Incremental Conductance MPPT Method For Photovoltaic System

Soham Ghosh, Venmathi Mahendran
[1]Dr. MGR Educational and Research Institute, Chennai, India
[2]Senior Lecturer, Dr. MGR Educational and Research Institute, Chennai, India

Abstract

Solar power being a renewable energy resource has tremendous potential of usage in the imminent future and this paper is going to discuss an effective strategy to maximize solar energy harvest. This study has been done using MATLAB/Simulink combining solar modules, incremental conductance MPPT algorithm block and boost converter control block. Though solar energy harvest is dependent of irradiance, temperature and other climatic conditions it is imperative that a photovoltaic system operates at a maximum power point (MPP) in order to extract maximum energy from the system. The incremental conductance algorithm is an energy optimization strategy that provides fast dynamic response and well regulated photovoltaic (PV) output voltages. In addition, the number of parameter needed to be monitored are significantly lower than other algorithms, making the implementation much more streamlined and cost effective. This paper is going to discuss the observations of maximum power point tracking implemented on a solar power grid, thus augmenting its efficiency.

Keywords— perturb-and-observe, maximum power point tracking, incremental conductance, boost converter.

I. INTRODUCTION

There has been a rapid depletion in fossil fuel reserves and a concomitant rise in the demand of alternate renewable energy in recent times. Solar power, wind energy and tidal energy promises to be the most dominant energy resources for the imminent future. According to a recent projection by the International Energy Agency, solar power generators may produce most of the world's electricity within the next fifty years, thus dramatically reducing the greenhouse gases that threats the environment of irreversible climatic changes. Moreover, there is an increased market for low power electronics devices located in remote locations, away from power grids that rely solely on solar energy.

Unfortunately, usage of solar energy systems are limited because the conversion efficiency of the solar array based systems are low (typically lies in the range of 17- 20 %) and the power generated by solar arrays changes continuously with varying weather condition. Moreover it is to be noted that the voltage-current characteristic curve of a typical solar cell is non-linear and varies with external environmental factors. In general there is a unique point in the voltage-current characteristic curve, called the Maximum Power Point at which the solar array operates with maximum efficiency. Any deviation from this specific point results in a decrease in the output power extracted from the system. Through rigorous search algorithms this point can be located and the system can be made to operate in this point.

A. Other prevalent algorithm

There are about eighteen different algorithm to implement Maximum Power Point tracking each with different strategy and performance. Some of the prevalent methods apart from the incremental conductance method are linear approximation method, perturb-and -observe method (P&O), hill climbing method and fuzzy control method [1]. Methods as DSP controlled PV system with peak power tracking ability has also been improvise which gives one an efficient maximum power point tracking at a nugatory cost.

II. OVERVIEW OF MAXIMUM POWER POINT TRACKING

Peak power point tracking is an effective strategy to increase the power output of a PV system. From Fig. 1 it can be noted that not at all operating conditions, the system delivers the maximum power, which is due to the non-linear nature of the current-voltage characteristic curve. Only at a particular condition of voltage and current, the power output of the system is maximum. Thus, irrespective of irradiance and temperature, it is imperative that this maximum power point (MPP) is tracked by suitable algorithm [2].

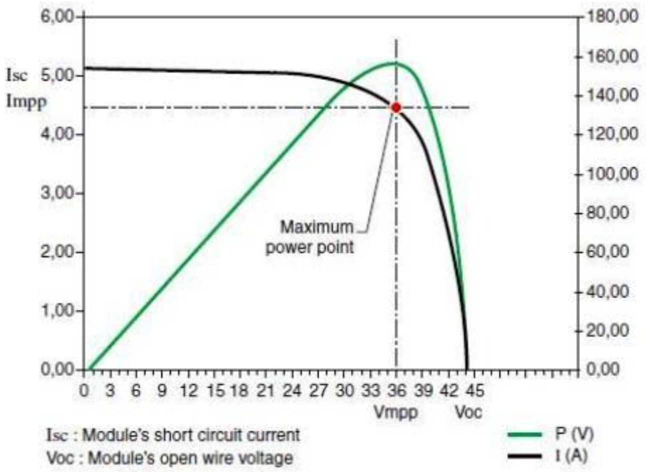

Fig. 1 A typical voltage-current characteristic of a solar panel with the red dot indicating maximum available power.

