iJRASET

International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 4 Issue: III Month of publication: March 2016

DOI:

Volume 4 Issue III, March 2016
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Adaptive P&O MPPT Method Using Zeta Converter for Solar PV Systems

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Abstract: This paper implements an Adaptive Perturb and Observe (P&O) Maximum Power point tracking (MPPT) method using Zeta converter (Dc-Dc converter) for photovoltaic systems. In this proposed method current perturbation is considered to speed up the tracking performance under suddenly changing environmental conditions using Peak Current Control technique which eliminates the PI controller. The Adaptive P&O MPPT controller controls the duty cycle of the Zeta converter, which finally controls the PMDC motor used for solar PV application. The proposed method is implemented in MATLAB/SIMULINK simulation software and the results validate that the proposed system has faster dynamics, improved stability compared to Conventional P&O method and capable of tracking Maximum Power Point (MPP) accurately and rapidly under suddenly changing environmental conditions.

Key words— PV module; maximum power point tracking (MPPT); Adaptive perturb and observe (P&O) method; zeta converter.

I. INTRODUCTION

The availability of solar power in abundance, depletion of the non-renewable energy sources and the reducing capital cost of photovoltaic panels leads to emerging trends in solar energy. Many researches are being done and have resulted in new technologies in this field. The power that can be utilized from the panel varies with the atmospheric and load conditions. Hence Maximum Power Point Tracking (MPPT) algorithm becomes an indispensable part of the photovoltaic system to extract the maximum power from the panel. The main objectives of all these MPPT algorithms are to achieve faster and accurate tracking performance and reduce the oscillations around MPP. Each algorithm can be categorized based on the type of the control variable it uses: 1) voltage; 2) current; or 3) duty cycle. Among different algorithms, much focus has been on perturb and observe (P&O) and hill climbing (HC) methods. The P&O method involves perturbation in the operating voltage of the solar array, and the HC method involves perturbation in the duty ratio of the power converter. In the P&O method, the voltage is being increased or decreased with a fixed step size in the direction of reaching the MPP. The process is repeated periodically until the MPP is reached. At steady state, the operating point oscillates around the MPP. A variable perturbation size algorithm is suggested to reduce the oscillations and improve the response speed. However, these algorithms are not accurate and fast because they do not consider the irradiance and temperature effects, even though they are simple in implementation. In this paper, an adaptive P&O algorithm is designed in order to overcome the drawbacks in the conventional P&O method. In this proposed method, current perturbation is considered to speed up the tracking performance.

MPPT devices are to be interfaced with the converter system. Different converters are discussed in the literature .The buck, boost and buck-boost are the basic converter topologies. The buck converter works as a step down converter and is not suitable for power factor correction applications. On the other side, boost converter can be used only to boost the input. It does not have over current protection. The buck-boost converter can be used either to increase or decrease the voltage. But the problem is that the output voltage has opposite polarity with respect to the source and so it is not widely used. The cuk converter also suffers from the problem of polarity reversal on the output. SEPIC is single-ended primary inductance converter. It is also a buck-boost converter, with no reversal of the polarity. But Cuk and Sepic converters need additional circuit to limit the inrush current. Also they do not have any overload protection. These limitations could be avoided by the usage of zeta converter. Zeta converter provides positive output from input voltage. It can be used to increase or decrease the voltage. The converter is good for power factor correction applications and has short circuit protection. It provides controlled output voltage with only one power processing stage. So it is a solution for regulating uncontrolled power supply. The implementation of the same is simple. Hence the zeta converter is used, whose switching is controlled by Adaptive Perturb and Observe algorithm, so as to track the maximum power point. MPPT system with a PI controller requires longer time (4t, t is the time constant of the MPPT system) to settle down, which slows the response speed of the MPPT system. In the proposed system the peak current control technique is used which has fast response speed (one-cycle response

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ISSN: 2321-9653
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time).

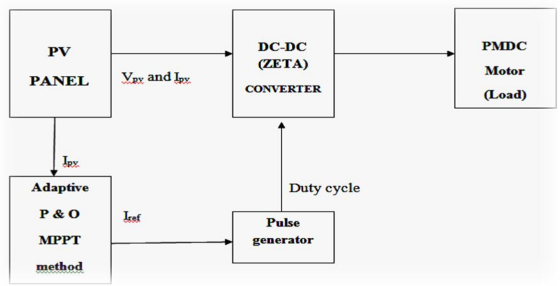

Fig 1 Overall Block Diagram

This paper is organized as follows. In Section II, modeling of PV module and array is discussed. The proposed adaptive P&O MPPT algorithm is designed and analyzed in Section III. Zeta converter working in CCM is presented in section IV.Simulation study is reported in Section V. Finally, conclusions are summarized in Section VI.

