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Design and Implementation of Maximum Power Point Tracking (MPPT) Algorithm for a Standalone PV System

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Abstract- Maximum power point trackers (MPPTs) play a vital role in photovoltaic (PV) systems because they increase the efficiency of the solar photovoltaic system by increasing the power output. MPPT algorithms are necessary because PV arrays have a non linear voltage-current characteristic with a unique point where the power produced is maximum. The output power from the solar panel varies with solar irradiance, temperature and so on. To increase the power extracted from the solar panel, it is necessary to operate the photovoltaic (PV) system at the maximum power point (MPP).This paper presents the Matlab/simulink arrangement of perturb& observe (P&O) and incremental conductance (INC) MPPT algorithm which is responsible for driving the dc-dc boost converter to track maximum power point (MPP). This paper also presents the theoretical analysis of variable step size(VSS) of INC MPPT which can effectively improve the tracking speed and accuracy of maximum power.

Index Terms : PV, MPPT, P&O, Incremental Conductance (INC),VSS INC

1 INTRODUCTION

Energy is the prime mover of economic growth and is vital to the sustenance of a modern economy. Future economic growth crucially depends on the long-term availability of energy from sources that are affordable, accessible and environmentally friendly. Government, industry and independent analyses have shown that cost-effective energy efficiency improvements could reduce electricity use by 27% to 75% of total national use within 10-20 years without impacting quality of life or manufacturingoutput. Besides India is world's 6th largest electrical energy consumer, accounting 3.4% of global energy consumption. The present installed power generation capacity of India stands at1, 85,496.62MW as on 31.11.2011. About 66% of the electricity consumed in India is generated by thermal power plants and 20.88% by hydroelectric power plants and 2.57% by nuclear power plants and 11.2% from renewable energy sources.According to a 2011 projection by the International Energy Agency, solar power generators may produce most of the world's electricity within next 50 years, dramatically reducing the emissions of greenhouse gases that harm the environment.

Photovoltaic and solar-thermal plants may meet most of the world's demand for electricity by 2060 and half of all energy needs with wind, hydropower and biomass plants supplying much of the remaining generation.

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Photovoltaic and concentrated solar power together can become the major source of electricity.India receives solar energy equivalent to over 5,000 trillion kWh per year. The daily average solar energy incident over India varies from 4 -7 kWh per square meter per day depending upon the location. Solar photovoltaic (PV) energy is nowadays one of the most important available resources because is free,abundant, and pollution-free and distributed all over the world. Unfortunately, PV generation systems have two majorproblems: the conversion efficiency of electric powergeneration is low (in general less than 17%, especially under low irradiation conditions), and the amount of electric power generated by solar arrays changes continuously with weather conditions.Moreover, the solar cell V-I characteristic is nonlinear and varies with irradiation and temperature. In general, there is a unique point on the V-I or V-P curve, called the Maximum Power Point (MPP), at which the entire PV system (array, converter, etc.,) operates with maximum efficiency and produces its maximum output power. The location of the MPP is not known, but can be located, either through calculation models or by search algorithms. Therefore Maximum Power Point Tracking (MPPT) techniques are needed to maintain the PV array's operating point at its MPP. The P&O, incremental conductance (INC) method are the most known methods to track the MPP byupdating repeatedly the operating voltage of the PV array varying the duty cycle of the power converter with a fixed step size. Even though the solar energy is present throughout the day but the solar irradiation levels vary continuously due to sun intensity on the solar panel varies continuous due to the variation in direct and diffused radiation falling on the solar panel and also because of the unpredictable shadows cast by clouds, birds, trees, etc. The common inherent drawback of wind and photovoltaic systemsare their intermittent natures that make them unreliable. However, by incorporating maximum power point tracking (MPPT) algorithms, the photovoltaic system's power transfer efficiency andreliability can be improved significantly as it can continuously maintain the operatingpoint of the solar panel at the MPP pertaining to that irradiation and temperature and so on as shown in Fig.1.

