# Evaluation of Predictive Control Based MPPT Model to Enhance PV System

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*Abstract*—

Rapid growth and development of Solar PV has led to increasing demand of competitive technological solutions. One of the niche field in the solar PV technology is Maximum Power Point Technique (MPPT) algorithms and one of the most popular and robust algorithms which is used extensively is Perturb & Observe (P&O). Among several proposed MPPT techniques, the Perturbation and Observation (P&O) and Model Predictive Control (MPC) methods are adopted in this work. This paper enriches and explores an advanced MPPT model based on predictive control. A detailed study of implementing MPC is demonstrated on PV Module and high gain DC-DC boost converter simulated in MATLAB Simulink. And a comparative study of P&O and MPC technique is presented in this paper thus exploring the better algorithm to enhance the PV system with improved efficiency, robustness and simple yet effective control model.

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Keywords—

Boost Converter, Model Predictive Controller (MPC), Modelling, Perturb and observe, Solar PV.

## I. INTRODUCTION

With discriminable increase in the energy demand it seems that renewable energy is the only promising source in the near future[1]. Also with the increased environmental awareness and an attempt to fight global warming renewable energy resources are getting extended push from the world. Among renewable energy resources, interest in photovoltaic (PV) systems has been increased in last decades. Hence as engineers it is important to explore best possible technologies to reap maximum from the PV. In this paper, it is explained about the photovoltaic applications, the DC/DC power converters and the methods to track the maximum power point (MPPT) of the PV cell. A novel MPC algorithm is proposed and implemented in MATLAB Simulink [3].

The paper summarises a brief comparison of P & O algorithm and Model Predictive Controller in terms of response time and efficiency.

## II. MODELING OF PHOTOVOLTAIC SYSTEM

### A. General Topology of Photovoltaic System

To understand the generation of electricity from the solar PV system, it necessary to understand the material principle of PV cell. A PV cell is a nonlinear device whose parameters depend on major two factors, temperature and irradiation level of sunlight. In general PV panel is constructed through a number of PV cell connected in series or parallel and PV cell is made of semiconductor with p-n junction to absorb solar irradiation and convert it to electrical energy which is shown in Fig. 2.1.

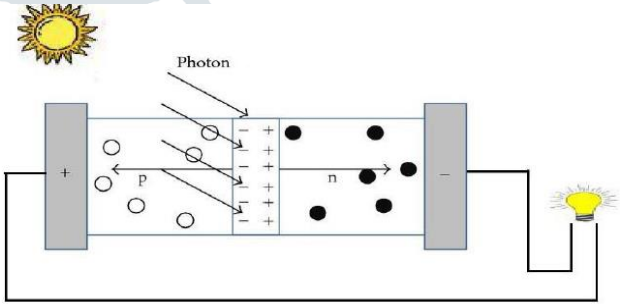


*Fig. 1 Electricity from Photons, basic working principle*

The voltage which is produced by solar energy can feed a DC load or connect to an inverter to generate AC voltage. Depending on the way that cells are connected, the model of photovoltaic array can be obtained

### B. Basics of Solar PV

The process of transforming light into electricity was proven to be known as photovoltaic effect. Solar Photovoltaic cells convert the solar light directly into usable solar electric power. These cells are thin layers of semiconducting materials that are charged differently between the top and the bottom layers. When exposed to sunlight electrons in this semiconducting material absorb the photons, causing the electrons to get highly energized.

A photovoltaic system is made of numerous solar PV arrays. An individual cell can generate up to 1 to 2 W of power depending on the material used. Higher power output can be obtained by connecting the PV cells together to form a module. The rating of the maximum power capacity of commercial module is 1 KW. Beyond this the power generation can be obtained by connecting appropriate solar modules in series and parallel to form PV arrays.

