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Original Article

Maximum Power Operation of a PV System Employing Zeta Converter with Modified P&O Algorithm

Kavita Joshi[1], Vaishali Raut[2], Surendra Waghmare[3], Manisha Waje[4] and Rupali Patil[5]

[1,2,3,4,5] *Electronics and Telecommunication Engineering Department, G H. Raisoni College of Engineering and Management, Maharashtra, India.*

[1]kjpune759@gmail.com

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Abstract - *The Zeta converter is a non-inverted DC-DC converter composed of four energy storage components, capable of operating in step-down and step-up mode. This paper presents a zeta converter modelling and its analysis. The widely used Averaging Method such as State-Space is adapted in CCM (continuous conduction mode). The Zeta Converter acts as an interface between the load, solar PV array, and load. A solar PV array feeds the input power to the Zeta converter. The single diode model is employed for the solar module for simulation studies. The optimum power from the solar PV array is extracted using a modified Perturb and Observation algorithm. This controller is tuned to evaluate the Zeta converter and PV array performance under varying insolation conditions. The proposed system guarantees stability during steady-state and ensures that the maximum power is always tracked irrespective of changes in insolation level. The simulation results show the validity of the model's effectiveness.*

Keywords - *Maximum power point (MPP), Zeta converter, Photovoltaic (PV), proportional and integral (PI), Continuous conduction mode (CCM).*

1. Introduction

Solar energy is becoming increasingly popular nowadays due to the demand for alternate sources of electrical energy. The main advantages of a solar photovoltaic system (PV) are decreasing cost, being freely available, no noise pollution, and reducing CO2 emissions. Solar energy is widely used worldwide can be either PV cells that convert light to electrical energy or solar heaters which convert light to heat directly [6]. With emerging technologies in solar systems, the dependency on conventional energy sources is reduced. The usage of conventional energy sources is expensive and depleting day by day. These systems require regular maintenance and servicing of machine parts. It also requires the purchase of fuel again and again. The battery backup systems maintain the continuity and reliability of the system during night hours [1]. It increases demand for the PV generation system day by day. Many PV systems are installed worldwide for connected grids and standalone battery-operated PV systems in rural household applications. Therefore, efficient maximum power tracking is essential for overall efficiency improvement. [2-5].

PV system is always interfaced with dc-dc converter for regulated dc output and setting the operating point for sable steady-state operation under varying load conditions. Researchers have used many converters: boost, SEPIC, buck-boost, buck, and isolated converters for high-power applications. Zeta converter [9-14] is also implemented in many applications as an interface between the solar PV systems and load for stable operation and performance improvement. The output voltage could be either stepped up or down with a Zeta converter. The dc-dc zeta converter is used for many applications dc power supply, battery chargers and power factor correction [15,16], and PV systems. The stable operation of the PV system [24-26] is obtained from the feedforward control system. Many dc converters, especially stepped-up converters, are discussed in [27-32] and can be used for MPPT operation.

In this paper, the control and stable operation of a Zeta converter-based low-power (3 kW) PV system are mainly undertaken for the proposed work. The controller design is tuned for stable operation under varying insolation and temperature conditions. Section 2 describes the modeling of the PV panel and Zeta converter, respectively. Section 3 deals with the configuration proposed system, design of PV array, design of Zeta converter, and control strategy of modified MPP algorithm for maximum power and stable operation. The MATLAB-Simulink simulation of the proposed PV system is described in section 4. Section 5 explains the simulation results obtained under varying insolation conditions, and the work is finally concluded in section 6.

2. Modelling of PV panel

Representation of PV module using single diode model is depicted in Fig. 1[18]. It consists of a diode, shunt resistance, and a current source. This combination is now connected with the series resistor, as shown in Fig 1. Equation 1 represents the current equation of the diode model. Where S is insolation in W/m2, *R*se (series) and *R*sh (shunt) are the resistances of the solar PV module. The Ipv & Vpv are output current and voltage, respectively. The ideality factor of the diode is γ, k= is Boltzmann's constant, The temperature 'T' (degree/ kelvin) is the parameter of the solar cell, q is an electron charge, Ns=cells in a series of PV modules, and the diode current, I_0 = reverse saturation current of the diode.