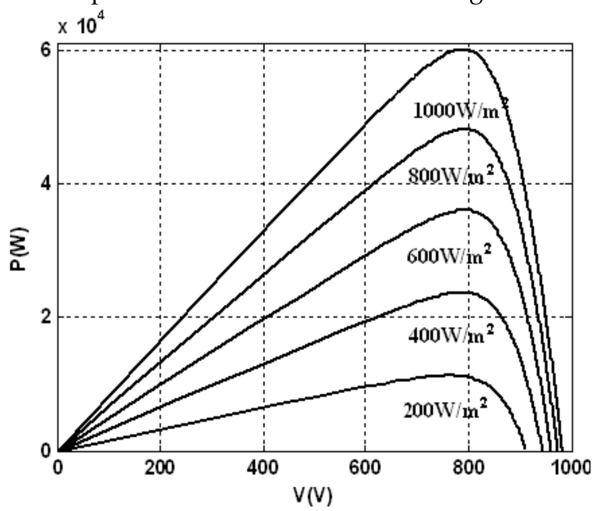

Fig.1 Power-voltage characteristics of photovoltaic module at different irradiance levels

The output power of a PV cell is indeed a non linear function of the operating voltage and this function has a maximum power point (mpp) corresponding to a particular value of voltage. In order to operate at the MPP, an energy power converter must be connected at the output of a PV array, such converter forces the output voltage of the PV array is equal to the optimal value, also taking into account the atmospheric condition.

2PHOTOVOLTAIC MODULE

A general simulation model of photovoltaic cells is adopted proposed by [3] in this paper. The typical model of a solar cell is shown in Fig. 2

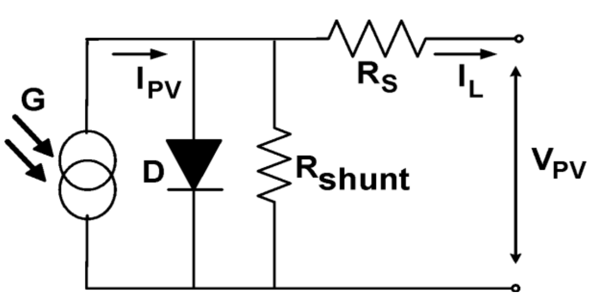

Fig. 2 Equivalent circuit model of PV cell

$$I_c = I_{ph} - I_o\left\{exp\left[\frac{q(V+RI_s)}{AKT}\right] - 1\right\} - (V + IR_s)/R_{sh}(1)$$

I_{ph}: Photocurrent.

I_d: Current of parallel diode.

I_{sh}: Shunt current.

I_c: Output current.

V: Output voltage.

D: Parallel diode.

R_{sh}: Parallel resistance.

R_s: Series resistance.

A Single diode model based PV module considering constant insolation and temperature is developed in Simulink. This module is used as a source for the maximum power point tracker system. The proposed solar panel hasbeen modelled and simulated using the MATLAB/Simulink as shown inFig.3

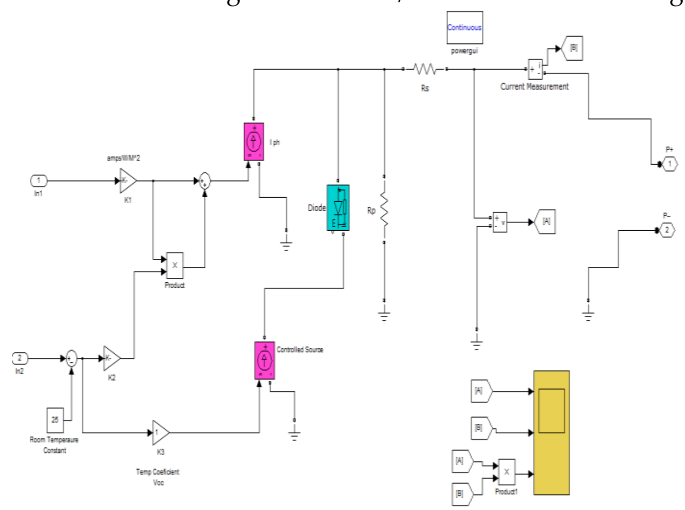

Fig. 3 Simulink model of PV cell (constant irradiation)

As the insolation and temperature is kept constant, the output voltage, current is constant as shown in Fig.4

