Model Predictive Controller As a Robust Algorithm for Maximum Power Point Tracking

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Abstract

In the recent years, solar energy has attended the world as a clean energy. Many researchers are focused on extracting maximum power from solar panels. So, Maximum Power Point Tracking (MPPT) is used for increasing efficiency of solar PV system. This paper presents Model Predictive Controller (MPC) as a method for Maximum Power Point Tracking (MPPT) and compares it, with Perturb and Observe (P&O) and Incremental Conductance algorithm (IC) techniques. The MATLAB/Simulink and SimPower Systems software packages are used to model a proposed strategy. Simulation results show that Perturb and Observe (P&O) and Incremental Conductance algorithm (IC) techniques have limitation for tracking the exact maximum power point in transient insolation conditions. However, Model Predictive Controller (MPC) method is robust against fast varying of insolation conditions. Also, MPC method is faster than P&O and IC technique according to the simulation results.

***Keywords*—Solar energy, Model Predictive Controller, Perturb and Observe, Incremental Conductance, Maximum Power Point Tracking**

1. Introduction

Solar energy has many advantages compared with fossil-fuel energy such as being inexhaustible and free of charge, naturalness, being clean, having no ecological pollution, etc. However, it has an important disadvantage, which is the low efficiency of conversion of light to electrical energy [1]. Moreover, the power extracted by PV generation depends on some factors, such as the luminosity, the temperature, and the connected load.In operating region, there is just one point that PV array produces maximum power. It is very crucial to achieve the peak-power from the photovoltaic generator. Thereby, an MPPT technique is needed to be used in power electronic devices [1-5].

The Perturbation and Observation (P&O) [6,7] and the Incremental Conductance (IC) algorithms [8,9] are two control algorithms which are used commonly by researchers up to date for this purpose. In industrial applications, the PI controller is preferred due to its efficiency, simplicity and low cost [10]. PI controller consists of two terms:

1) The proportional one (P) generates a correction control action proportional to the error.

2) The Integral term (I) generates a correction proportional to the integral of the error.

This verifies that if a sufficient control effort is applied, the tracking error is reduced to zero [11]. Also, another method can be used to enhance this system. The maximum power point tracking photovoltaic systems is a fuzzy logic controller (FLC) [12,13,14]. In these works, some fuzzy rules are proposed for an error input which is based on the increment of the power versus the increment of the current. However, this method may be inappropriate if the current measurements contain noise. Moreover, another disadvantage of the FLC is the configuration and tuning of a high number of rules, which needs a large amount of operation on the plant [15].

In this paper, performance Perturb and Observe (P&O) as a conventional method is compared with Model Predictive Controller technique under fast solar tracker irradiation. Results show that MPC has better performance than a P&O algorithm.

2. Component modeling

Fig1. Show the block diagram which consists of a solar panel, DC-DC converter, and MPPT algorithm. The output of MPPT drives the DC-DC converter.

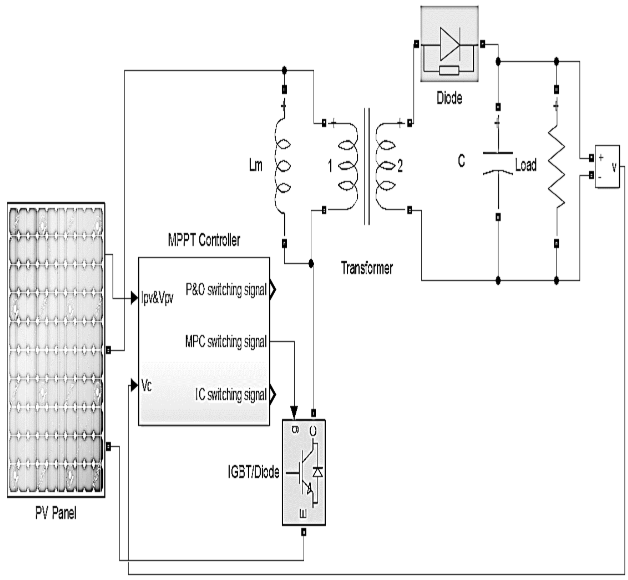

Fig. 1. Flyback Converter schematic

2.1. Equivalent circuit and characteristics of PV panel

The solar cell is the basic component, which can convert directly the sunlight into electricity. The equivalent circuit of the PV module is shown in Fig. 4 [16,17]. Equation related to PV panel can be expressed by the following [18,19]:

$$I_{pv} = N_p I_{ph} - N_p I_s \left[\exp\left(\frac{V_{pv} + \left(\frac{N_s}{N_p}\right) R_s I_{pv}}{n_s \alpha v_t} \right) - 1 \right] - \frac{V_{pv} + \left(\frac{N_s}{N_p}\right) R_s I_{pv}}{\left(\frac{N_s}{N_p}\right) R_p} \quad (1)$$

$$I_{ph} = [I_{sc}^* + k_i (T - T^*)] \frac{G}{G^*} \quad (2)$$

$$I_s = \frac{I_{sc}^* + k_i (T - T^*)}{\exp\left(\frac{V_{oc}^* + k_v (T - T^*)}{n_s v_t}\right) - 1} \quad (3)$$

In these equations, I_{pv} is the PV array output current (A), V_{pv} is the PV array output voltage (V), N_s and N_p are the numbers of PV modules connected in series and parallel, R_s and R_p are the PV module series and parallel resistance (Ω), α is the p-n junction ideality factor. Also, I_{ph} is photo-current which depends on solar irradiance G and temperature T, k_i is the short-circuit current temperature coefficient, I_{sc}^* is the short circuit current at standard test conditions (STC) that are: solar irradiance $G^* = 1000 W/m^2$, cell temperature $T^* = 298K$ and a spectral distribution AM 1.5. Furthermore, I_s is the reverse saturation current, V_{oc}^* is the open circuit voltage at STC conditions, k_v is the open circuit voltage temperature coefficient, and $v_t = \frac{k_b T}{q}$ is the Boltzmann's constant and $q = 1.60218.10^{-19} C$ is the charge of an electron. Fig. 2 and fig. 3 show the *I–V* and *P–V* characteristic of the PV system for different irradiance levels.