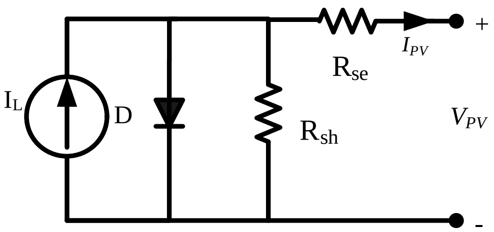

Fig.1. Representation of PV module using single diode model

$$I_{pv} = \left(\frac{S}{1000}\right) * I_L - I_0\left(e^{\frac{V_{pv}+IR_{se}}{u}} - 1\right) - \frac{V_{pv} + I_{pv}R_{se}}{R_{sh}} \qquad (1)$$

$$\text{Where.} \quad u = \frac{N_S \gamma KT}{q} \qquad (2)$$

3. Zeta Converter

3.1. Modelling of Zeta Converter

Fig. 2 shows the complete representation of the proposed model. It is built with a semiconductor switch (S_1), inductors (L_1, L_2), a diode (D_1), and two capacitances (C_1, C_2), respectively. The zeta converter operated in modes: i) On mode and ii) Off mode [19-20], respectively. During the on-mode, D_1 is in the off state, and switch S_1 is on; while switch S_1 is off and D_1 is on state, the operation is in off mode. Table I depicts the switching modes of operation.

Table 1. Switching modes of zeta converter

ON Mode	Switch (S_1) On	D_1 off
Off Mode	Switch (S_1) Off	D_1 on

The output voltage (V0) under steady-state conditions is obtained by applying volt-sec balancing of inductor voltage for the on and off period of the switch. The voltage equation of the zeta converter related to duty ratio (D) is given by

$$V_0 = V_{in}\frac{D}{1-D} \qquad (3)$$

The Zeta converter state-space representation is derived by writing Kirchhoff's loop and node equations in two modes (ON & OFF) of converter operation. The states of state-space representation are two inductors (I_{L1} & I_{L2}) currents, and the voltage across the capacitor (Vc1) can be written as follows [17]

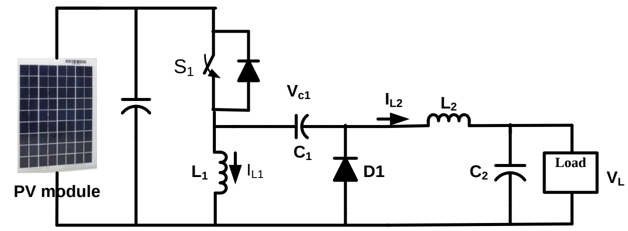

Fig. 2 Zeta converter fed by PV source

$$\begin{bmatrix} \dot{I}_{L1} \\ \dot{I}_{L2} \\ \dot{V}_{c1} \end{bmatrix} \begin{bmatrix} 0 & 0 & -\frac{(1-D)}{L_1} \\ 0 & 0 & \frac{D}{L_2} \\ \frac{(1-D)}{C_1} & \frac{D}{C_1} & 0 \end{bmatrix} \begin{bmatrix} I_{L1} \\ I_{L2} \\ V_{c1} \end{bmatrix} + \begin{bmatrix} \frac{D}{L_1} & 0 \\ \frac{D}{L_2} & -\frac{1}{L_2} \\ 0 & 0 \end{bmatrix} \begin{bmatrix} u_1 & u_2 \end{bmatrix} \quad (4)$$

Where $u_1 = V_{pv}$ & $u_2 = V_L$

4. Configuration of Proposed PV System

Fig. 3 depicts the diagram of the proposed solar PV system. It employs a zeta converter fed through a PV array. The constituents of a proposed PV system are a PV array, a zeta converter, an MPPT algorithm (Modified P&O), a PI controller, a pulse generator, and a heating load. The pulse generator generates pulses for switching and controlling the zeta converter at the Maximum power point (MPP).