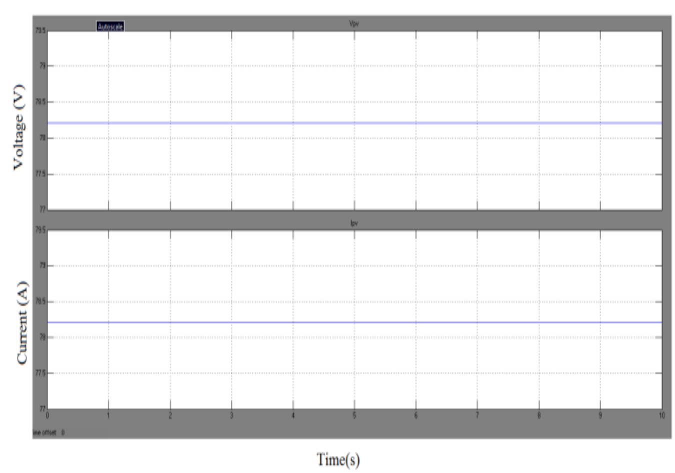

Fig. 4 Voltage, Current output of PV cell under constant radiation

The power output obtained under constant radiation of the proposed PV model is shown in Fig. 5

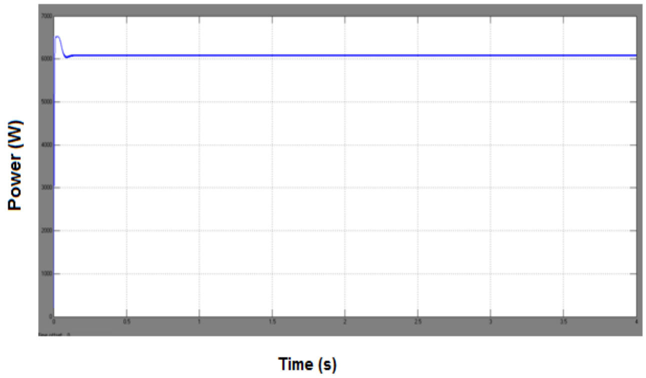

Fig. 5 Power output of PV cell under constant radiation

During the start of the system, the controller varies the duty cycle 'α' to increase the power output, when the MPP is reached, the controller maintains a constant duty cycle which can be evidenced in the PWM signal generated by the controller as shown in Fig. 6.

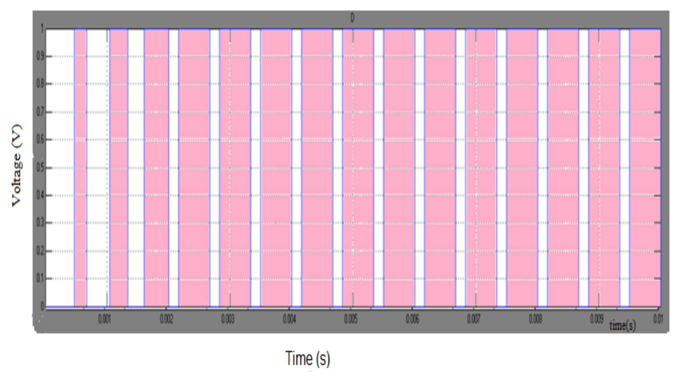

Fig. 6Duty cycle variation

As constant insolation and temperature are not practically possible due to natural changes in weather, a solar cell or PV model with varying insolation and temperature were also designed. The variation in the inputs such as insolation and temperature are applied using repeatingsequence stair.

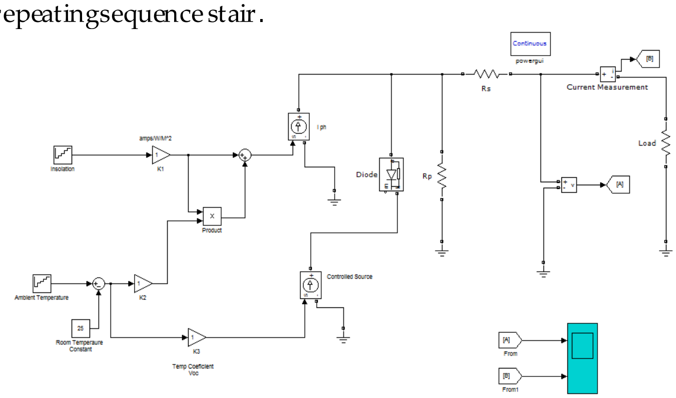

Fig. 7 Simulink model of PV cell (different radiation)

The Simulink model in Fig.7 takes in to consideration the variation of temperature and insolation.

