Performance Assessment of Photovoltaic Generator (PVG) Power System Using Maximum Power Point Tracking (MPPT) DC to DC Boost Converter and DC to AC Inverter

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Abstract. Output power of Photovoltaic Generator (PVG) in a power system was tracked using duty cycle perturbation pulse applied into Maximum Power Point Tracking (MPPT) DC to DC boost converter. Perturbation pulse was controlled by Perturb and Observe (P&O) algorithm which is written in Arduino Uno microcontroller. Power system consist of PVG connected directly with MPPT DC to DC boost converter and then with DC to AC inverter and selected load is 20 W bulb. PVG efficiency was determined by the ratio between the PVG output electric power and the amount sunshine irradiation power received on the surface of PVG. MPPT efficiency was calculated based on output power of PVG work as an input power of MPPT and both input and output power of MPPT was measured using voltage sensor and ACS 712 current sensor. Voltage and current measurements was carried out in online system using Parallax Data Acquisition (PLX-DAQ) software and then voltage, current and power was tabulated in excell table. The graph of voltage, current and power was plotted as a function of time and shows the occurrence of power tracking of MPPT to extract maximum power from PVG after duty cycle of perturbation was applied. The performance of power system was determined by multiplying efficiency of PVG, MPPT and Inverter which gives the performance value around 93 percent of PVG efficiency.

1. Introduction
Output power of Photovoltaic Generator (PVG) depend on irradiation intensity, temperature and load impedance. Among these three factors, load impedance strongly affects PVG output power. When a PVG is directly connected to the load the value of extracted output power delivered to the load would decrease from its maximum value due to a nonlinear voltage-power characteristics of PVG. Maximum power occurs at optimum load impedance and at maximum power point voltage and current [1][2][3][4]. In order to extract a maximum power from PVG, a special tracking technique, maximum power point tracking (MPPT) has been used to track maximum voltage and maximum power and then deliver it into the load. The tracking process is controlled by algorithm code in microcontroller which gives time varying Pulse Width Modulation (PWM) to activate MPPT[1][2][3].

Many researchers using algorithms such as Perturb and Observe (P&O), Incremental Conductance (IncCon) and Fuzzy Logic algorithm to control MPPT and the code is implemented into hardware configuration using microcontroller and also addressed into simulation method using MatLab. Among them P&O technique is simple and easily implemented into hardware [5][6][7] and can be applied in irradiance changes [8][9]. Implementation of Fuzzy Logic method into practice are very complicated in term of hardware implementation/configuration [10][11]. It was, therefore, most of implementation...
of algorithm in PVG power tracking system was controlled by P&O algorithm code to produce PWM pulse into MPPT[11][12][13]. Microcontroller deliver PWM pulse into MOSFET switch in MPPT and code of P&O algorithm is used to perturb the duty cycle of PWM pulse and then resulting in changing of voltage and power. During perturbations code, maximum voltage and power of PVG was tracked and then delivered into load. The hardware implementations of P&O algorithm into MPPT was conducted using DC to DC buck converter, combination of DC to DC buck and boost converter and DC to DC boost converter. The difference between these three converters was related with the code used to perturb the duty cycle of PWM pulse which was applied into MOSFET switch in converter for the purpose of tracking maximum voltage and power [15].

Generally, the stand alone PVG (off grid) was used as a power system to supply electricity power into home electrical appliances in remote area, street lights and to energize induction motor of water pump in agriculture plantation and others [16][17][18]. Many studies and researches has explained tracking and extraction of maximum power of standalone PVG power system (off grid)[19][20] and extraction maximum power of PVG power system (on grid)[21] in simulation method using MatLab. Theoretically, in simulation, the extraction of power can be observed and displayed graphically as a function of time; but it should be noted that in simulation, the calculation has been made with an assumption of pure value of inductor without resistance and assumption that there is no voltage drop in diode [15]. The implementation using hardware of MPPT converter and inverter therefore is needed to observe the presence of tracking and extraction of maximum power from PVG in real time and then to analyze performance of the power system under combination of MPPT and AC to DC inverter efficiencies.