4.1. Ratings of PV Array

1. The MPP voltage rating of the PV array with 5 modules in series is computed as
$$V_{array} = 5 \times 54.7 = 273.5\,V$$
2. The MPP current rating of the PV array with 2 modules in parallel is computed as
$$I_{array} = 2 \times 5.58 = 11.16\,A$$
3. The total maximum power rating of the PV array is calculated with 5 modules in series and 2 in parallel as

4.2. Design of Zeta Converter

The parameters of the zeta converter [21-23] consist of determining the values of inductors (L_1 & L_2) and capacitor (C_1). The designed values of inductors and capacitors ensure the converter operation (3) in Continues conduction mode (CCM). The CCM mode gives fewer ripples due to which converter's component stress reduction takes place. Equations 5 to 8 are used to calculate the design value of converter parameters. The ripples in inductor currents

$\Delta I_{L1}$and ΔI_{L2} are approximately 5 %, whereas the ripple in capacitor voltage $\Delta Vc1$ is 10 %.

4. $$L_1 = \frac{V_{mpp}D}{f\Delta I_{L1}} = \frac{273\times0.59}{40\times11.16\times0.05} = 7.21mH \quad (5)$$

5. $$L_2 = \frac{V_L(1-D)}{f\Delta I_{L2}} = \frac{400(1-0.59)}{40\times11.16\times0.05} = 7.34\ mH \quad (6)$$

6. $$C_1 = \frac{I_L D}{f\Delta V_{C1}} = \frac{7.5\times0.59}{40*400\times0.1} = 2.765\ uF \quad (7)$$

Table 2. Specification of PV module used for simulation

Sr No.	**Typical Electrical Characteristics (PV Module)**	**Symbol**	**Values**
1	No of the cells in each module	Ns	96
2	Maximum power	Pmax	305.2 W
3	Maximum Power voltage	(V_{mp})	54.7 V
4	Maximum Power current	(I_{mp})	5.58 A
5	Module Short circuit current	I_{sc}	5.96 A
6	Module Open circuit voltage	V_{oc}	64.2 V
7	Diode ideality factor		0.9
8	Shunt resistor	Rsh	269
9	Series resistor	Rse	0.37

5. CONTROL OF PROPOSED SYSTEM

5.1. Open Circuit Voltage Control Technique

This method takes the voltage corresponding to the maximum power point as a fraction of the open circuit voltage. This voltage can be taken as 80% to 90% of open circuit voltage, as shown in equation 8. This speeds up the MPP tracking process and stabilizes the operating point initially. After reaching the operating point at a fractional set value of open circuit voltage, the P& O algorithm is started.

$$V(m+1) = 85\%\ of\ V(m) \quad (8)$$

5.2. Modified Perturb & Observation-based MPPT Algorithm

The basic perturb and observation (P&O) algorithm combined with fractional set value is employed for extracting maximum power point. Fig. 4 shows the flow chart showing a series of steps to be followed for tracking maximum power. The P&O algorithm [7-9] continuously searches for reference voltage corresponding to MPP. This voltage always fluctuates around the MPP given by Equation 9. The PV array voltage is continuously perturbed for searching MPP, and the operating point continuously oscillates near peak power.

$$V(m+1) = V(m) + \Delta V \quad (9)$$

Where ΔV is a small disturbance

Table 3. Design Specifications of Zeta converter

Sr. NO	**Parameters**	**Symbol**	**Values**
1	I/p voltage	V_{pv}	250-300 V
2	Output voltage	V_L	350 V
3	Switching frequency	f_S	40 kHz
4	Input inductor	L_1	7.21 m H
5	Output Inductor	L_2	7.34 mH
5	Intermediate capacitor	C_1	2.675 μ F
6	Output capacitor	C_2	500 μF
7	Power	P	3 Kw

A modified P&O algorithm generates the reference voltage corresponding to MPP. The voltage difference is obtained by comparing the actual PV array and the reference voltage. This difference voltage is used to generate the duty cycle and control the switching of the zeta converter. The perturbation in duty ratio generated due to variation in reference voltage of MPP algorithm is shown in equation 10.