II. MODELING OF PV ARRY

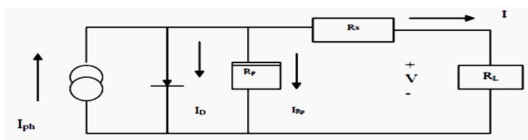

Fig .2 Equivalent circuit of a PV cell

An ideal PV cell is modeled by a current source in parallel with a diode as shown in figure 2. However no solar cell is ideal and thereby shunt and series resistances are added to the model as shown figure above. R_S is the intrinsic series resistance whose value is very small. R_P is the equivalent shunt resistance which has a very high value.

Applying Kirchoff's law to the node where Iph, diode, Rp and Rs meet, we get

$$I_{ph}=I_D+I_{Rp}+I \qquad (1)$$

We get the following equation for the photovoltaic current,

$$I=I_{ph}-I_{Rp}-I_D \qquad (2)$$

$$I = I_{ph}-I_o[\exp\left(\frac{V+I.Rs}{Vt}\right) - 1] - \left[\frac{V+I.Rs}{Rp}\right] \qquad (3)$$

Where, I_{ph} is the Insolation current ,I is the Cell current ,I_O is the Reverse saturation current ,V is the Cell voltage, R_S is the Series resistance, R_P is the Parallel resistance, V_t is the Thermal voltage (KT/q),K is the Boltzman constant, T is the Temperature in Kelvin, q is the Charge of an electron. The PV mathematical model used to simplify our PV array is represented by the equation

$$I = n_p I_{ph} - n_p I_{rs}\left[\exp\left(\frac{q}{KTA} * \frac{V}{ns}\right)\right] \qquad (4)$$

Where, I is the PV array output current, V is the PV array output voltage, n_s is the number of cells in series, n_p is the number of cells in parallel, q is the charge of an electron, k is the Boltzmann's constant, A is the P-N junction ideality factor, T is the cell temperature (K),I_{rs} is the cell reverse saturation current. The factor A in equation (4) determines the cell deviation from the ideal p-n junction characteristics; it ranges between 1-5 but for our case A=2.46.

III. ADAPTIVE P&O MPPT ALGORITHM

The novel adaptive P&O MPPT algorithm incorporates two major modifications to conventional P&O method
Considering current perturbation instead of voltage perturbation in conventional P&O method to speed up the tracking performance.
Moving the operating point to left hand side (LHS) of MPP to handle the sudden changes in weather conditions.

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A. Considering Current perturbation

Flowchart of the proposed MPPT algorithm is shown in Figure 3, where $I_{pv}(k)$, $V_{pv}(k)$ and $P_{pv}(k)$ are output current, voltage and power of PV array at k_{th} iteration respectively and ΔI is current perturbation size. The generalized equation is derived for the proposed MPPT algorithm as given,

$$Iref = Ipv(k) + sign\big(Ipv(k) - Ipv(k-1)\big) * sign\big(Ppv(k) - Ppv(k-1)\big) * \Delta I \qquad (5)$$

Where, the function sign (.) gives either +1 or -1 depending on positive or negative value inside the function respectively.

