

SOLAR POWERED BRUSHLESS DC MOTOR DRIVE USING ZETA CONVERTER

B. Arundhati¹, S. Murali²,
Madisa V G Varaprasad³

¹Department of Electrical &
Electronics Engg., Vignan's
Institute of Information and
Technology, Visakhapatnam,

²Department of EEE, VIIT,
Visakhapatnam,

³Department of Electrical
Engineering, NIT, Rourkela,

¹b_arundhati@rediffmail.com

²muralisai333@gmail.com

³mvgvaraprasad@gmail.com

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Abstract

This paper proposes a zeta converter fed by photovoltaic array as input power source for effective control of BLDC motor. A zeta converter is a fourth order dc-dc converter capable of amplifying and reducing the input voltage levels without inverting the polarities. The ZETA converter for Maximum power point tracking (MPPT) is preferred due to the

current, low ripple input and output currents with zeta converter compared with the conventional Boost, Buck-boost, Cuk converter. The effectiveness of proposed system under various atmospheric conditions is evaluated and compared with the traditional Boost converter using MATLAB/Simulink.

Key Words and Phrases: Solar photovoltaic array, Zeta converter, P&O-MPPT, BLDC Motor.

1. INTRODUCTION

In present scenario, global attention is towards non-conventional energy sources to meet the electrical load demand for the consumer and to supply the electricity for rural areas. Solar photo voltaic array system is one among the non-conventional energy sources helpful in various applications like lightening load, water pumping and fan etc. (see [1], [2]). In general, Photovoltaic panels operate very rarely at maximum power point, this condition results in poor efficiency of the system. Optimization of Photovoltaic system is performed by using Maximum power point tracking (MPPT) algorithm for better efficiency. Generally, in MPPT, Perturb and Observe (P&O) algorithm is widely adopted (see [3]). Nowadays BLDC motor is becoming popular because of the low power consumption as compared to conventional motors. The higher efficiency, reliability, maintenance free properties of BLDC motor attracts the attention to utilize in solar powered application (see [7]). BLDC motor is employed to drive the fan load which can be utilized as exhausted fans, to separate the dust from rice grain post harvesting. In this work Zeta converter is preferred compare to the other conventional DC-DC converters due to the advantages of soft starting, continuous output current, boundless region for MPPT, low ripple input and output currents (see [4]). The solar photovoltaic array, ZETA converter & BLDC motor ratings are selected to suit for different atmospheric conditions and operating conditions of the BLDC motor. The analysis of proposed system performance is evaluated using MATLAB/Simulink software.

2. The PROPOSED SYSTEM

The proposed solar powered Zeta converter fed BLDC driven fan is depicted in Fig. 1. The proposed system consists of solar photovoltaic array, DC-DC Zeta converter, voltage source inverter (VSI), BLDC motor and fan load. The power required to run the BLDC motor is supplied by the solar photovoltaic array, the maximum power is extracted by the ZETA converter through the MPPT algorithm. The current and voltage information of PV array is provided to the MPPT controller and it produces the duty ratio to operate at peak power point. The firing pulses to the controlled switch in the ZETA converter are generated by the pulse generator. The power at input stage and output stage is same for ideal case. The DC output voltage of zeta converter is applied to the PMSM motor through the Voltage Source Inverter (VSI). The gate signals to the VSI are given according to the signals from position sensors (Hall sensors).

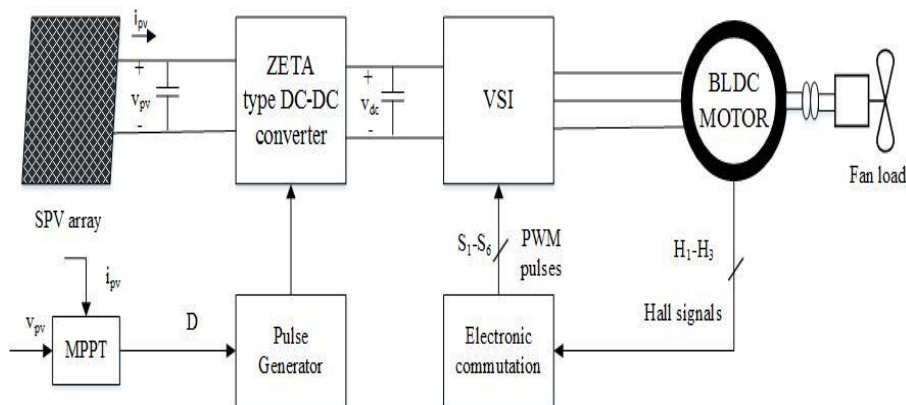


Fig. 1: Solar powered zeta converter fed BLDC driven fan.