$$D(m+1) = D(m) + \Delta D \quad (10)$$

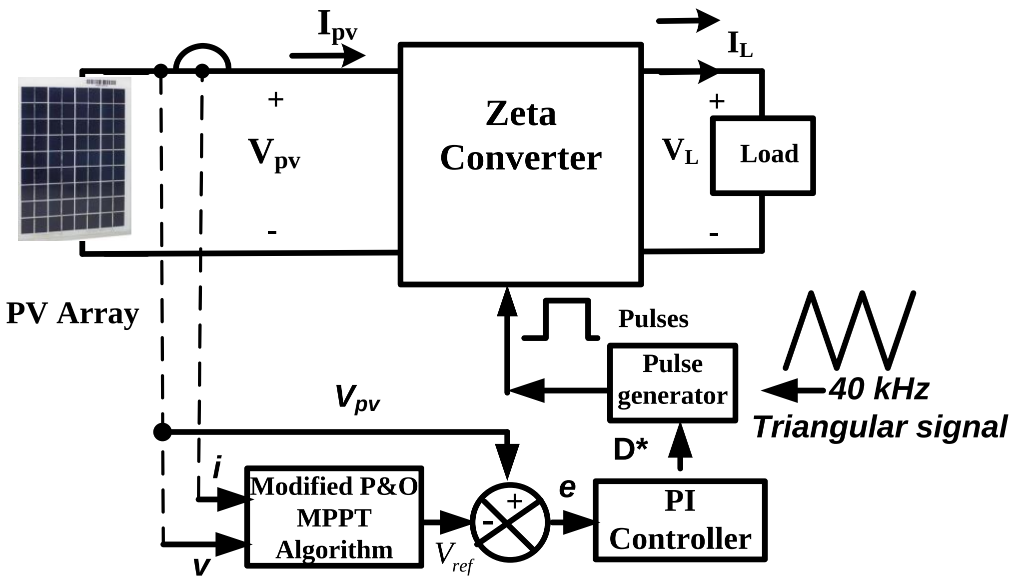

Fig. 3 Proposed PV system for MPPT operation.

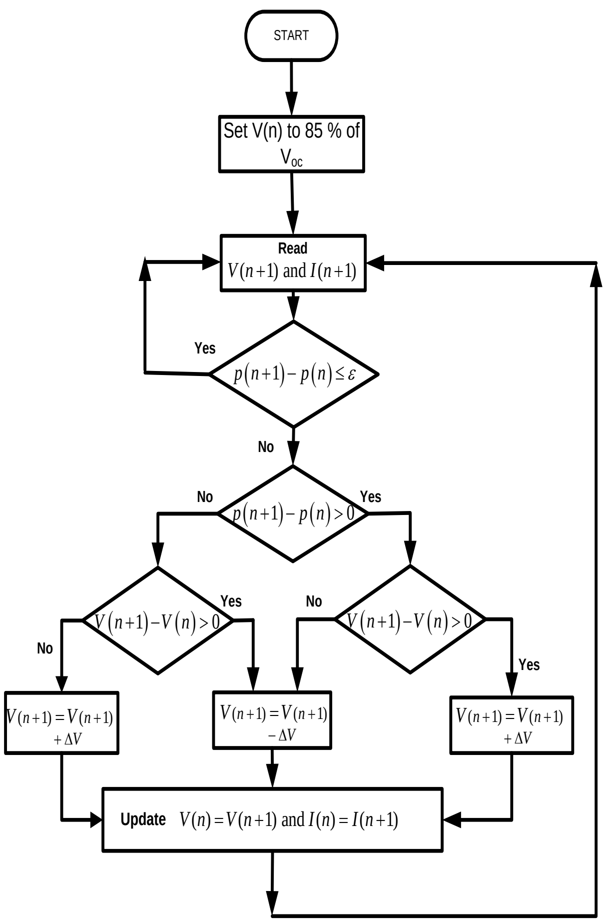

Fig. 4 Modified P&O method

6. MATLAB Simulation

Using MATLAB/ SIMULINK toolbox, the modified P&O algorithms, Zeta converter, PI controller, and PV array are simulated. Fig.5 shows the schematic diagram for the complete simulation of the proposed system. It consists of subsystem blocks: PV array, zeta converter, MPP algorithm with PI controller, and load. Table II shows the parameters of the PV module used for the simulation under study, whereas Table III shows the design parameters for the zeta converter.

