

DESIGN OF A MAXIMUM POWER POINT TRACKING SYSTEM BASED ON PERTURB AND OBSERVE ALGORITHM USING PI CONTROLLER

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Abstract: The solar energy is considered as the most promising renewable energy source to harvest due to its eco-friendliness. But the conversion of solar energy into electricity is costly and the efficiency of PV panels is not good enough. Moreover, PV panels are forced to give output according to the voltage rating of the connected load. To utilize the maximum power generating capacity of PV panels' maximum power point tracking (MPPT) system is used. There are several algorithms are developed to track the MPP. In this paper Perturb & Observe (P&O) algorithm is used to design the MPP tracker in a simple way using PI controller. The proposed system tracks the MPP almost exactly with least oscillation.

Keywords: PV System, MPPT, Buck Converter, PI regulator.

1. INTRODUCTION

The reserves of fossil fuel will be depleted in a few decades. The solar energy can be a good alternative source of energy. The sunlight is abundant and free on this earth. The conversion of solar energy is pollution-free and needs no moving parts. But the production process of PV cells and panels involves much cost. The efficiency of PV panels is typically around 20-25%. In recent time many researches are going on to increase the cell efficiency and panel's output power through modifying cell construction and panel fabrication. To utilize

the maximum power generating capacity of PV panels, electrical tracking methodology is used, that is known as maximum power point tracking (MPPT).

In MPPT system, PV panels are operated at their maximum power point (MPP) to maximize the PV array output power. Figure 1 and 2 shows the variation of power-voltage characteristics of a PV module as a function of solar irradiation and temperature. Temperature changes mainly affect the PV output voltage and irradiation changes mainly affect the PV output power [1].

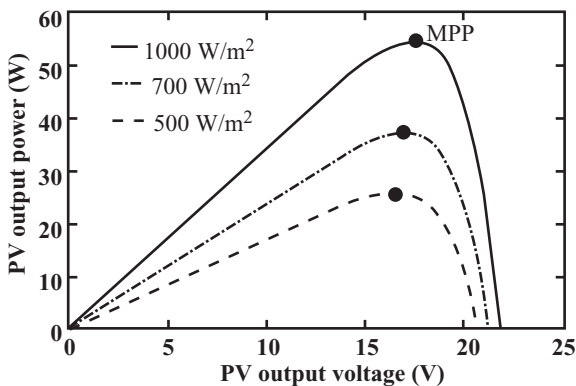


Fig. 1 P-V characteristics for different solar irradiation level.

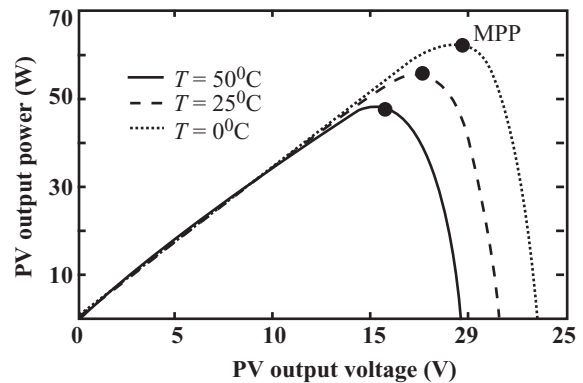


Fig. 2 P-V characteristics for different temperature level.

MPPT system operates a PV panel at its highest output power level for any solar irradiation and temperature level. Stand-alone Photovoltaic system serves load through charging battery. Usually there is a dc-dc converter which regulates the charging voltage level of the battery. The conventional system design cannot extract maximum power from a PV panel. Several MPPT algorithms have been developed and tested, such as Perturb and Observe (P&O) method, Incremental Conductance (I.C.) method, Forced Oscillation method, Open Circuit and Short Circuit Photovoltaic Generator method [2]. Artificial neural networking and fuzzy logic controllers are also used to track the MPP.

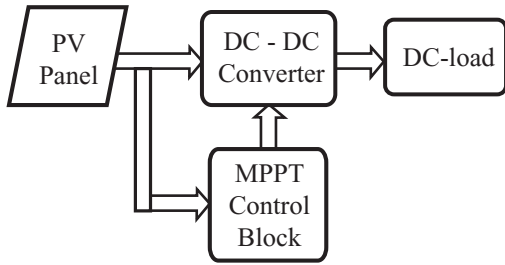


Fig. 3 Block diagram of a PV system.