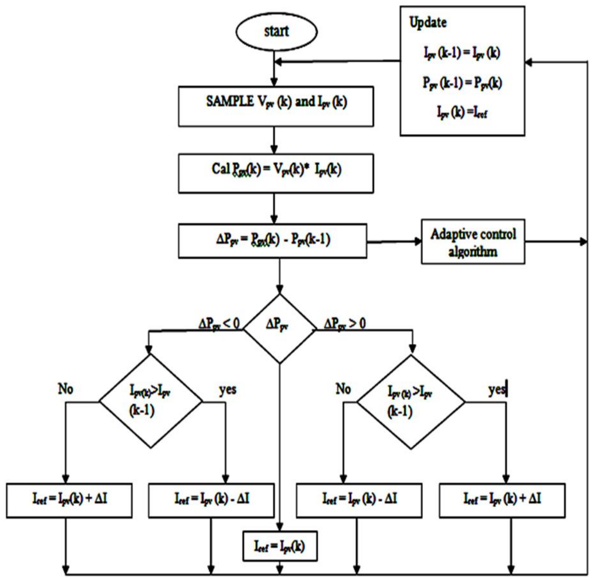

Fig 3 flow chart of Adaptive P&O MPPT algorithm

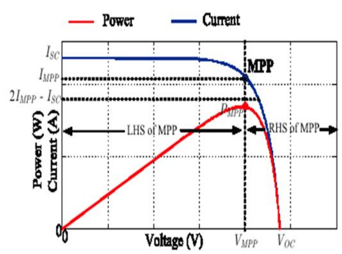

Fig .4 Nonlinear characteristics of PV array

The output current of PV array in the left hand side (LHS) of MPP i.e. 0 i.e. 0 to VMPP region is almost constant. On the other hand the current is drastically changing in the right hand side (RHS) of MPP i.e. V_{MPP} to V_{OC} region. Therefore, if the operating point lies in the LHS of MPP, then the current perturbation gives faster response than voltage perturbation in reaching the MPP with reduced oscillations. On the other hand, if the operating point lies in the RHS of MPP and operating current $I_{pv}(k)$ is less than $[I_{MPP}-(I_{SC}-I_{MPP})]$ as shown in Fig4.3, then current perturbation gives slower response. To avoid this situation an Adaptive control algorithm is proposed. The operating current range for which current perturbation gives satisfactory response is given as,

$$I_{SC} \leq I_{pv}(k) \leq 2I_{MPP} - I_{SC} \qquad (6)$$

B. Set the Operating Point to Left Hand Side of MPP

If there is a significant change in weather conditions or the operating current violates the current limit, then the adaptive control algorithm comes into action. It always tries to keep the operating point within the limits.

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IV. ZETA CONVERTER

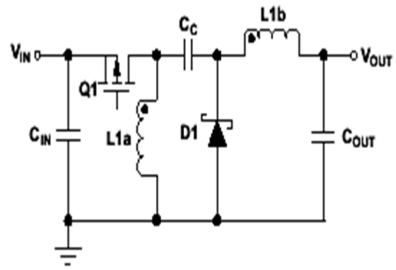

Fig.5 Circuit Diagram Of Zeta Converter

The ZETA converter topology provides a positive output voltage from an input voltage that varies above and below the output. The ZETA converter also needs two inductors and a series capacitor, sometimes called a flying capacitor. ZETA converter is another option for regulating an un regulated input-power supply. Figure 1 shows a simple circuit diagram of a ZETA converter, consisting of an Input capacitor, C_{IN} ; Output capacitor, C_{OUT} ;Coupled inductors L_{1a} and L_{1b};AC coupling capacitor, C_C ;FET, Q1;Diode, D_1.When the ZETA converter operating in CCM i.e., when Q_1 is on and when Q_1 is off and to understand the voltages at the various circuit nodes, it is important to analyze the circuit at DC. when both switches are off and not switching. Capacitor C_C will be in parallel with C_{OUT}, so C_C is charged to the output voltage, V_{OUT}, during steady-state CCM. When Q_1 is off, the voltage across L_{1b} must be V_{OUT} since it is in parallel with C_{OUT}. Since C_{OUT} is charged to V_{OUT}, the voltage across Q_1 when Q_1 is off is $V_{IN} + V_{OUT}$; therefore the voltage across L_{1a} is $-V_{OUT}$ relative to the drain of Q_1. When Q_1 is on, capacitor C_C, charged to V_{OUT}, is connected in series with L_{1b}; so the voltage across L_{1b} is $+V_{IN}$, and diode D_1 sees $V_{IN + VOUT}$.