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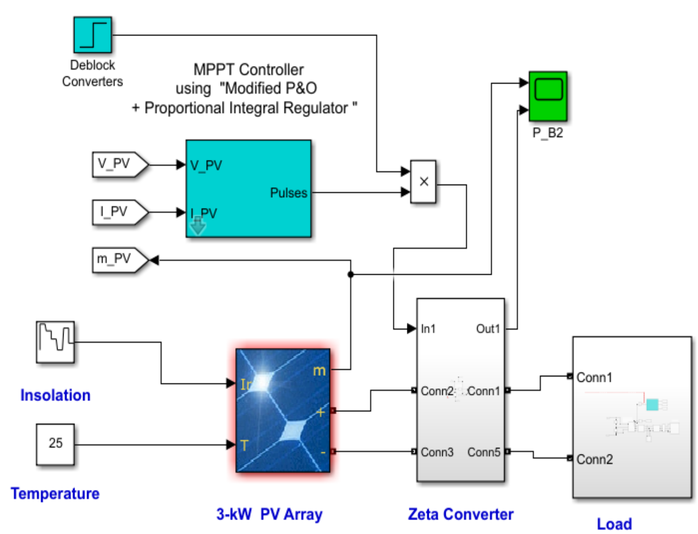
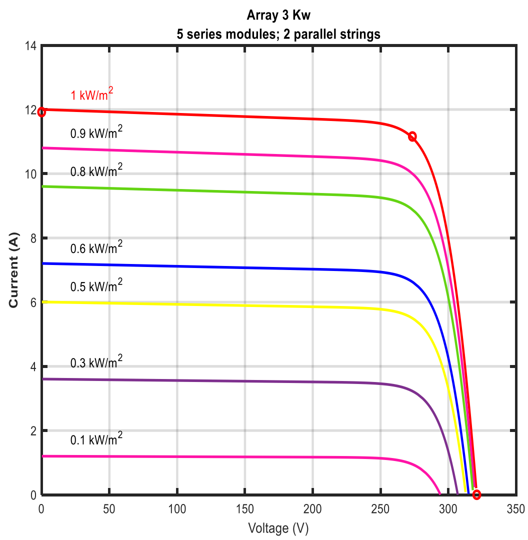
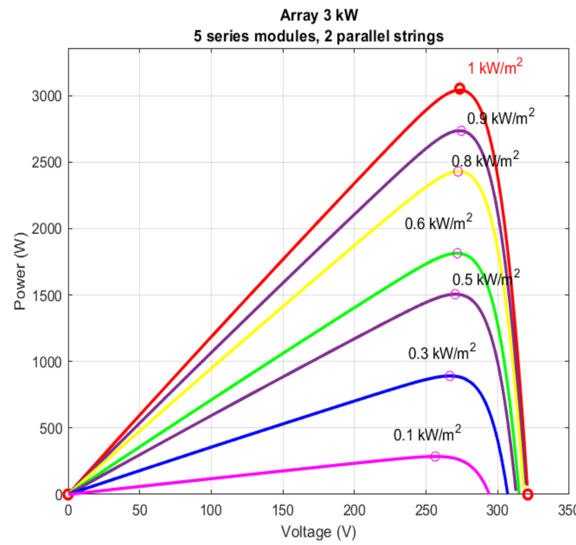


Fig. 5 Complete simulation set-up of the proposed system.