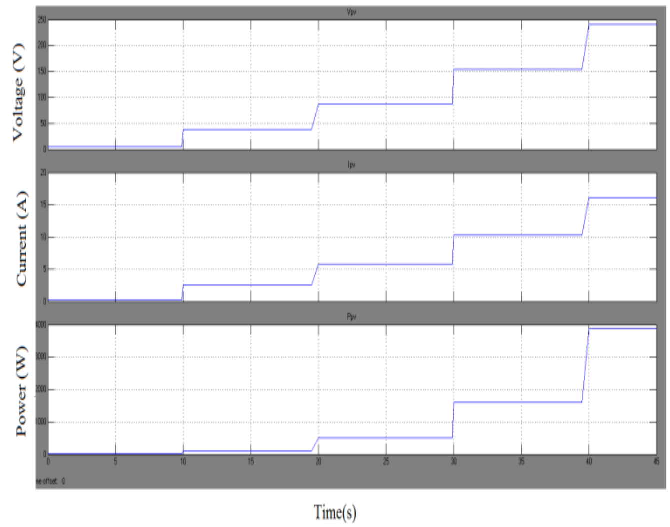

Fig. 8 Voltage, Current, Poweroutput of PV cell under different radiation

On the basis of this model, the output characteristics of PV are simulated and shown in Fig. 8, using MATLAB/Simulink. The insolation change affects the photon generated current and has very little effect on the open circuit voltage. Whereas the temperature variation affects the open circuit voltage and the short circuit current varies very marginally.

3MAXIMUM POWER POINT TRACKING

A typical solar panel converts only 30 to 40 percent of the incident solar irradiation intoelectrical energy. Maximum power point tracking technique is used to improve the efficiency of the solar panel. According to Maximum Power Transfer theorem, the power output of a circuit is maximumwhen the source impedance matches with the loadimpedance. In the source side a boost converter is connected to a solar panel in order to enhance the output voltage. By changing the duty cycle of the boost converter appropriately the source impedance is matched with that of the load impedance.Several approaches have been proposed for tracking the MPP [4]. Among those methods, the perturb and observe (P&O) and incremental conductance (INC) methods are widely usedalthough they have some problems such as the oscillation around MPP and confusion by rapidly changing atmospheric conditions [6,7]. In general, these tracking approaches use a fixed iteration step size, which is determined by the accuracy and tracking speed requirement.

3.1 PERTURB& Observe (P&O) method

The most commonly used MPPT algorithm is the P&Odue to its simplicity of implementation.However, it has

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some drawbacks, like oscillations around theMPP in steady state operation and also slow response speed at the event of changes in solar irradiance.Fig. 9 shows the algorithm of P&O.

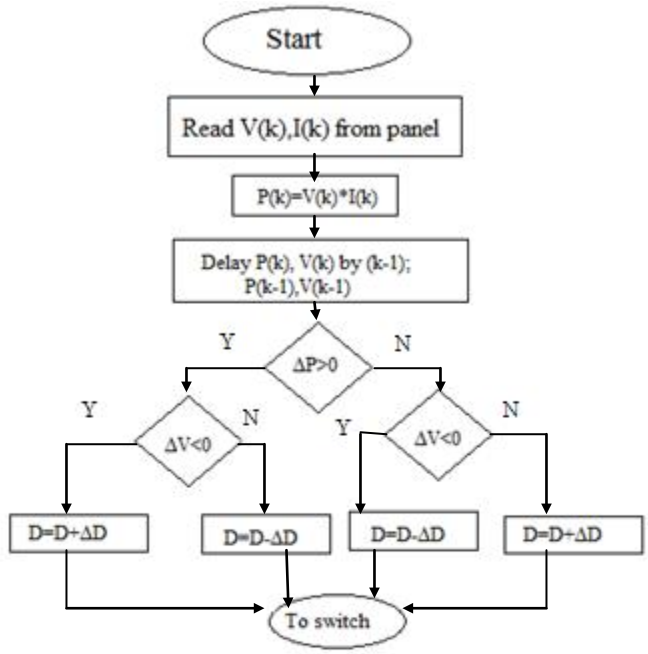

Fig.9 Flow chart of P&O MPPT Algorithm

P&O algorithm is based on the calculation of the PV array output power and the power change by sensing both the PV current and voltage. The controller operates periodically by comparing the present value of the power output with the previous value to determine the change on the solar array voltage or current. The algorithm reads the value of current and voltage at the output solar PV module. Power iscalculated from the measured voltage and current. The magnitude of voltage and power at k^{th} instant are stored. Then the magnitude of power and voltage at $(k+1)^{th}$ instant are measured again and power is calculated from themeasured values.