V. SIMULATION RESULTS

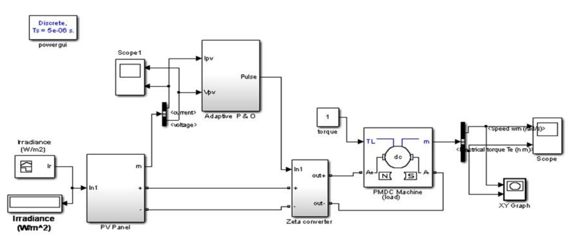

Fig.6 Simulation diagram of Adaptive P&O method using Zeta converter using PMDC load

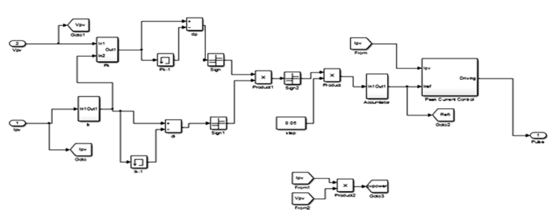

Fig.7 Simulation diagram of Adaptive P&O algorithm

TABLE I
SPECIFICATIONS OF PV ARRAY AT STC ($S=1000W/m^2$, $T = 25\ ^OC$)

Maximum power (Pmax)	234W
Voltage at MPP (Vmpp)	31.88V
Current at MPP(Impp)	7.34A
Open circuit voltage(Voc)	37.51V
Short circuit current(Isc)	8.63A

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TABLE II
SPECIFICATIONS OF ZETA CONVERTER

Inductor L_1	0.0133H
Capacitor C_1	0.1mF
Inductor L_2	0.0133H
Capacitor C_2	0.2mF
Resistance	100ohms

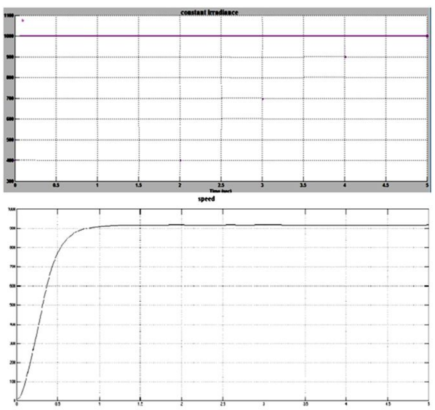

Fig. 8 1000W/m^2

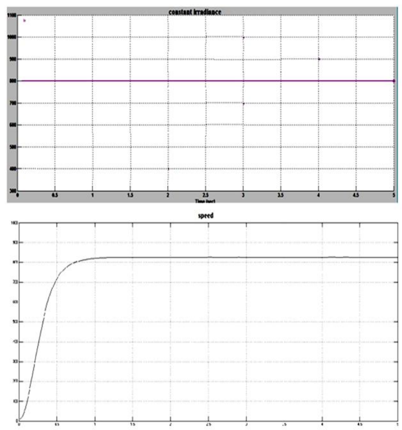

Fig. 9 800W/m^2

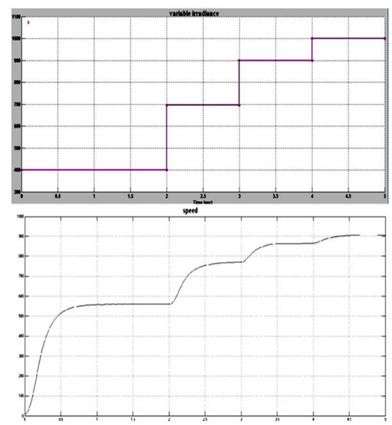

Fig. 10 Variable irradiation

Figure (8) ,(9),(10) shows Simulation output waveform of PMDC motor speed at constant solar irradiation of 1000 W/m^2, 800 W/m^2, PMDC motor speed at variable irradiation.

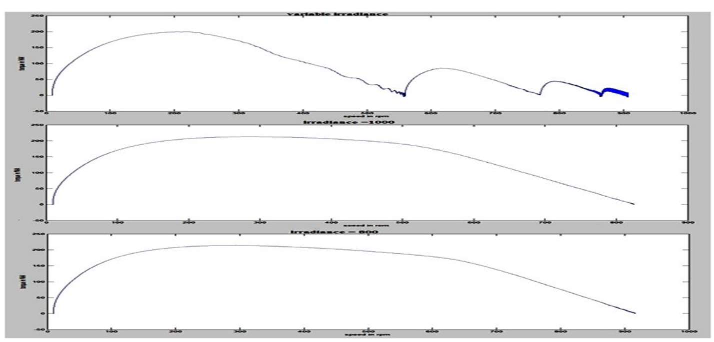

Fig.11 Simulation output waveform of Torque-speed curves of PMDC motor variable irradiation, 1000W/m^2, 800W/m^2 respectively.

