. Input cell temperature for PV module

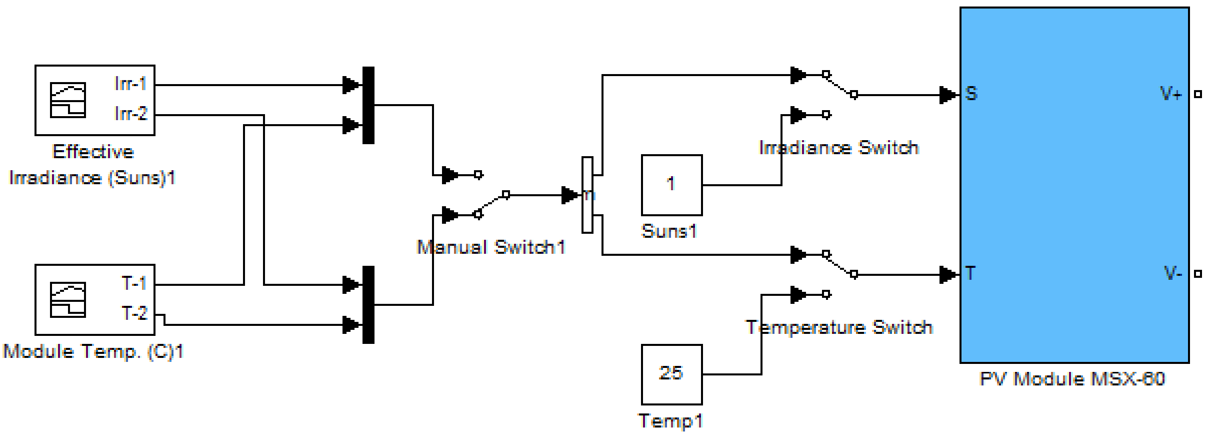


Fig. 5. Configuration on input irradiance and temperature in simulation

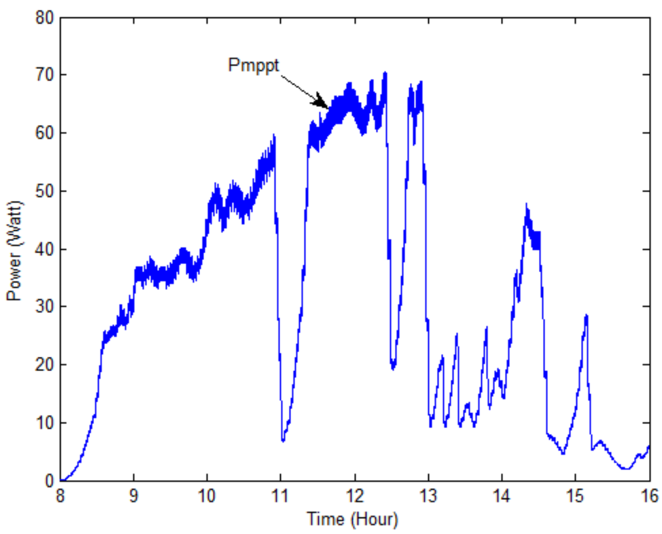


Fig. 6. MPPT output power from MATLAB-Simulink

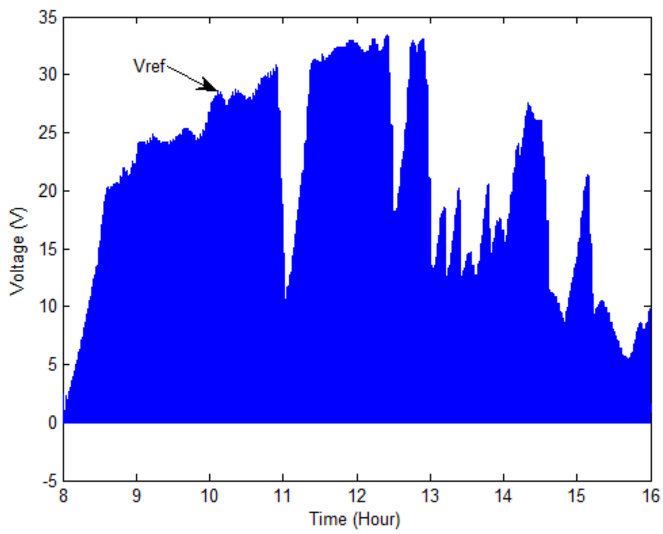


Fig. 7. MPPT output voltage reference (V_{ref}), from MATLAB-Simulink

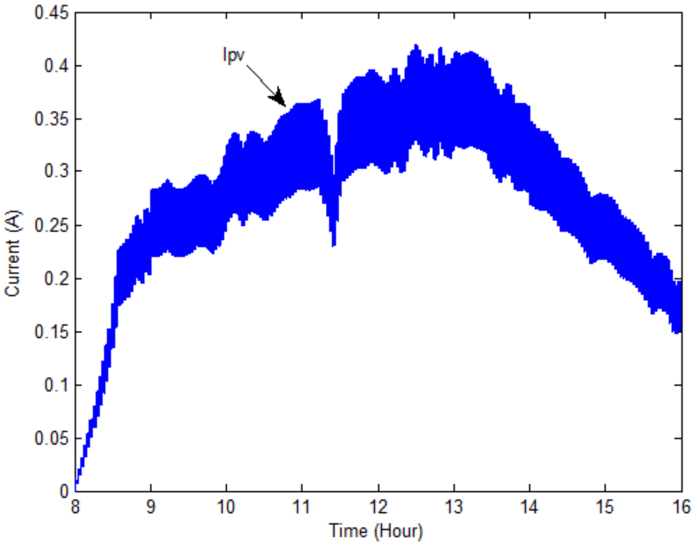
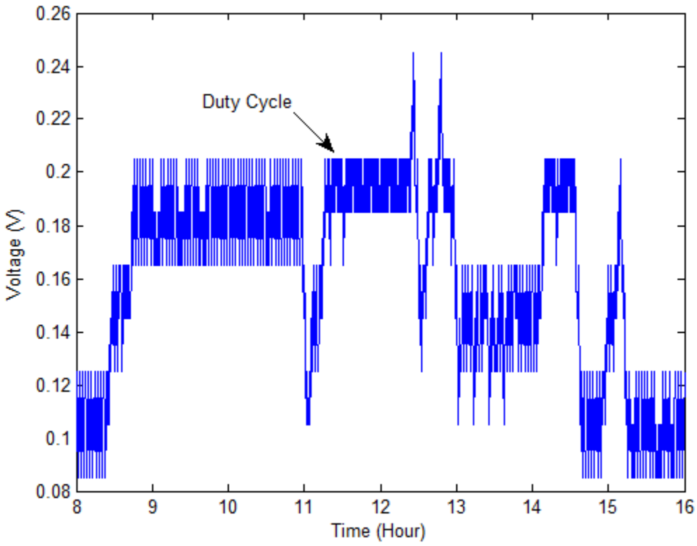
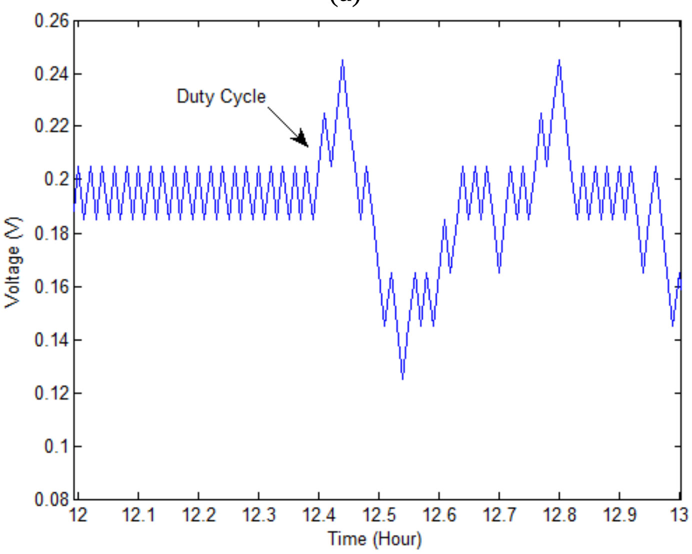


Fig. 8. Photovoltaic current from MATLAB-Simulink



(a)



(b)

Fig. 9. (a) Overview value of duty cycle (b) zoom-in value of duty cycle from MATLAB-Simulink.

6. MPPT MODEL SIMULATE USING QUARTUS II SOFTWARE

The input voltage and current is obtained from previous MATLAB-Simulink simulation. The value of the V_{ref} and *Ipv* from Figure 7 and 8 are sampled with 10 ms. Since there have huge of data to simulate by Quartus II, it just consider sample of PV voltage and current as shown as in Figure 10. Figure 10 shows the plotted graph of input voltage and current that had been used in Quartus II software.

The vector waveform is used to simulate the MPPT controller in Quartus II software. The input voltage and current is key-in manually into Quartus II software. Figure 11Fig. shows the screen shot of the simulator in the Quartus II software. The result can be observed at four signals which is *delta_p*, *delta_v*, *mppt_dir*, and *duty*. The final result which is *duty* signal will be compared with result from MATLAB-Simulink.