(a) I-V



(b) P-V

Fig. 6 characteristics of a 3 Kw solar Array

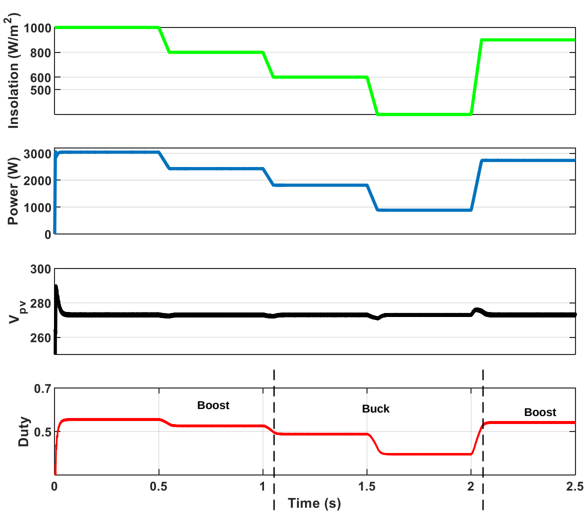


Fig. 7 Transient response of PV array power and duty ratio for the variation in insolation level.

7. Results and Discussion

Fig. 6(a) & 6(b) show of current and power variation of a 3 Kw solar PV Array system under varying insolation from 10 % to 100 %, respectively. It shows the highly non-linear behaviour of the solar PV module. The current is constant, equal to light-generated current I_L, and suddenly decreases when the load is reduced to open circuit condition. The voltage variation is reverse to that of the current. The simulation is performed at 25°C. The modified P&O MPPT-based algorithm continuously tracks the MPP for particular current and voltage conditions.

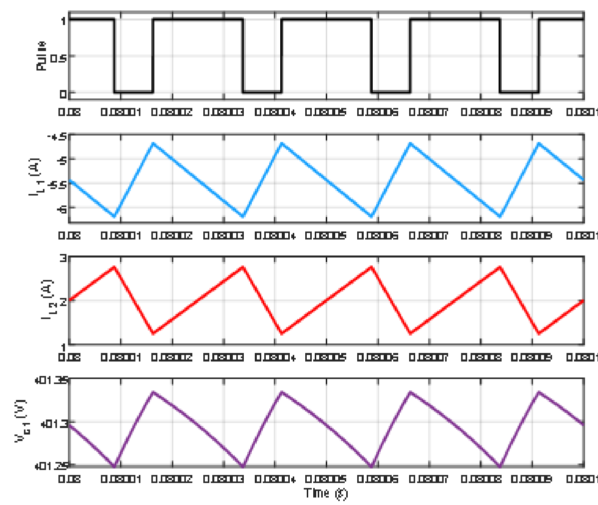


Fig. 8 Transient response of switching pulses, inductor currents, and capacitor voltage

Fig. 7 shows the simulation results of MPP tracking under steady operation. The insolation is randomly changed to different levels of 900, 800, 600, 300, and 1000 W/m^{2,} and MPP is tracked. The tracking is suddenly achieved by varying the zeta converter's duty ratio (D). Moreover, it is observed that MPP tracking is achieved in a very short time under a dynamic change in insolation level. Fig. 8. shows the transient response of switching pulses, inductor currents, and capacitor voltage of the zeta converter at insolation of 1000 W/m^2. The zeta converter is working in CCM, which reduces the component stress. The inductor currents (I_{L1}, I_{L2}) and intermediate capacitor voltage (V_{c1}) are presented. It shows the small ripples in currents and voltage, which are allowed up to the point where the size of components is acceptable.

8. Conclusion

A Solar PV system controlled by a zeta converter feeding Heating load has been proposed. The performance analysis has been carried out through simulation results. The PV array has been designed and modelled for appropriate ratings of voltage and power levels. The zeta converter has also been modelled and designed appropriately for boost and buck mode of operation. The PI controller has been tuned by selecting appropriate constants (Kp and KI) to get stable operation of the Zeta converter within the prescribed limit for variation insolation levels. The proposed system's combination of PV array, MPP algorithm, PI controller, zeta converter, pulse generator, and Heating load has shown excellent dynamic and steady-state performance. This proposed system can be implemented using a low-cost microcontroller with high stability. The proposed system had also shown operation successfully even under 30 % of insolation levels., Based on the measured results, it is concluded that the proposed modified MPPT algorithm is most suitable for standalone solar PV systems that operate under sudden variation in insolation conditions with lesser convergence time than conventional P&O algorithms.

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