P&O is the simplest MPPT algorithm. It tracks the MPP through sensing the difference of power and adjusting the duty cycle of the switch of a dc-dc converter. In this paper P&O algorithm based MPP tracking system has been developed. The proposed system compares the power difference with a ground signal and generates an error signal for a PI regulator. The system has been simulated using Matlab-Simulink software.

2. THEORITICAL BACKGROUND

2.1 Modeling of Photovoltaic Cell and Panels

A solar cell is basically a PN junction. When the PN junction is exposed to light, photons with energy greater than the band-gap energy of the cell material are absorbed. This creates electron-hole pairs. These carriers are separated under the influence of build-in electric field within the junction, creating a current in the external circuit that is proportional to solar irradiance. Figure 4 shows an equivalent circuit of a solar cell, which consists of a current source I_L in anti-parallel with diode driven by a current I_D [3].

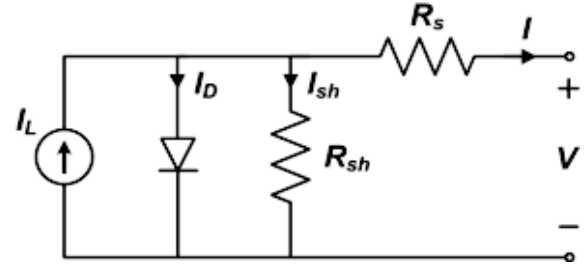


Fig. 4 Equivalent circuit of a solar cell.

The governing equation for this equivalent circuit is formulated using the Kirchoff's law of current,

$$I = I_L - I_D - I_{sh} \quad (1)$$

Here, I_L represents light-generated current in the cell, I_D represents the voltage-dependent current lost due to recombination, and I_{sh} represents the current lost due to shunt resistance. Using Shockley equation for a diode I_D can be modeled as,

$$I_D = I_0 \left[e^{\frac{V + IR_s}{nV}} - 1 \right] \quad (2)$$

Where n is the diode ideality factor, I_0 is the saturation current and V is the thermal voltage given in [4] as the following,

$$V = \frac{kTc}{q} \quad (3)$$

Where k is the Boltzmann's constant (1.381×10^{-23} J/K) and q is the elementary charge. The shunt current would be, $I_{sh} = (V + IR_s) / R_{sh}$ and combing this and above equations the output current of a solar cell can be written in the following way,

$$I = I_{ph} - I_0 \left(e^{\frac{q(V_o + IR_s)}{nkTc}} - 1 \right) - \frac{V_o + IR_s}{R_{sh}} \quad (4)$$

And the output voltage and power respectively,

$$V_o = -IR_s + \frac{nkTc}{q} \ln \left(\frac{I_{ph} - I + I_0}{I_0} \right) \quad (5)$$

$$P_o = IV_o \quad (6)$$

I and V_o are, respectively, the output current and voltage of solar cell. R_s and R_{sh} are the internal series and parallel resistances respectively. These equations show that, the output current of solar cell depends on temperature and solar irradiation. Hence the output power is also a function of climatic condition. Solar cells are connected in series/parallel to get desired output current and voltage [3].

2.2 The MPPT Algorithm

P&O method is an iterative method of obtaining the MPP. It measures the PV array characteristics and perturbs the operating point of the PV system. It is essentially a trial and error method [2].

In this method, the operating point of the PV panel is perturbed by a small increment δV in V_{ref} , which is modeled as C in the algorithm flowchart in Fig. 5. Then the change in power, δP is measured. If δP is positive it means, the perturbation is in correct direction. And negative δP means the perturbation is in wrong direction. The algorithm senses it and perturbs the system to increase the operating point in correct direction.