In this paper, DC to DC boost converter which is controlled by P&O algorithm written in Arduino code was selected as converter in MPPT to extract maximum power. Extraction of maximum power was then delivered into DC to AC inverter and finally delivered into load; in this case using 20 W bulb. The use of bulb as a load is preferred since there is no inductance in the bulb and then cos phi factor is not included in term of power calculation. The power consumed by the bulb is simple as the multiplication of measured voltage and current flow through the bulb. Performance assessment of the PVG power system was finally evaluated by measuring efficiencies of PVG, MPPT and Inverter.

2. Methodology

Block diagram of hardware implementation of PV power system which consists of PVG MPPT and Inverter was shown in Figure 1. PVG was selected which consist of 36 crystalline silicon solar cells connected in series and with maximum power of 85 W in Standard Test Condition (STC). Efficiency of PVG was calculated by measuring output power of PVG comparing with power received by PVG surface after irradiating with halogen lamp. Power received by PVG surface was determined by measuring radiation intensity on the surface of PVG using TES 312 Solarimeter and the intensity was multiplied with area of 36 cells of PVG. Efficiency of MPPT DC to DC converter was determined by measuring voltage and current of MPPT input and voltage and current of MPPT output. Voltage and current was measured using voltage sensor and ACS 712 current sensor in online system using PLX-DAQ software application. Inverter available in the market was selected as DC to AC inverter (12 V DC to 220V AC, 2000W) and bulb 20 W is connected to inverter as a load. The performance of PVG power system was calculated by multiplying efficiency of each block such as Efficiency of PVG with efficiency of MPPT and efficiency of DC to AC inverter.
3. MPPT DC to DC converter

MPPT DC to DC converter was shown in Figure 2 which consists of inductor L (100 mH), IRFZ44 fast switching Mosfet, diode (20 A) and capacitor C (2 mF). When duty cycle (D) of perturbation pulse period T was applied into MOSFET, the MOSFET switch S will be closed and inductor would work as an energy storage during TD time. Afterward during (T-D) time MOSFET switch S will be opened and the energy in inductor will be delivered into Load through diode D and the energy would be accumulated by capacitor C since the energy cannot be backed during MOSFET state is on again due to diode blocking. The voltage and power is then increased and tracking was continued by the P&O code written in microcontroller [10].

![Figure 2. MPPT DC to DC converter](image)

The booster converter related output voltage and input voltage such as [1]:

\[
\frac{V_o}{V_{in}} = \frac{1}{(1-D)}
\]

(1)

Since D value is between 0 and 1, it is expected from equation (1) that MPPT output voltage is greater than input voltage.
4. Perturb & Observe Algorithm
In order to activate switch S into on and off states with perturbation duty cycle D, an algorithm P&O is written in source code suitable with Arduino Uno and obey the flow chart as shown in Figure 3. The principle of tracking is to decide the direction of perturbation after first measurement of voltage and current and followed with calculation of power through multiplication of voltage times current. If the calculation of power increase comparing with initial condition then perturbation direction is correct and tracking is continue in the same direction. If the calculation of power decrease comparing with initial condition, then perturbation direction is not correct and tracking direction must be done in reverse direction [10].

![Flow chart of P & O algorithm](image)

5. Result and Discussion
5.1. MPPT power tracking
The illumination was given into PVG surface and illumination intensity was adjusted using dimswitch. The presence of MPPT tracking was implemented by measuring voltage, current and then calculation of MPPT input power when duty cycle perturbation is absent (non tracking) and then calculation of power after applying duty cycle perturbation (tracking). The process of delivering and not delivering of perturbation duty cycle was controlled using switch. It was observed that PVG output power increased from 6 W up to 20 W after perturbation of duty cycle from Arduino microcontroller is delivered into MOSFET as shown in Figure 4. The PVG maximum voltage and
then maximum power has been tracked during perturbation of duty cycle resulted by written P&O code in Arduino. The output power of MPPT after tracking are shown in nearly a constant value. The stable value of MPPT output power gives a such proof that maximum power tracking occurs in our MPPT controller.

![Figure 4. MPPT power tracking after PWM is delivered](image)

5.2. MPPT Input and Output Voltage, Current and Power

The measurement of MPPT input and output voltage was given in Figure 5 and gives the increment of voltage during tracking with increment of duty cycle in a boost DC to DC MPPT converter.