If the magnitude of power is increasing, the perturbation will continue in the same direction in the next cycle, otherwise the perturbation direction is reversed. When the MPP is reached, the system then oscillates around the MPP. In order to minimize the oscillation, the perturbation step size should be reduced such that when the operating point is away from the MPP, the step change in duty cycle should be large, when it nears the MPP, the step change in'α' should reduce.The simulation of output of P&O MPPT algorithm at varying irradiance condition is shown in Fig. 10

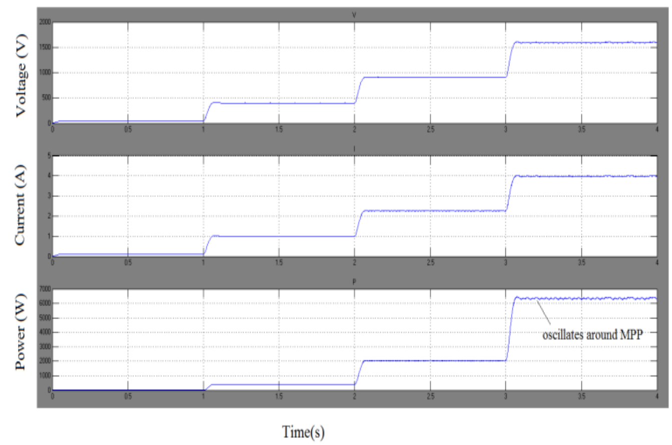

Fig.10 Voltage, Current, Power output of P&O MPPT algorithm

3.2 INCREMENTAL CONDUCTANCE

The incremental conductance (INC) method is based on the fact that the slope of the PV array power curve is zero at the MPP also positive on the left of the MPP and negative on the right, as given by the following equation and corresponding characteristics is shown in Fig. 11.

$$\frac{dP}{dV} = 0,\ at\ MPP$$
$$\frac{dP}{dV} > 0\ ,\ left\ of\ MPP$$
$$\frac{dP}{dV} < 0,\ right\ of\ MPP$$

$$\frac{dP}{dV} = \frac{d(IV)}{dV} = I + V.\frac{dI}{dV} = I + V.\frac{\Delta I}{\Delta V} \qquad (2)$$

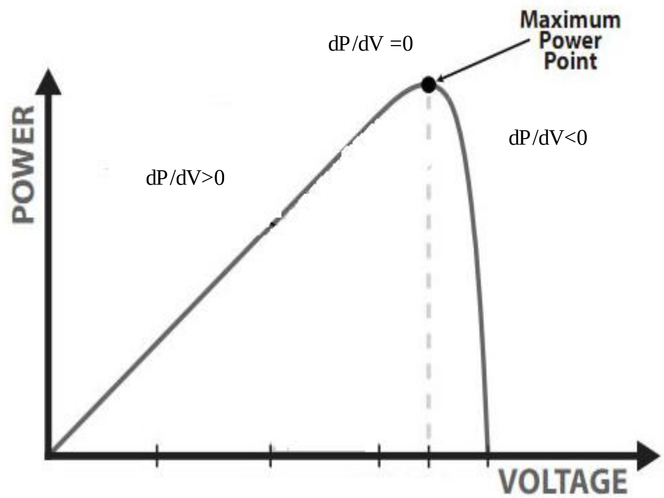

Fig.11Typical power-voltage characteristics of PV array

$$\frac{\Delta I}{\Delta V} = -\frac{I}{V},atMPP$$

ISSN 2229-5518

$$\frac{\Delta I}{\Delta V} > -\frac{I}{V}, left of MPP$$

$$\frac{\Delta I}{\Delta V} < -\frac{I}{V}, right of MPP$$

Fig.12 represents the flowchart for INC MPPT algorithm. The PV array terminal voltage can be adjusted relative to the MPP voltage by measuring the incremental conductance (I/V) and instantaneous conductance ($\Delta I/\Delta V$). Once the MPP is reached, the operation of thePV array is maintained at this point unless a change in ΔI is noted. Incase of dP/dV>0, the voltage is increased and in case of dP/dV<0, the voltage is decreased to select the MPP.