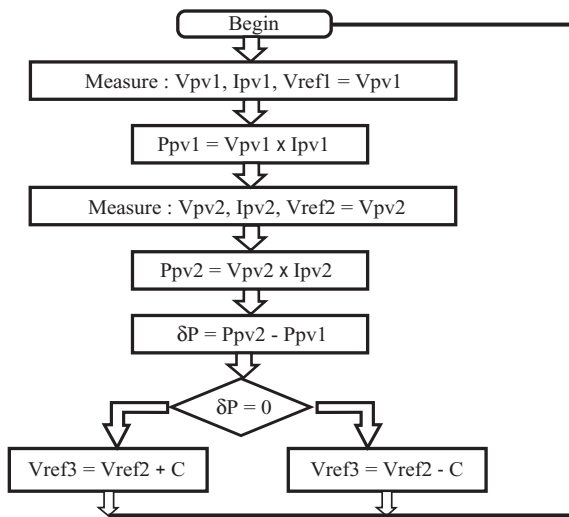


Fig. 5 Flowchart of the P&O algorithm.

P&O algorithm operates the system by using only one parameter - the PV panels' output power. For this reason the operating point becomes very oscillatory under rapidly changing solar irradiation. To reduce this problem in this paper a new approach has been proposed. The direction of perturbation is decided along with a PI controller.

2.3 DC-DC Converter: Buck Converter

In an MPPT based PV system a DC-DC Buck converter is used to match the load impedance with PV panel's impedance and to regulate the charging voltage level of the battery at maximum power level of the PV panel. In a Buck converter the output voltage level can be controlled from zero to the input voltage level at

a high frequency using power semiconductor switches, such as MOSFET, IGBT etc [5].

2.3.1 Buck Converter Topology

The Buck converter, as shown in Fig. 6, operates at continuous mode of operation [5]. The inductor L stores energy during the ON-period of switch. The stored energy is transferred to the capacitor, C through the free-wheeling diode D_{FW} during off-period. By varying the duty cycle of the switch the proposed system regulates the charging of a 12V battery.

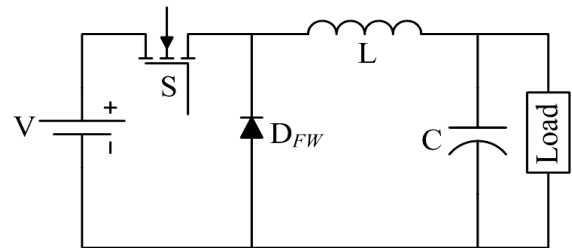


Fig.6 Circuit topology of a DC-DC buck converter.

2.4 Proportional Integral (PI) Controller

In order to control the output voltage of Buck converter by varying duty cycle of the switches PI controller is used. The output of PI controller is made up of the proportional and integral action. There is a set point or reference signal and a process variable or feedback signal in the system as described in Fig. 7. The feedback signal obtain from Buck converter output is subtracted from the reference signal to obtain an error output. When there is a deviation of battery voltage from the desired set point value an error signal is introduced which is processed through the proportional and integral controller. The PI controller improves the steady-state error without affecting the transient response [6].

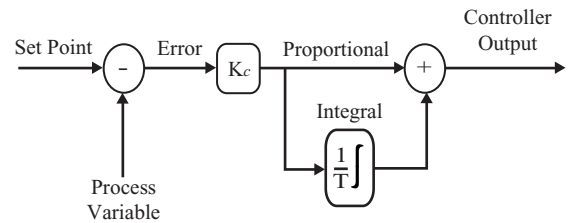


Fig. 7 Block diagram of a Proportional Integral (PI) controller.

3. DESIGN OF THE PROPOSED MODEL – IN SIMULINK

Fig. 8 shows the Simulink model of the proposed MPPT system. Physical parameters of solar irradiation and temperature are given as inputs to the PV model subsystem. A dc-dc converter is powered by the PV model subsystem. The DC-DC converter is a 12V buck converter. There is a MPPT control block. In this subsystem block MPPT control logic is processed and a switching signal is generated for operating the switch of the DC-DC buck converter. The ratings of the PV system used in this model are, $V_{oc} = 22.2V$ and $I_{sc} = 5.424A$.

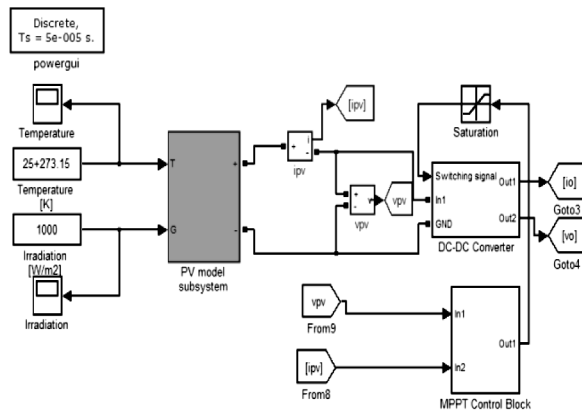


Fig. 8 Maximum power point tracker with PV panel and DC-DC converter.