Figure 12 shows the compared result from Quartus II and MATLAB-Simulink. From the observation, the tracking pattern of both cases is same. However, the amplitude of blue signal is higher. This is due to miss tracking at a certain point. This is because the radix for the input is unsigned, but the input provided from MATLAB is floating point. Therefore, at a certain point, the controller cannot produce the correct value for *delta_p* and *delta_v*. However, the result proved that the MPPT controller can be implemented using FPGA.

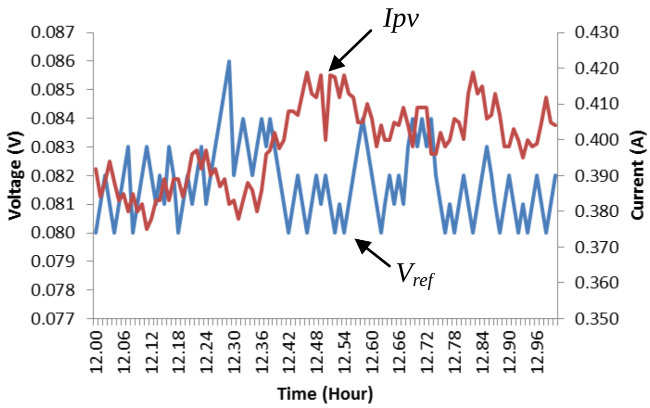


Fig. 10. Sample data of input voltage and current for Quartus simulation

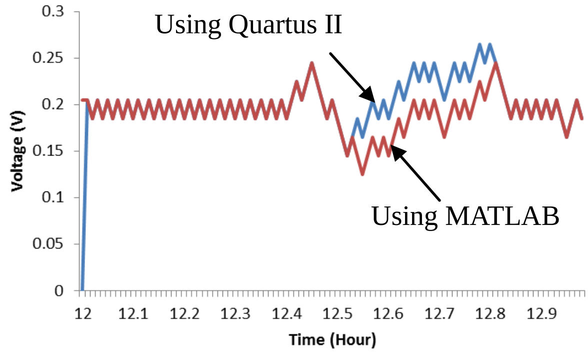


Fig. 12. Comparison of duty signal using Quartus II and Matlab simulation

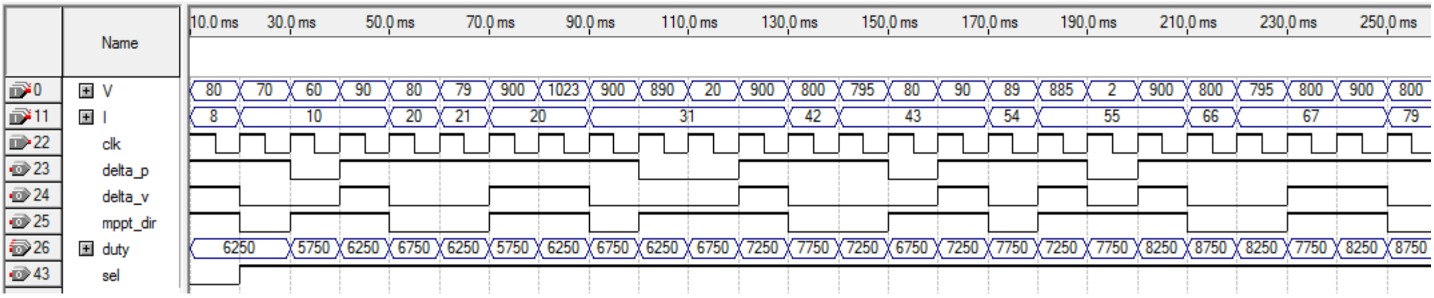


Fig. 11. Screen shot of output vector waveform file

7. CONCLUSIONS

This paper has presented the modeling of PV module and the development of the Maximum Power Point Tracking techniques (algorithm or controller). The proposed system is simulated by using MATLAB-SIMULINK. Based on the simulation result, the project has successfully achieved the objective of this project and covered the scope. This study proposes an FPGA-based implementation of a MPPT controller. At the core of this system, the P&O algorithm is used to track the maximum power point. The algorithm runs on an Altera DE1 FPGA board. Integrating FPGA in an MPPT control system provides numerous advantages. To meet performance requirements, FPGAs are desirable since their performance can easily surpass the performance of microcontrollers and DSPs. The system comprising of PV module and the MPPT controller has been implemented in this study to propose and validate an efficient maximum power tracking system based on P&O algorithm. This system is being simulated using MATLAB SIMULINK firstly to get an idea of the working of this system. After the clarification and validation of the proposed setup by using MATLAB SIMULINK, the system is then implemented by using QUARTUS II simulation to extract the same output values as in MATLAB. The scheme proved to work effectively and the output from the QUARTUS II simulation is observed to be approximately same as MATLAB.

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