III. INCREMENTAL CONDUCTANCE METHOD

The theory behind the incremental conductance method [3-5] (IC) is to determine the terminal voltage of the PV module by measuring and comparing the incremental and instantaneous conductance of the PV module. If it is observed that the incremental conductance is equal to the instantaneous conductance, it indicates that the maximum power point is found.

It has been observed that within operating limits, output power increases with increasing terminal voltage of the PV module (slope of the power curve is positive, dP/dV >0). On the contrary, at operating points past MPP there is a decrease in the output power with an increase in terminal voltage of the PV modules (the slope of the power curve is negative, dP/dV <0). When the operating point is exactly at the MPP, the slope of the curve as expected is zero. These observations are graphically represented in Fig. 2.

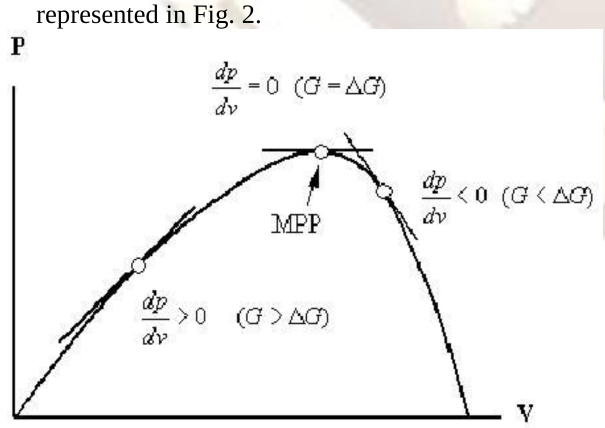

Fig. 2 A schematic representation of the power curve and the slope at the maximum power point.

From the concepts of differential equations, it follows that

$$\frac{dP}{dV} = \frac{d(VI)}{dV} = I\frac{dV}{dV} + V\frac{dI}{dV} = I + V\frac{dI}{dV} \quad (1)$$

During MPP scenario, as observed from Fig. 2 dP/dV = 0. Thus the expression (2) can be rearranged as follows,

$$\frac{dP}{dV} = I + V\frac{dI}{dV} = 0$$

$$\frac{dI}{dV} = -\frac{I}{V} \quad (2)$$

(3)

Defining the terms static conductance (Gs) and dynamic/incremental conductance (Gd) as follows,

$$Gs = -\frac{I}{V} \quad (4)$$

$$Gd = \frac{dI}{dV} \quad (5)$$

From the expressions above, it follows that during MPP scenario, Gs = Gd where V=Vm. Further from the Fig. 2 it can be stated that:

$$\frac{dP}{dV} > 0; Gd > Gs; \frac{dI}{dV} > -\frac{I}{V} \quad (6)$$

$$\frac{dP}{dV} < 0; Gd < Gs; \frac{dI}{dV} < -\frac{I}{V} \quad (7)$$

Expression (6) and (7) are used to locate the peak power point and once the point is located through iterative perturbation, expression (3) holds good.

From the flow diagram in Fig. 3 it can be observed that if dV=0 but dI>0, the solar irradiance has increased and voltage at the maximum power point rises. Thus, the operating voltage of the PV module has to be increased in order to track the maximum power point. On the contrary, if the solar irradiation decreases, voltage at the maximum power point falls. The operating voltage at this point needs to be decreased.

In addition, when the voltage and current of the PV array changes and expression (6) holds good, the operating voltage is located at the left of the maximum power point and thus needs to be increased. Similarly if expression (7) holds good at any point of time the operating voltage of the PV array will be located at the right of the maximum power point and thus the operating voltage needs to be decreased.