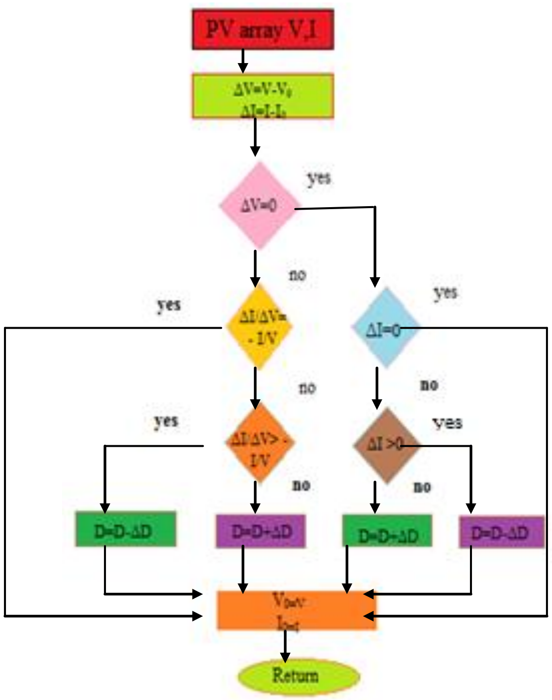

Fig.12 Flow chart of INC MPPT Algorithm

A maximum power point (MPP) tracker is designed by the combination of incremental conductance algorithm [4],[11] Which triggers the duty cycle of the DC/DC converter. Bychanging the duty cycle of converter, the PV panel is made to deliver the maximum power at that irradiance to the load. The Matlab/simulinkmodel of Incremental conductance algorithm to track maximum power output, along with a DC/DC boost converter is shown in Fig. 13.

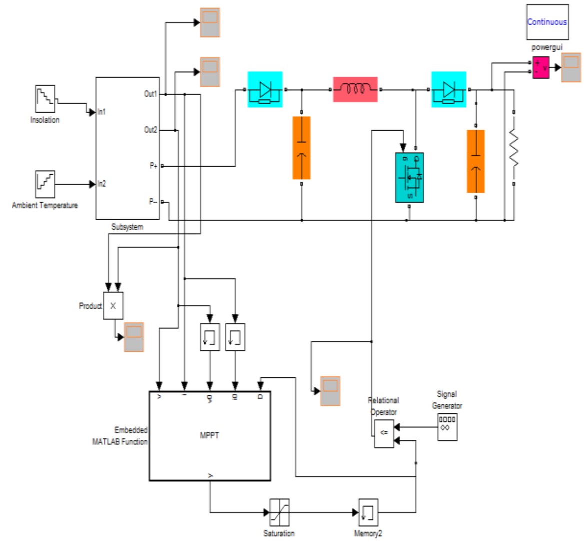

Fig .13 Matlab/Simulink arrangement of Incremental conductancealgorithm.

The voltage, current, power output of the Incremental Conductance MPPT algorithm under varying irradiance and temperature condition is shown in Fig. 14

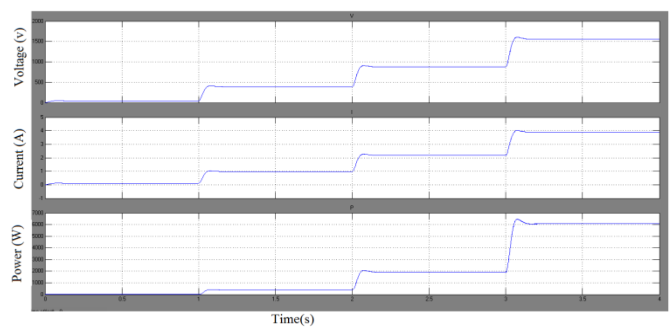

Fig. 14 Voltage, Current, Power characteristics of INC MPPT algorithm

The MPPT controller adjusts the duty cycle of the boost converter on the event of any change in the irradiance to deliver maximum power possible. The variation of duty cycle in fixed step size corresponding to the change in insolation and temperature is shown at time t (sec) in Fig. 15.

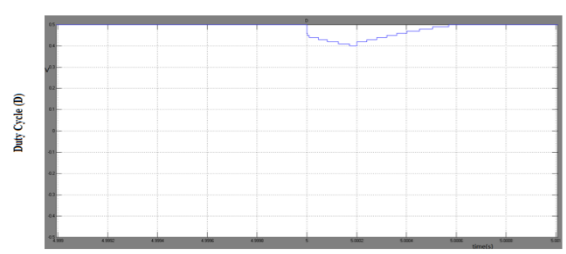

Fig. 15 Variation in Duty cycle

Even though the P&O and INC method tracks the maximum power under varying atmospheric condition, the INC method tracks the maximum power efficiently than P&O

method. Hence the comparison of P&O and INC MPPT of power tracking is shown in Fig.16.