## III. Study Of P-V & I-V Characteristics

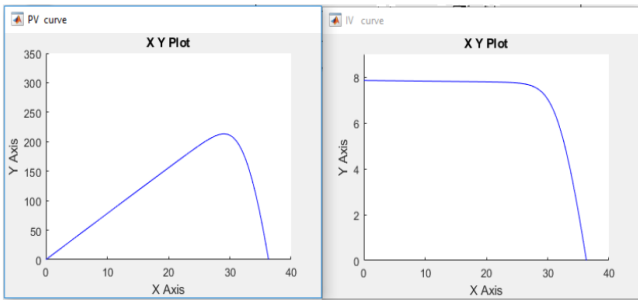


*Fig. 2 P-V & I-V Characteristics*

The operating characteristics of a PV panel depends on various environmental parameters such as solar irradiance, temperature and wind speed. Solar irradiance plays a major contribution on the power delivered by solar panel. The P-V and I-V curves characterise the behaviour of solar panel at different conditions. Fig 2.6 shows the I-V characteristics of PV panel at various irradiances. It is observed that as the solar irradiance decreases there is considerable drop in the current for same voltage. The current output of the solar panel is directly proportional to the power output of solar panel. Hence it is observed as the irradiance is decreased the maximum power output of the panel reduces, clearly indicated by the P-V curve in fig 2.7. Also, if one makes keen observation of the P-V curve it exhibits unique nature i.e. the solar PV panel is capable of delivering maximum power (*Pmpp*) only at a particular value of voltage and current identified as *Vmpp* and *Impp* respectively as represented in fig 2.8. Thus, it is known that the solar panel delivers maximum power to the load only for a particular load resistance *Rmpp*.

## IV. Maximum Power Point Tracking

Maximum Power Tracking is an electrical control technique in which maximum power from the wind or Solar PV can be extracted by controlling the power electronic converters implying different control algorithms.

### *A. Perturbation and Observation Method*

The main objective of maximum power point tracking technique is to track the maximum power of PV array under particular irradiance and temperature. Among all the techniques that were previously explained, perturbation and observation method (P&O) is the most common because of easy implementation and fewer required parameters but it has two main drawbacks, it is not fast enough and the oscillation around MPP. The procedure of P&O method is based on observation of the changes in terminal voltage and output power of PV array, comparison to the reference and decide for the next perturbation.

If there is an increment in the power, the perturbation is in the right direction and should be kept in the same direction but if there is a decrement in the perturbation, the perturbation is in the opposite direction and should be changed at the next step. Based on these facts, the maximum output power point of PV system can be obtained.

| Case | Condition | Position | Control Action |
|---|---|---|---|
| 1 | ΔP<0, ΔV<0 | Left of MPP | Increase perturbation |
| 2 | ΔP>0, ΔV>0 | Left of MPP | Increase perturbation |
| 3 | ΔP>0, ΔV<0 | Right of MPP | Decrease perturbation |
| 4 | ΔP<0, ΔV>0 | Right of MPP | Decrease perturbation |

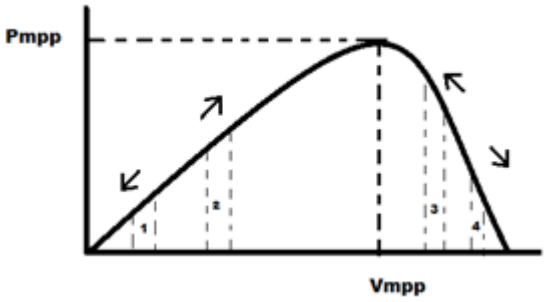


*Fig. 3 P-V curve indicating $P_{MPP}$ & $V_{MPP}$*

- P&O Method for MPPT on DC/DC Boost Converter and Simulation Results

The parameters that are measured in this method are photovoltaic voltage and photovoltaic current, then the power is calculated by using these two parameters. The sign of power indicates the location and the next control action to stay at MPP. The flow chart for P&O method is demonstrated in Fig. 4.2

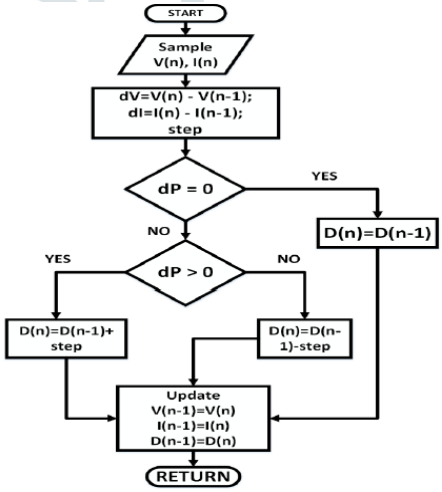


*Fig. 4 Flow chart for P&O algorithm*

As the solar irradiance and an environment temperature varies, the load characteristic which gives the maximum power of panel changes, so that it is crucial to find a new point which gives the maximum power for any changes in irradiance or temperature level and keep the load characteristics there.