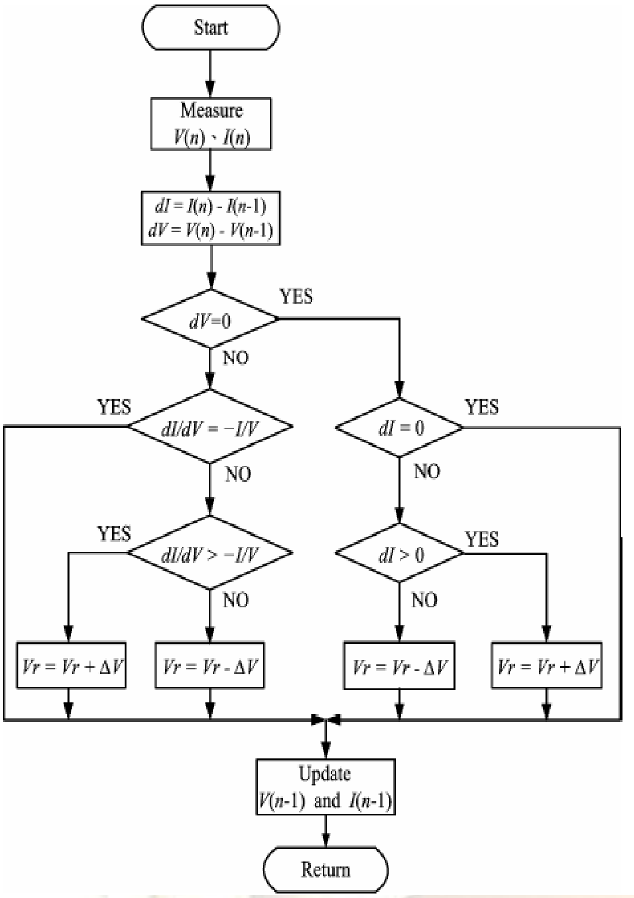

Fig. 3 The flow diagram of incremental conductance method.

One of the major advantages [6-7] of the incremental conductance method is that it can determine the exact direction of perturbation at any point of time. In addition many perturbation phenomena as operating point oscillation around the MPP is avoided by using the incremental conductance method.

IV. Implementation and Simulation Details of MATLAB/Simulink Blocks

For simulation of the above algorithm a MATLAB/Simulink model of a 100 kW PV array connected to a 25kV grid via a DC-DC boost converter was generated. Maximum Power Point Tracking was implemented in the boost converter by means of a Simulink model using incremental conductance technique. The PV module used in the system is a SunPower SPR-305-WHT module with the following specification as tabulated in Table. 1.

TABLE I
ELECTRICAL SPECIFICATION OF THE IMPLEMENTED SUNPOWER PV MODULE

ITEM	VALUE
STC Power per unit area	186.9 W/m^2
Number of cells	96
Peak Efficiency	18.7%
Maximum System Voltage	600V
V_{mp} and I_{mp}	54.7 V and 5.58 A

The Simulink model used for the above simulation has the following specifications:

- The PV delivers a maximum of 100 kW power at 1000W/m^2 of solar irradiance.
- A 5 kHz boost converter increasing the PV modules in-build voltage level (272 V DC at maximum power) to 500 V DC. Switching of the duty cycle of the converter is optimized by MPPT controller that uses the incremental conductance technique.
- A 1980 Hz 3-level 3-phase voltage source converter. This voltage source converter converts the 500 V to 260 V and keeps unity power factor.
- 10-kvar capacitor filter banks filtering harmonics generated by the voltage source converter.
- 100-kVA 206V/25KV three-phase coupling transformer.
- Utility grid model (25-kV distribution feeder + 120 kV equivalent transmission system).

A block diagram of the Boost converter control is show in Fig.4. An internal regulator minimizes the error in the expression (1).

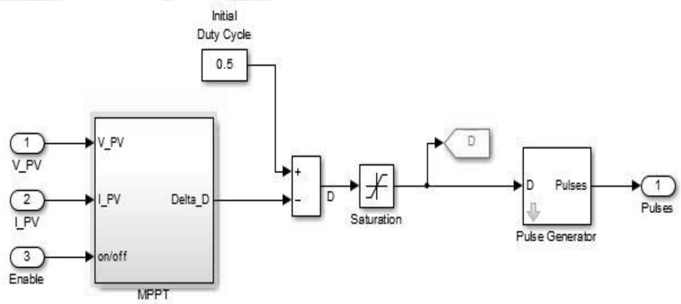

Fig. 4 The figure shows the MATLAB/Simulink block of a MPPT controller with a subsystem.