VI. CONCLUSION

This paper presents a Adaptive P&O MPPT algorithm capable of maximizing output of PV array under varying irradiance and temperature conditions to extract maximum power is discussed and simulated using MATLAB software. The algorithm increases the tracking speed to reach MPP by considering current perturbation under steady weather conditions and moves the operating point to LHS of MPP to consider the sudden changes in temperature and irradiance. The simulation results successfully demonstrate that, the algorithm works well and shows good dynamic and steady state performance. MPPT devices are integrated to the designed zeta converter system to have duty ratio control. The converter is working in continuous conduction mode and provides well-regulated output power. This converter ultimately controls the PMDC motor load which can be used for solar PV application such as water pumping.

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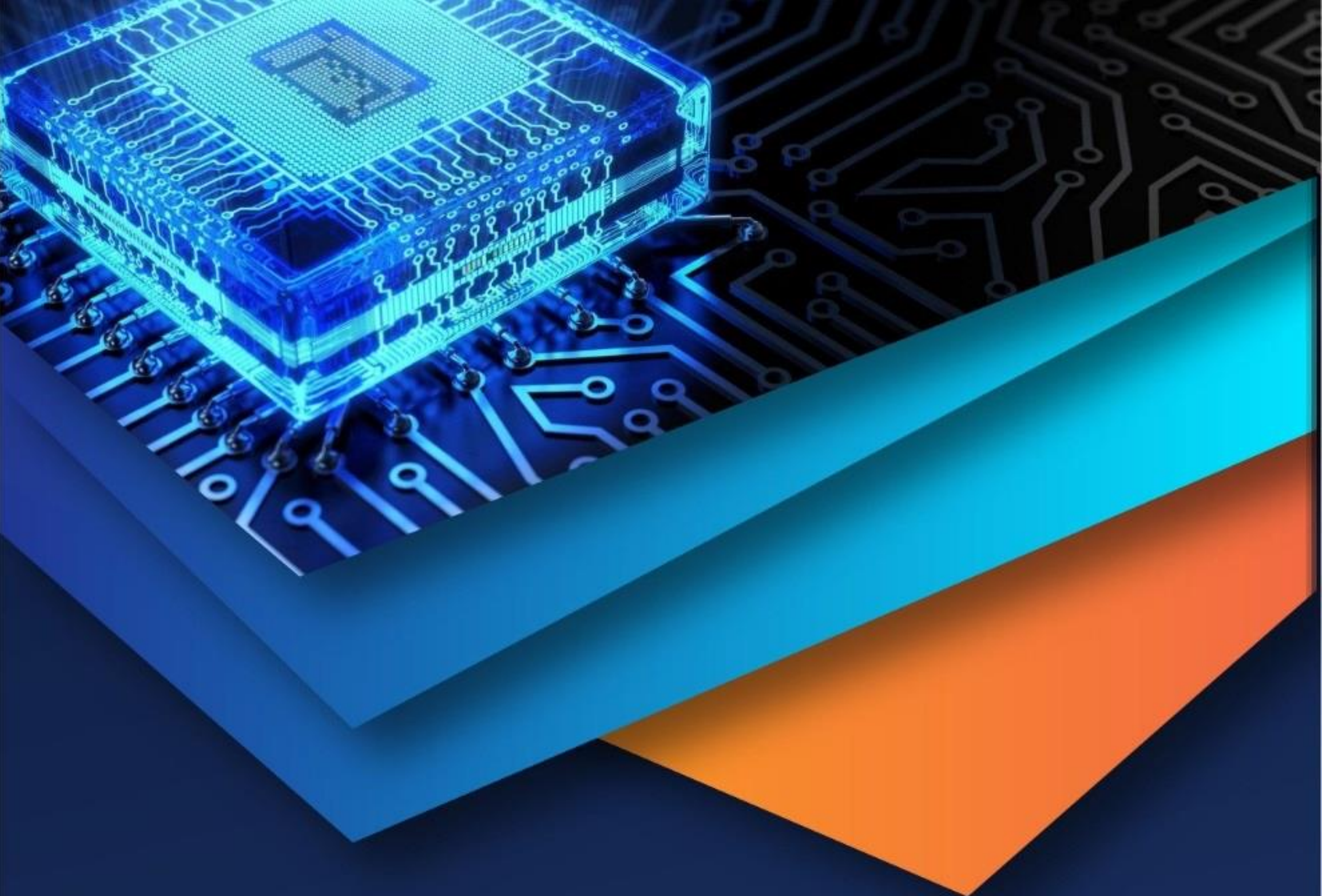

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