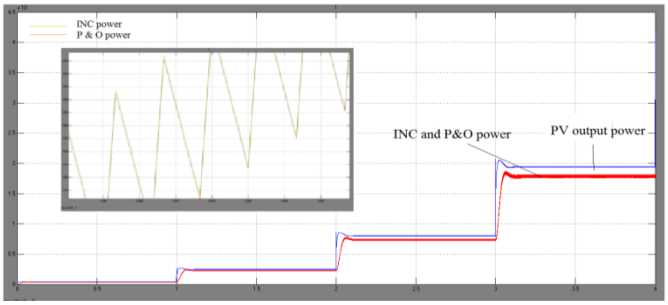

Fig. 16 Output power comparison of P&O and INC MPPT

3.3 Variable step size INC MPPT algorithm

The power drawn from the PV array with fixed step size contributes to faster dynamics but create excessive steady state oscillations, resulting in low efficiency. To solve these oscillation problems variable step size INC is implemented in this paper.The update rule for duty cycle to determine the variable step size INC can be obtainedas follows:

$$D(k) = D(k-1) \pm N * \left|\frac{\Delta P}{\Delta D}\right| \quad (3)$$

Scaling factor 'N' is necessary since manual tuning is tedious. Thus the scaling factor canbe obtained as

$$N < \Delta Dmax\left|\frac{dP}{dV}\right| \quad (4)$$

If the above equation cannot be satisfied, the variable step size INC MPPT will be working with a fixed step size of the previously set upper limit$\Delta Dmax$.The variation in the step size follows the aspects such as when the tracking system operates far away from the MPP;the variation in the step size is large. In addition, when the operating point is close to the MPP, the tracker reduces the step size until it is coincides with the MPP. The dynamic performance of the variable step size MPPT ensure a good transient and steady state response. The current, voltage, power output of VSS INC MPPT algorithm is shown in Fig.17.

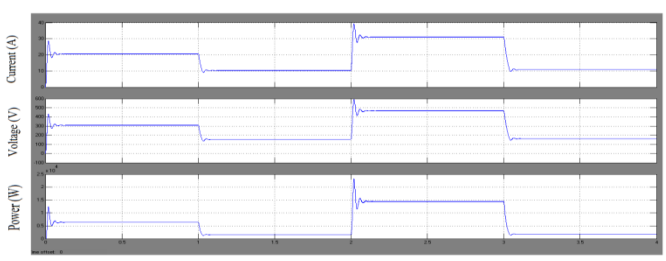

Fig.17 Current, Voltage, Power characteristics of INC VSS MPPT algorithm

The dynamic performance is faster than that of fixed step size. It also can be seen a bigger N can be chosen to achieve a faster response when a change in the solar irradiance occurs. The higher value of scaling factor exhibits faster dynamic response when the irradiance and temperature varying continuously than lower value of scaling factor [10]. The variable step size of INC characteristics is shown in Fig. 18.

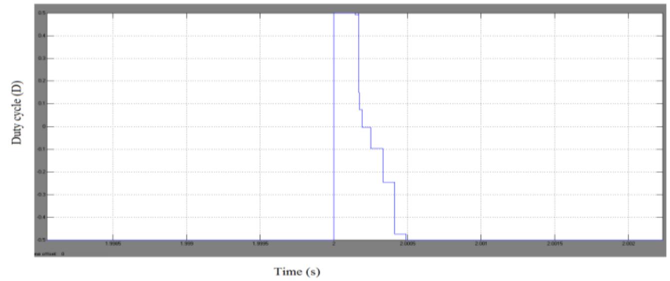

Fig.18 Variable Step Size (VSS) INCMPPT

4CONCLUSIONS

P&O and Fixed step size INC and VSS INC MPPT methods are implemented with MATLAB-SIMULINK for simulation. The MPPT method simulated in this paper is able to improve the dynamic and steady state performance of the PV system simultaneously. Through simulation it is observed that the system completes the maximum power point tracking successfully despite of fluctuations. When the external environment changes suddenly the system can track the maximum power point quickly.

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