![Figure 5. MPPT input and output voltage](image)

The increment of voltage after increment perturbation /duty cycle obey equation 1 of boost DC to DC converter and as a proof that written P & O code in arduino microcontroller was worked excellently.

The measurement of MPPT input and output current was given in Figure 6 and gives the increment of current in accordance with increment of tracking voltage in Figure 5. The calculation of input power and output power of MPPT as a result of multiplication of voltage and current was plotted in Figure 7. It shows that output power of MPPT is smaller than input power and from that graph we can determined efficiency of MPPT.
5.3. Inverter Input and Output Power

5.4. Performance assessment of PVG Power System

PVG efficiency was determined by the ratio between the PVG output electric power \( P_{\text{PVG}} \) and the amount sunshine irradiation power received on the surface of PVG \( P_{\text{SN}} \) such as:

\[
\eta_{\text{PVG}} = \frac{P_{\text{PVG}}}{P_{\text{SN}}} \times 100\% \tag{2}
\]

Since the surface area of all cells equal to 0.56 m\(^2\) and irradiation intensity was measured as 320 W/m\(^2\), the power received on the surface PVG \( P_{\text{SN}} \) is 180 W. PVG output electric power \( P_{\text{PVG}} \) was
measured shown in Figure 7 as an input power applied into MPPT and the average power value equal to 20.49 W. Using equation (2) the PVG efficiency was calculated and equal to 11.38 %.

Efficiency of MPPT($\eta_{MPPT}$) was measured by using data in Figure 5 and Figure 6 to calculate input and output power as shown in Figure 7. The average input power was achieved during the interval time of 50 minutes in the order of 20.49 W, and output power is 19.55 W. MPPT efficiency was finally calculated is equal to 95 %.

Efficiency of inverter ($\eta_{INV}$) was calculated by using average output power of MPPT which is work as an input power into inverter. The value of input power of inverter was shown in Figure 7 and Figure 8 is equal to 19.55 W. Output power of inverter was achieved by measuring voltage and current flowing through the bulb using AC digital multimeter. The average value of inverter output power was shown in Figure 8 and equal to 18.98 W. Using values of input and output power of inverter, efficiency was calculated and equal to 97 %.

Performance of PVG power system ($\eta_{PVGPS}$) was determined [20] using equation:

$$\eta_{PVGPS} = \eta_{PVG} \times \eta_{MPPT} \times \eta_{INV}$$

Using Equation 3, performance of the PVG power system was calculated and is equal to 93 percent of PVG efficiency. In other words overall efficiency would be in the order of 10.45 %.

5.5. Discussion

Parameters measurements are carried out in a short time in the order of one minute and under radiation Intensity of 320 W/m$^2$ to make sure that temperature during measurements can be considered constant[20]. The presence of power tracking has been achieved using written P&O algorithm code as shown in Figure 4, since the value of achieved tracked maximum power was in accordance with optimum power observed in PV curve characteristics at intensity in the order of 320 W/m$^2$ that has been carried out in separate experiment. It can be compare with power tracking implementation of other researches using P&O, IncCon and Fuzzy Logic [2]. Performance that has been achieved in the order of 93 percent of PVG efficiency after connecting with subsystem of MPPT boost converter and AC to DC inverter seems to be higher than performance achievements by other researches using subsystem of MPPT buck converter and permanent magnet DC motor [20]. Finally it can be deduced that P&O algorithm in MPPT has been succesfull tracking maximum power from PVG and then inverting power into AC using DC to AC inverter with performance 93 percent of PVG efficiency.

6. Conclusion

PVG power system under constant intensity irradiation, using MPPT boost DC to DC converter and controlled by P & O algorithm results a good maximum power tracking and inverting of maximum power into AC power using AC to DC inverter. The designing of P&O algorithm which is written in Arduino Uno has been worked sucessfull to track maximum voltage and then power after Arduino delivering duty cycle perturbation into MOSFET in boost converter. Performance of power system was achieved in the order of 93 percent of PVG efficiency which means that the maximum power extraction and subsequent delivering of power into load shows a good performance.

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