The simulation results of P&O method and a proposed DC/DC converter is illustrated in following figures under different irradiance and temperature levels. The system has been tested under three irradiance level changes and three temperature level changes by rapidly and gradually change.

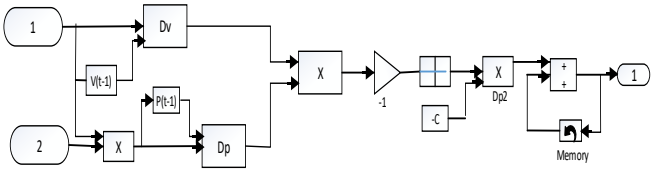


*Fig. 5 Implemented P&O control block in Simulink*

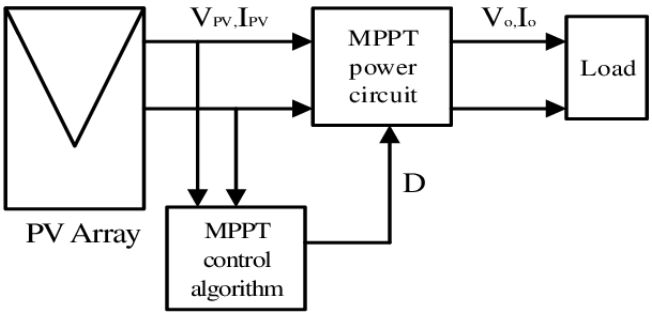


*Fig. 6 Block diagram for PV system*

PV panel is connected to resistive load through boost converter. Duty of boost converter is controlled using P & O algorithm as described in above section.
Result obtained from varying the resistance represented in below table.

*1) Observation & Results*

Maximum Power Point Tracking (MPPT) control is the main point in utilization of PV modules as a source of power generation. A maximum power point tracker (MPPT) is used for extracting the maximum power from the PV module and transferring this power to the load. As mentioned previously, dc-dc converter (step up or step down) is required to serve the

| Load R | Available Power | Duty | output Power | Output voltage |
|---|---|---|---|---|
| 10 | 204.8 | 0.32 | 202.7 | 45.02 |
| 20 | 208.1 | 0.5 | 198 | 62.93 |
| 30 | 208.6 | 0.59 | 197 | 76.87 |
| 40 | 208.2 | 0.64 | 196.6 | 88.69 |
| 50 | 209.5 | 0.66 | 197 | 99.25 |
| 60 | 207.5 | 0.7 | 194.1 | 107.9 |
| 70 | 207.9 | 0.72 | 193.3 | 116.3 |
| 80 | 209.5 | 0.74 | 192.3 | 124 |
| 90 | 210 | 0.75 | 191.6 | 131.3 |
| 100 | 210.8 | 0.77 | 189.4 | 137.6 |

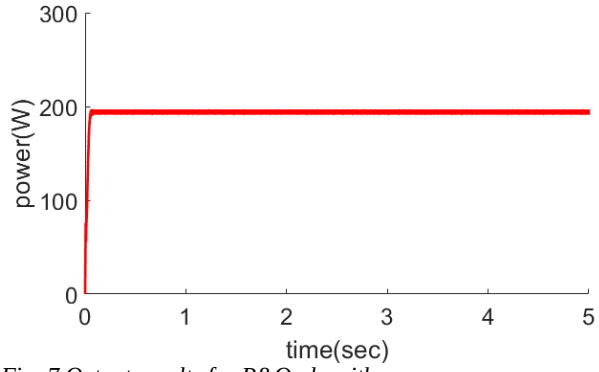


*Fig. 7 Output results for P&O algorithm*

purpose of transferring maximum power from the PV module to the load. A dc-dc converter acts as an interface between the load and the module. By changing the duty cycle, the load impedance as seen by the source is varied and matched at the point of the peak power with the source to transfer the maximum power.