3.1 Circuit Parameters of the DC-DC Buck Converter

In this MPPT system the DC-DC buck converter acts as the impedance matching system. It shows the PV panel the optimum impedance at any solar irradiation and temperature. Fig. 9 shows the Simulink model of the DC-DC Buck converter.

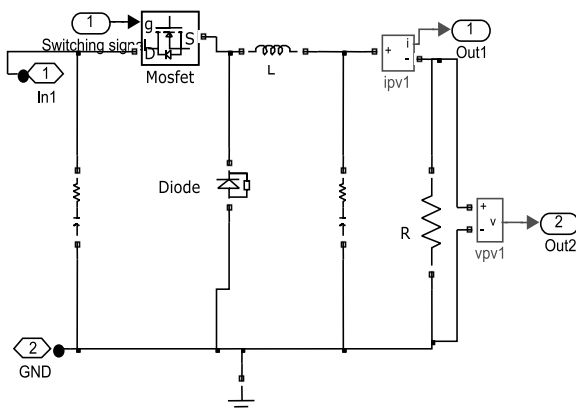


Fig. 9 DC-DC converter subsystem in Simulink.

The output voltage of the PV panel is the input voltage of the buck converter. The output voltage rating is 12VDC. The switching frequency is 40 kHz. The inductor current ripple (Δi_L) is 75mA and the capacitor voltage ripple (Δv_C) is 500 μ V. The output load resistance is selected as 3 Ω . The value of inductor is selected as 2 μ H. The value of input and output capacitance is selected as 1000 μ F and 470 μ F respectively. The value of the inductor and the output capacitor should be selected carefully. Otherwise the output voltage may be higher than the input voltage. Because then the natural frequency of the LC filter would be much closer to the switching frequency of the DC-DC converter.

3.2 MPPT Control Block in Simulink

The maximum power point tracking control block consists of time delay blocks, PI regulator and PWM generator. The time delay blocks, multiplier and adder block generates deltaP (δP). This deltaP signal acts as the negative feedback input for the PI regulator based control section. In perfectly stable condition the actual input to the PI regulator is a zero or ground signal.

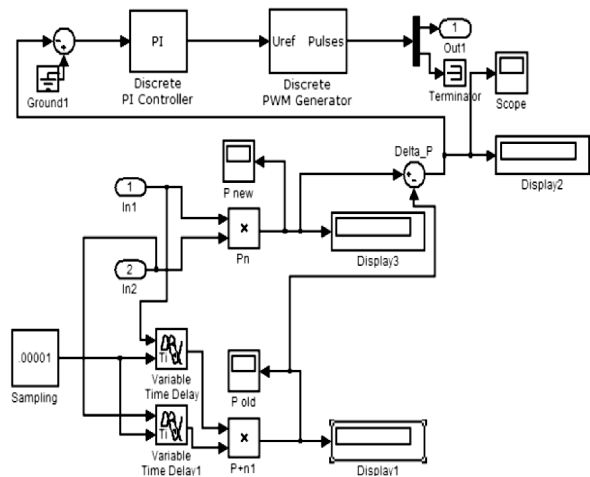


Fig. 10 MPPT controlling unit designed in Simulink.

When the maximum power point tracking system starts to operate then the negative feedback, deltaP generates an error signal to the PI regulator. The PI regulator tries to make this error signal equal to zero. It sends out a control signal to the PWM generator according to the magnitude and sign of the error signal. Thus the MPPT control block controls the average on-time and off-time of switch of the DC chopper.

4. SIMULATION RESULTS

The simulation results are described through figures and table. To illustrate the efficiency and stability of the system rapid irradiation and temperature change have been made during simulation.

Fig. 11 demonstrates the response of PV output power during changes in solar irradiation and temperature as shown in Fig. 12 and Fig. 13 respectively.