V. Simulation Results and Discussion

The simulation of the MATLAB/Simulink system was carried out for a time period of three seconds at a few varying conditions and the following observations are made:

- At t= 0.4 sec MPPT block enabled. The MPPT regulator starts regulating the PV voltage by varying the duty cycle in order to extract maximum power. At t= 0.25 sec PV array output power (P_{mean}) is 96 KW whereas at t= 0.6 sec a maximum power (P_{mean}) of 100.7 KW is obtained since the MPPT block is enabled. At this point, the PV mean voltage is 274V, as recorded by the Fig.5. The duty cycle (D) at this condition is equal to 0.453.
- From t=0.7 sec to t=1.2 sec, solar irradiance is ramped down from 1000 W/m^2 to 250 W/m^2. The duty cycle (D) equals 0.485. The corresponding system voltage and power are V_{mean} = 255V and P_{mean}= 22.6 kW. It is to noted that MPPT algorithm continues to track maximum power during this fast irradiance change.
- From t= 1.5 sec to 3 sec various irradiance changes are applied in the form of ramp signals to the irradiance (I_r) signal channel in order to illustrate the good performance of the MPPT controller.
- The simulation time in MATLAB/Simulink can be considerably decreased by using the 'Accelerator' mode instead of the 'Normal' simulation mode.

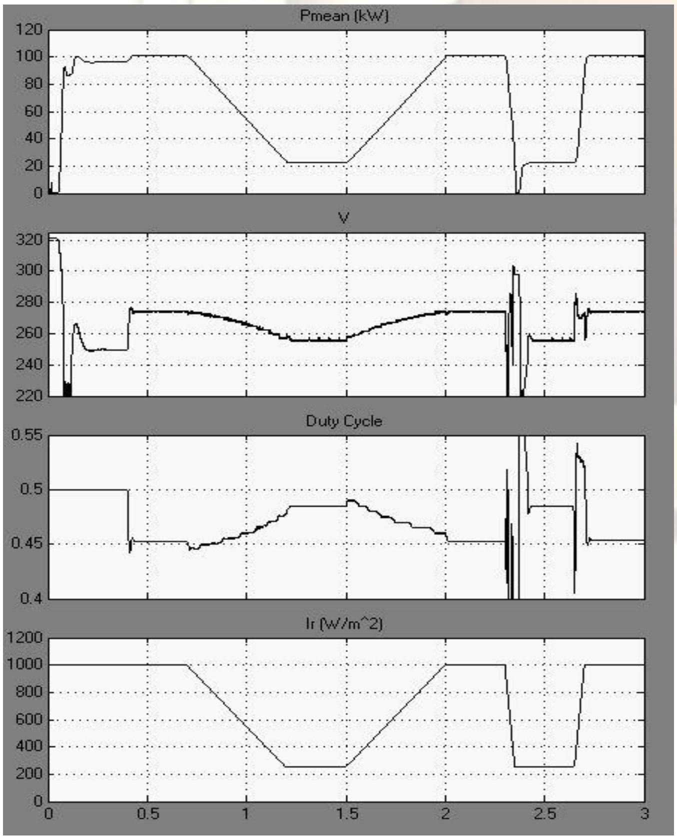

Fig. 5 The figure shows the MATLAB/Simulink output of the PV system optimized with incremental conductance MPPT method.

VI. CONCLUSIONS

The paper presents a comprehensive study of an effective strategy to augment the efficiency of a PV array-grid system, thus allowing the system to capture a higher amount of solar power. For simulation purpose a 100 W solar array was used which worked in tandem with a DC-DC converter and a subsystem of MPPT control block. Though output power depends on solar irradiance, a significant increase in the harvesting power can be achieved with MPPT technique. According to the results obtained in Fig.5 there has been a noted increase in the power harnessed by the system once the MPPT control block is enabled. The results obtained and the observations made can be extended to implement other prevalent MPPT algorithms as well.

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