*B. Model Predictive Control Based MPPT*

In this section, we will be discussing the differences between P&O algorithm and the Model Predictive Control
(MPC) based P&O. Also, we will discuss in detail the Algorithm for the current reference generation for the MPC-P&O.

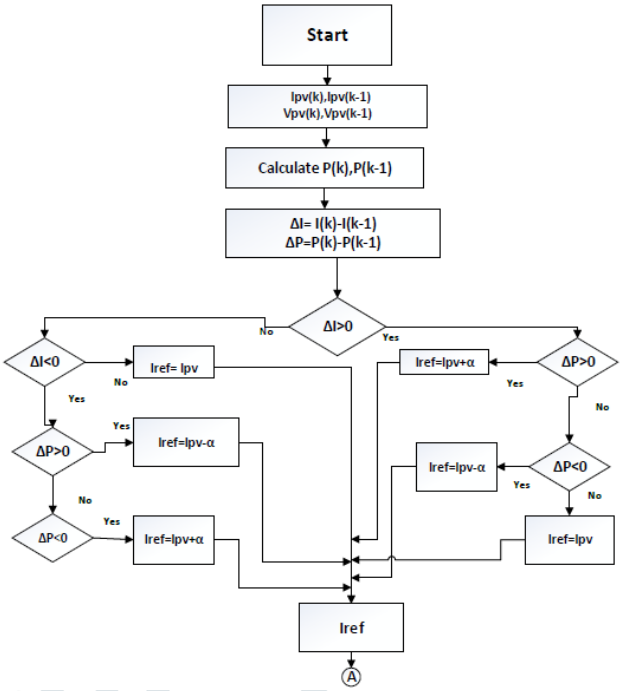


*Fig. 8 Flowchart for MPC algorithm part – 1*

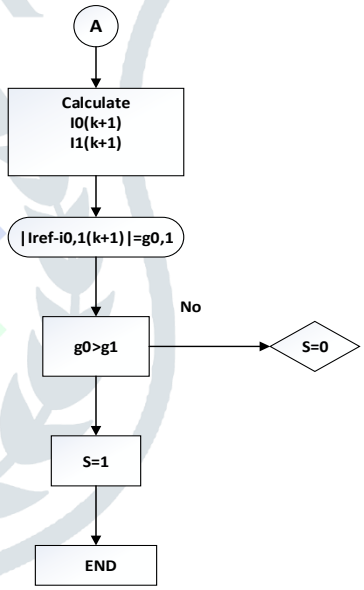


*Fig. 9 Flowchart for MPC algorithm part – 2*

In above flowchart, first stage is to generate reference current from P & O, beacause MPC requires some reference [2]. Then only it can track maximum power from PV. There are three conditions to generate reference current Iref as follows:

- If $\Delta I$ <0, $\Delta P$ >0; $Iref = I_{PV} - \alpha$ (Duty ratio Decreases)
- If $\Delta I < 0, \Delta P < 0$; $Iref = I_{PV} + \alpha$ (Duty ratio Increases)
- If $\Delta P = 0$; $Iref = I_{PV}$

**Equation for boost converter when switch is ON**

$$I_{PV}(k+1) = \frac{Ts}{L} V_{PV}(k) - \frac{Ts}{L} Vc(k) + I_{Pv}(k) \ldots (1)$$

$$Vc(k+1) = \frac{1}{c} I_{PV} - \frac{1}{RC} Vc(k) + Vc(k) \ldots (2)$$

$$V_{PV}(k+1) = \frac{L}{Ts} (I_{PV}(k+1) - I_{PV}(k)) + Vc(k) \ldots (3)$$

**Equation for boost converter when switch is OFF**

$$I_{PV}(k+1) = \frac{Ts}{L} V_{PV}(k) + I_{PV}(k) \ldots (4)$$

$$Vc(k+1) = \left(1 - \frac{Ts}{Rc}\right) Vc(k) \ldots (5)$$

$$V_{PV}(k+1) = \frac{L}{Ts} (I_{PV}(k+1) - I_{PV}(k) \ldots (6)$$

By using these equations (1) to (6) future value of current predicted ON & OFF and compared with reference value to calculate its cost function. The state which gives minimum cost is considered. The new duty cycle can be determined from the difference between the predicted and reference value as follows,

If difference is greater, then switch is to be ON and duty ratio is incremented.