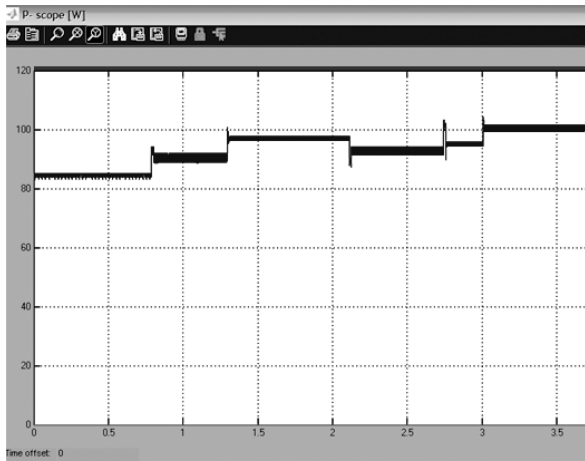


Fig. 11 The response (power) of PV panel with the MPP tracking system for irradiation and temperature changes as shown in Fig. 12 and Fig. 13 respectively.

In Fig. 12 the solar irradiation is changed from 1000 W/m^2 to 1100 W/m^2 , then to 1200 W/m^2 , and again to 1100 W/m^2 , 1200 W/m^2 and then to 1300 W/m^2 . In Fig. 13 the temperature is changed from 25°C to 28°C , then to 30°C and again to 25°C and then to 32°C .

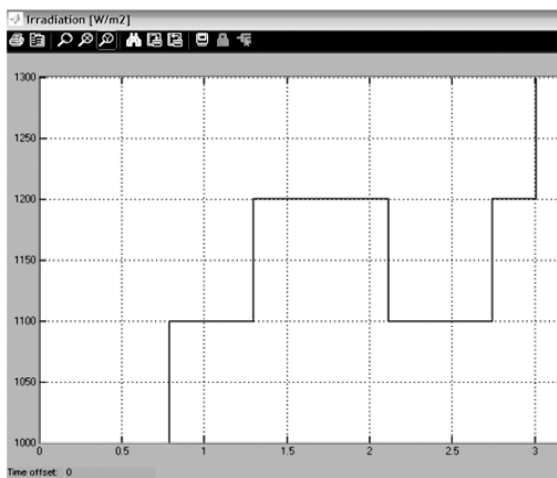


Fig. 12 Irradiation changes during simulation.

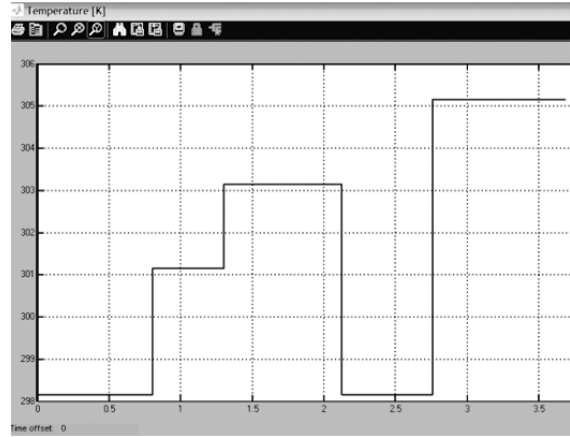


Fig. 13 Temperature changes during simulation.

Fig. 14 illustrates variations in PV output power in response to changes in solar irradiation and temperature as shown in Fig. 15 and Fig. 16 respectively.

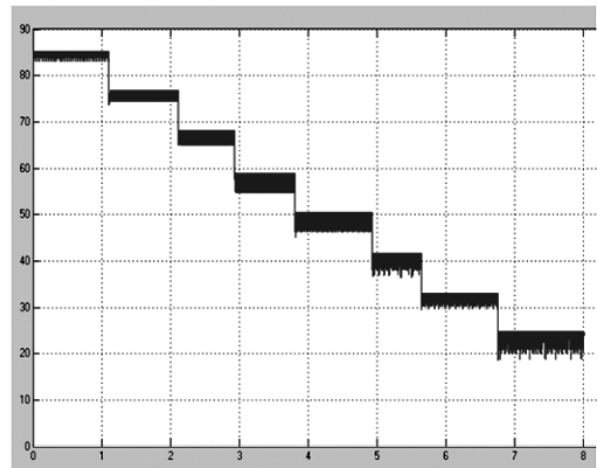


Fig. 14 The response (power) of PV panel with the MPP tracking system for irradiation and temperature changes as shown in Fig. 15 and Fig. 16 respectively.