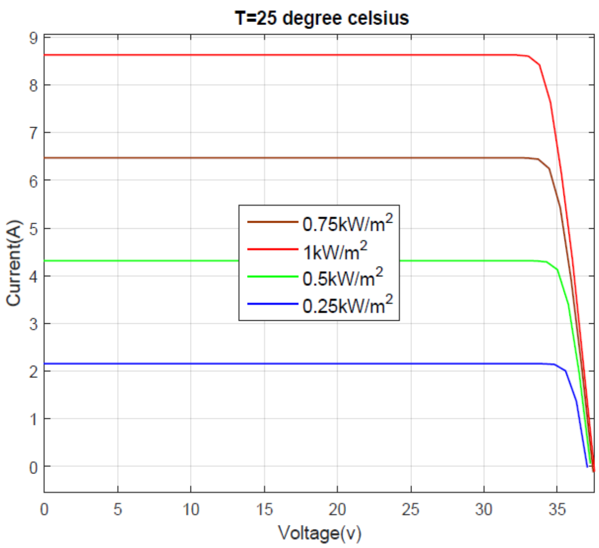

Fig. 2. P-V characteristics of PV array

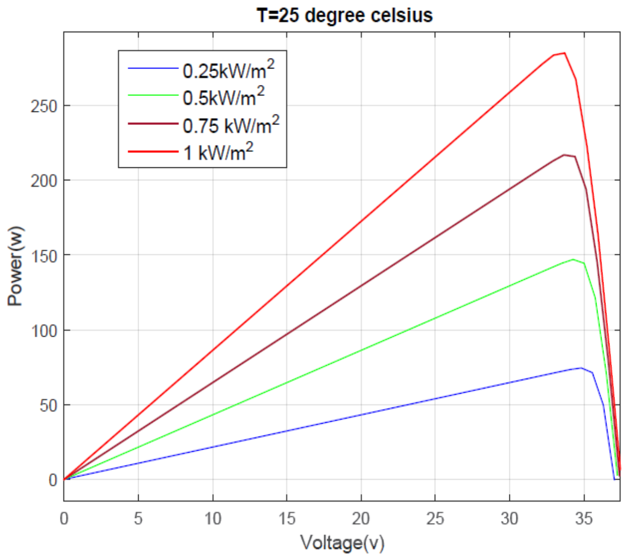

Fig. 3. P-V characteristics of PV array

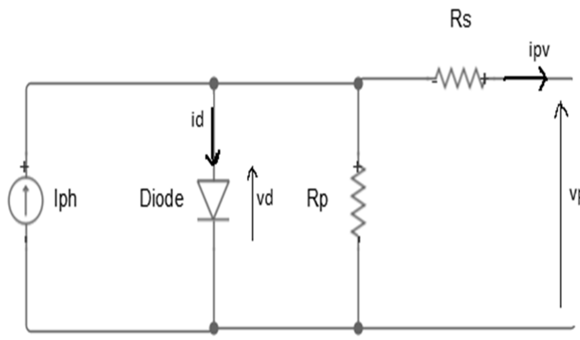

Fig. 4. Solar module equivalent circuit

2.2. Maximum Power Point Tracker Algorithms

2.2.1. Perturbation & Observation algorithm (P&O)

The Perturbation and Observation (P&O) algorithm is one of most widely used methods for controlling DC/DC converters due to its easy implementation. This algorithm works based on this idea that when the PV module is not working in MPPT point, the operating voltage of the module is disturbed periodically in small voltage V through DC-DC converter duty cycle. Then the change on the output power ΔP of photovoltaic is measured. If ΔP>0, the operating point is near to the MPP and same disturbance of V will occur in the same direction as the previous one. However, if ΔP<0, the system has moved away from MPP and next disturbance will occur in the opposite direction. Once the MPP has been reached, The P&O makes the point of operation of the photovoltaic module to work around it. However, if ΔP<0, the system has moved away from MPP and next disturbance will occur at opposite direction. Once the MPP has been reached, The P&O makes the point of operation of the photovoltaic module to work around it [20].

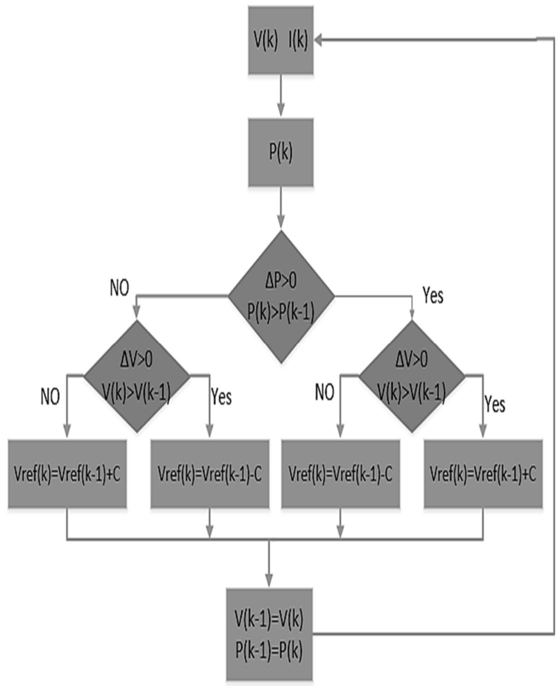

Fig. 5. Flowchart of the MPPT P&O algorithm

2.2.2. Incremental conductance algorithm (IC)

Incremental Conductance (IC) algorithm is very similar to the P&O algorithm. This algorithm is based on that the slope in the characteristic power-voltage curve of the photovoltaic module is equal to zero at the MPP, i.e., the derivative of the output power of the photovoltaic module is equal to zero at that point. It is possible to express this idea through Eq. (5) [20].

$$\frac{dP}{dV}\ \Big|MPP = 0$$

$$\frac{dP}{dV} = \frac{d(I.V)}{dV} = I + V\frac{dI}{dV} = 0$$

$$V\frac{dI}{dV} = -I$$

$$\frac{dI}{dV} = -\frac{I}{V} \tag{5}$$

The points around the maximum power point are analyzed as follows [22].

- dI/dV=-I/V, then dP/dV=0; and the working point is at the MPP
- dI/dV>-I/V, then dP/dV>0; and the working point is at the left of the MPP
- dI/dV<-I/V, then dP/dV<0; and the working point is to the right of the MPP.