If difference is less, then switch is to be OFF and duty ratio is decremented.

By increasing the number of predictions, the computation time will be increased but better control performance can be achieved. For the next predictions of the current, Vc an d Vpv at Previous step is to be available.

Equations 2,3,5,6 will determine the voltage for predicting the next current value.

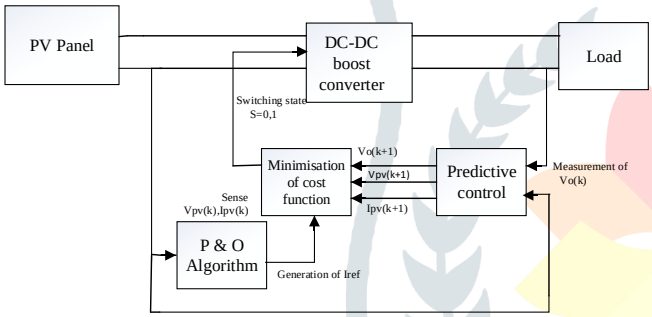


*Fig. 10 Simulation block diagram for PV system with MPC*

*1) Observations & Results*

| Load R | PV voltage | PV current | Power | Output I | Output V | Pmax | Duty |
|---|---|---|---|---|---|---|---|
| 10 | 28.62 | 7.43 | 212.7 | 4.53 | 45.3 | 205.2 | 0.38 |
| 20 | 32.37 | 5.38 | 174.3 | 2.59 | 51.98 | 135.1 | 0.46 |
| 30 | 28.76 | 7.39 | 212.8 | 2.63 | 78.94 | 207.7 | 0.62 |
| 40 | 28.81 | 7.38 | 212.9 | 2.26 | 90.6 | 205.5 | 0.67 |
| 50 | 28.74 | 7.4 | 212.8 | 2.02 | 101.1 | 204.3 | 0.7 |
| 60 | 28.84 | 7.38 | 212.9 | 1.84 | 110.7 | 204.1 | 0.72 |
| 70 | 28.92 | 7.36 | 212.9 | 1.7 | 119.2 | 203.1 | 0.75 |
| 80 | 28.99 | 7.33 | 212.8 | 1.59 | 127.2 | 202.3 | 0.77 |
| 90 | 28.9 | 7.36 | 212.8 | 1.49 | 134.7 | 201.7 | 0.77 |

In above observation table, It tracks maximum power from MPC for PV. Available power is constant for each load.

$I_{PV}$ checks current value of next instant. Different between switch on and off, it decides the reference value of current. With the help of switch ON and switch Off, it takes absolute value.

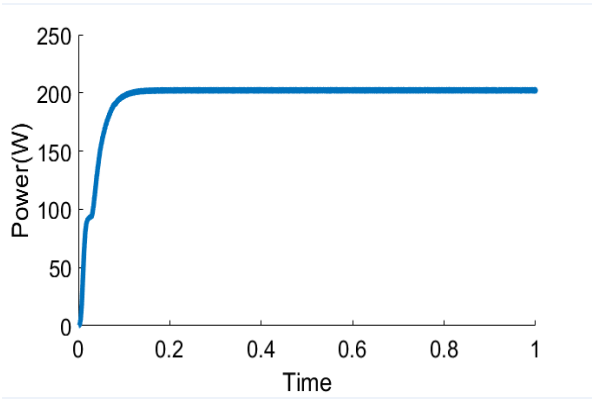


*Fig. 11 Output results for MPC algorithm*

*Comparison of P & O and MPC:*

| Method | Rise Time | Settling Time | Efficiency |
|---|---|---|---|
| **P & O** | 18msec | 40msec | 94.42% |
| **MPC** | 7msec | 18msec | 97.52% |

## V. Conclusion

P&O is a well-known technique with relatively good performance; however, P&O method cannot always converge to the true maximum power point. Also, the performance of P&O technique under dynamic weather condition may not be satisfactory. Performance of MPPT can be improved by implementing MPC with P & O. In this report, MPC is mathematically formulated and its performance is compared with P & O method. It is observed that tracking is faster with MPC and also extracted power is more with MPC as compared to P & O

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