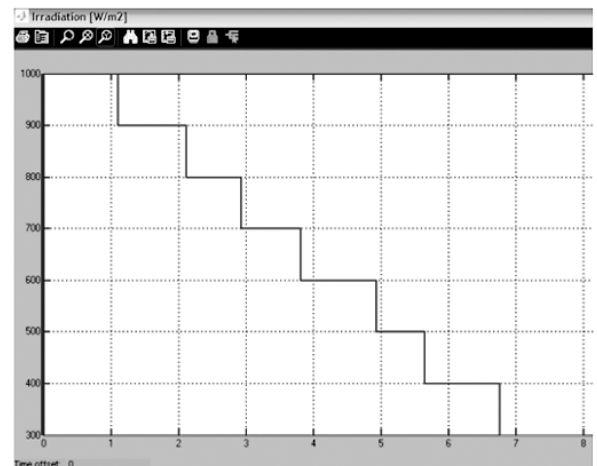


Fig. 15 Irradiation changes during simulation.

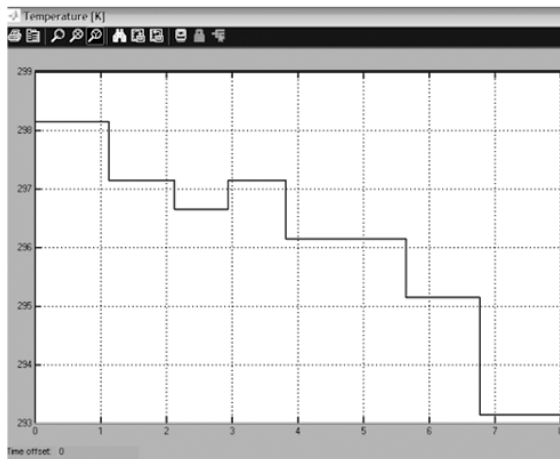


Fig. 16 Temperature changes during simulation.

In Fig. 15 the solar irradiation is changed from 1000 W/m² to 900 W/m², then to 800 W/m², 700 W/m², 600 W/m², 500 W/m², 400 W/m² and then to 300 W/m². In Fig. 16 the temperature is changed from 25°C to 24°C, then to 23.5°C and again to 24°C and then to 23°C, 22°C, 20°C.

Table 1 The Efficiency of the MPP Tracker.

Solar Irradiation, I (W/m ²) & Temperature, T (°C)	P _{max} (W)	P _{pv} (W)	Efficiency, η [P _{pv} /P _{max}] ×100
I = 1000; T = 25	85.16	84.78	99.55
I = 1100; T = 28	92.0	90.95	98.86
I = 1200; T = 30	99.25	96.9	97.63
I = 1100; T = 25	94.1	92.92	98.75
I = 1200; T = 32	97.77	95.08	97.25
I = 1300; T = 32	106.3	100.5	94.54
I = 900; T = 24	76.81	76.34	99.39
I = 800; T = 23.5	68.09	67.6	99.28
I = 700; T = 24	58.9	58.34	99.05
I = 600; T = 23	50.4	49.88	99.19
I = 500; T = 23	41.52	40.95	98.62
I = 400; T = 22	33.0	32.6	98.79
I = 300; T = 20	24.7	24.2	97.97

From Table 1 it has been seen that, the proposed tracker is highly efficient to extract the maximum power from a PV panel. The average efficiency is 98.37%. The P_{pv} shown in table 1 is the average output power of the PV panel. P_{max} is actual maximum power of the PV panel for the corresponding solar irradiation and temperature level.

5. CONCLUSION

The proposed maximum power point tracking system works most efficiently in lower irradiation level but with considerable oscillation. In higher or moderate irradiation level the oscillation is small and the efficiency level is good enough. Since typical PV system serves load through charging battery the MPPT tracker should be used with a charge controller. But the output of DC-DC converter used in the tracker is rated at 12V. So the tracker itself can serve as a single-stage charger. With this tracker the PV system can serve the load with enough power even at lower solar irradiation level.

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