2.2.3. Model Predictive Controller(MPC)

The main goal of this section is to improve the P&O and IC algorithms through predicting the future behavior of the desired control variables until [23] a predefined horizon in time. By using predicted variables, the switching state will be obtained through minimization of a cost function. Fig shows a flyback converter which is chosen as a DC-DC converter. Predicted behavior of control variables at the next sampling time k+1 can be described by a discrete-time set of equations by the following (equations (6) and (7) when switch is "ON" and (8) and (9) when switch is "OFF") [21].

$$i_{pv}(k+1) = \frac{T_s}{L_m} v_{pv}(k) + i_{pv}(k) \tag{6}$$

$$v_c(k+1) = \left(1 - \frac{T_s}{RC}\right) v_c(k) \tag{7}$$

$$i_{pv}(k+1) = i_{pv}(k) - \frac{T_s}{L_m n} v_c(k) \tag{8}$$

$$v_c(k+1) = \frac{T_s}{nC} i_{pv}(k) + \left(1 - \frac{T_s}{RC}\right) v_c(k) \tag{9}$$

Also, The cost function for the MPC algorithm is [21].

$$g_{S=0,1} = \left|i_{PV_{S=0,1}}(k+1) - i_{ref}\right| \tag{7}$$

The reference current, i_{ref}, found using the the procedure illustrated in Fig. 6 and generating of switching signals for MPC-MPPT is according to Fig. 7.

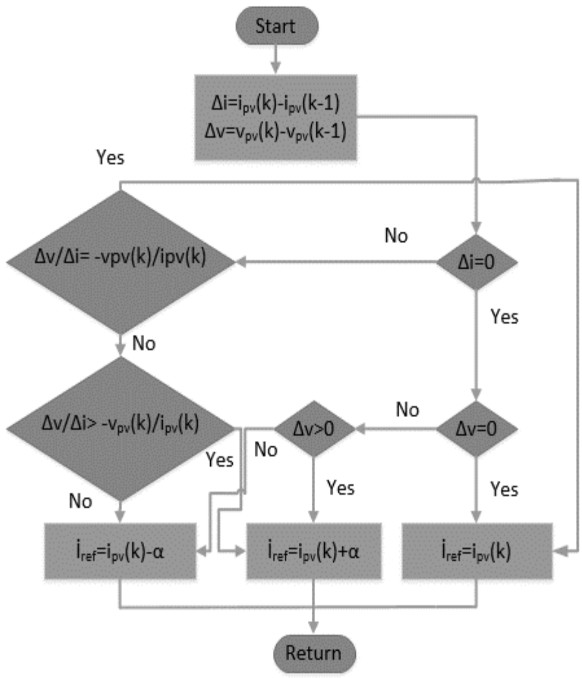

Fig. 6. Determine reference current using P&O for MPC-MPPT

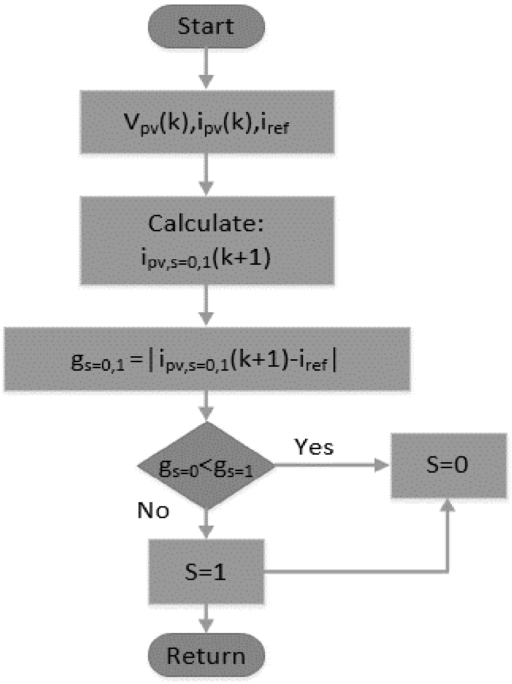

Fig. 7. Determine optimal switch MPC-MPPT procedure

3. Simulation Results

In this part, the performance of MPC for MPPT is compared with P&O and IC method. The sampling time is 2µs. Fig. 8 and Fig. 9 show comparison PV voltage and PV power for MPC-MPPT with P&O and IC under a step change in irradiance at time 0sec. Also, Fig. 10 shows the simulation results for output power of DC-DC converter for MPC-MPPT, P&O and IC. According to Fig. 7 and Fig. 8, MPC method as an MPPT has better dynamic than P&O and IC. Furthermore, P&O and IC are relatively slow to track maximum power point. Also, P&O and IC have oscillation in transient mode.

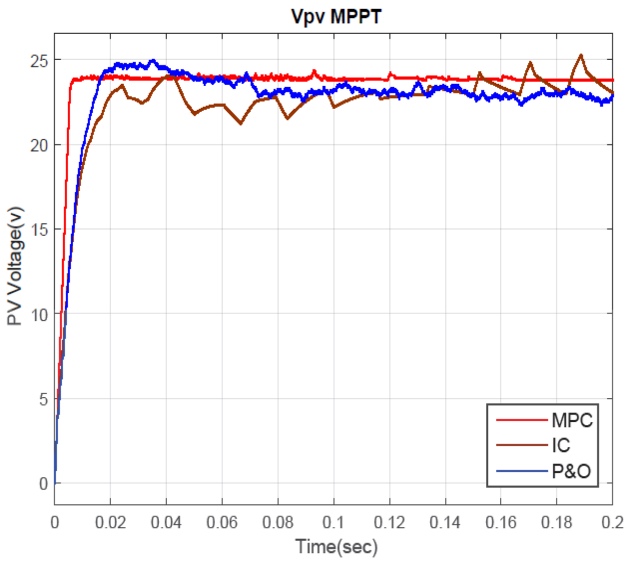

Fig. 8. Comparison PV voltage of MPC-MPPT with P&O and IC methods

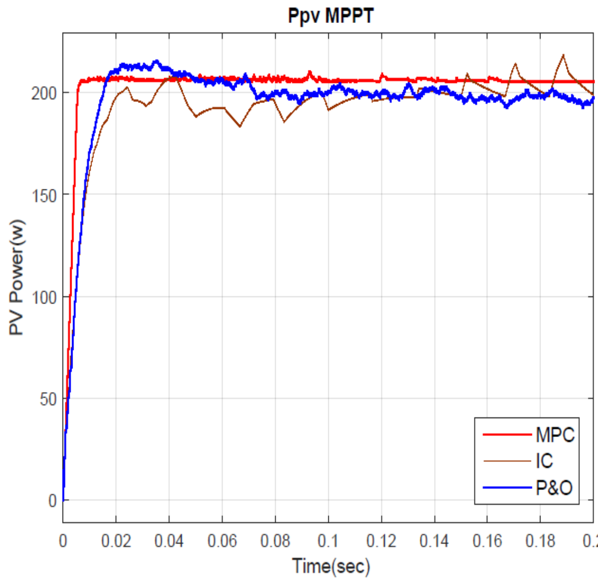

Fig. 9. Comparison PV power of MPC-MPPT with P&O and IC methods

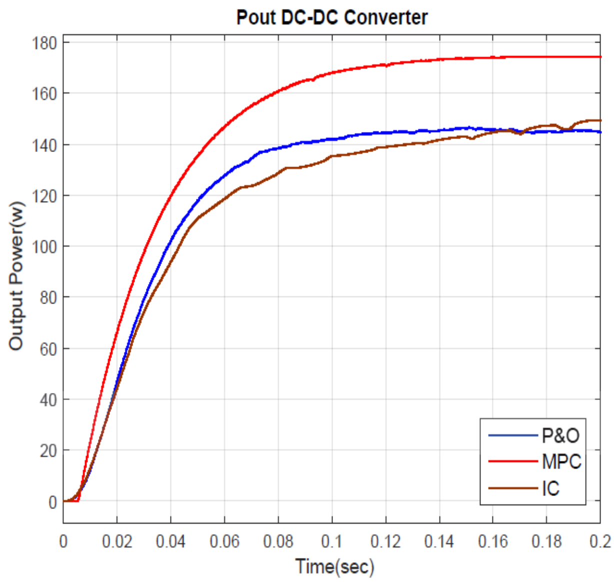

Fig10. Comparison output power of DC-DC converter for MPC-MPPT, P&O and IC method

4. Conclusion

In this paper, dynamic response of Model Predictive Controller(MPC) method is compared with conventional algorithms such as P&O and IC for Maximum Power Point Tracking (MPPT) under fast changes in irradiance. P&O and IC can not converge to the maximum power point in transient insolation conditions. To improve this algorithm, MPC is proposed by predicting the future error until the predifined horizon time. Simulation results show an improvement in speed and the efficiency of the MPP using the proposed method.

5. References

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