3. DESIGN OF PROPOSED SYSTEM

The proper design of system is mandatory for the efficient operation under uncertain conditions. A solar photovoltaic array of 1360W maximum power capacity is designed to run the 931W BLDC motor under standard test condition (STC).

Designing of solar photovoltaic array Solar photo voltaic array is modelled [5-6]. Due the losses in the various converter stages the power generated by the solar photo voltaic array is considered for a greater rating than that of the motor. Table.1 shows the specifications of the solar photo voltaic

PV array is as shown below

$$I_{pv} = N_p I_{ph} - N_p I_o \left[\exp \left(\frac{q(V_{pv} + R_s I_{pv})}{N_s k T a} \right) - 1 \right] - N_p \left(\frac{V_{pv} + I R_s}{R_{sh}} \right)$$

Where N_p & N_s are the number of modules connected in parallel and in series respectively

Table. 1: specifications of solar photo voltaic array

For a Photovoltaic array	
Maximum power point voltage, $V_{mpp}=V_{pv}$	82 Volts
Maximum power	1360W
Number of modules in series	5 (36 cells per module)
Number of modules in parallel	6 (36 cells per module)

Design of Zeta Converter Zeta converter consists of two inductors and capacitors as shown in Fig.3. Continuous conduction mode of zeta converter is considered in this work which ensures a lesser stress on the components. The design of inductors (L_1 & L_2) and capacitor (C_1) plays vital role to operate the converter in efficient manner.

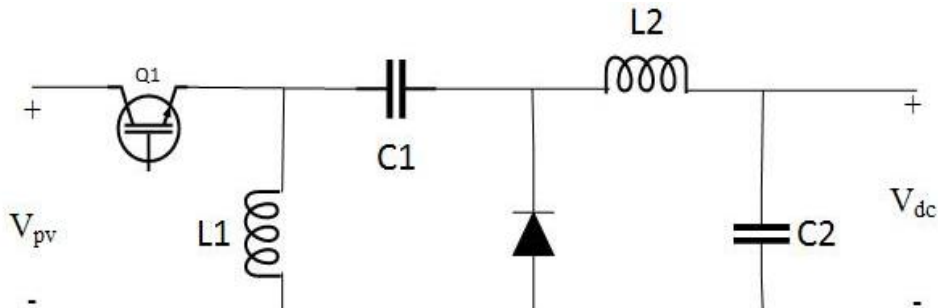


Fig. 2: Circuit diagram of zeta converter topology

Duty cycle is the main factor for designing of zeta converter, the estimated duty cycle is 0.782 in this work.

$$D = \frac{V_{dc}}{V_{dc} + V_{pv}} \quad ; \quad L_1 = \frac{D V_{pv}}{f_s \Delta I_{L1}} \quad ; \quad L_2 = \frac{(1-D) V_{pv}}{f_s \Delta I_{L1}} \quad ; \quad C_1 = \frac{D I_{dc}}{f_s \Delta V_{C1}}$$

L_1 , L_2 , C_1 values are taken as 6mH, 6mH & 22uF

respectively and are obtained by using above expressions. Where D is the duty cycle, V_{dc} is the voltage across the DC link capacitor, V_{pv} is output voltage of PV array, f_s is switching frequency of zeta converter, ΔI_{L1} is the ripple current of inductor & ΔV_{C1} is the ripple voltage across the capacitor

Capacitor C_2 in the Fig. 3 is the intermittent component of DC-DC converter and DC-AC converter. Designing of this capacitor C_2 is crucial for getting constant DC voltage across the DC-AC converter (VSI). The value of capacitor C_2 is determined as per the BLDC motor's rated and minimum speed. The DC link capacitor values are estimated by using the following equations

$$C_{2rated} = \frac{I_{dc}}{6 * \omega_{rated} * \Delta V_{dc}}$$

$$C_{2min} = \frac{I_{dc}}{6 * \omega_{min} * \Delta V_{dc}}$$

From the above expressions, the capacitor value considered as 850 μ F in this work.

Design of BLDC driven fan load The speed-torque characteristics of fan load is parabolic in nature and it can be represented in the mathematical expression given below

$$T_L = K \omega_{rated}^2$$

Where T_L is the load torque, ω_{rated} is the motor's rated speed in rad/sec. Proportionality constant K is estimated using the expression given below for the selection of fan load

$$K = \frac{T_L}{\omega_{rated}^2}$$

The proportionality constant $K = 3 * 10^{-5}$ is considered for this work.

The specifications of BLDC motor for this work is shown in Table. 2

Table.2: BLDC Motor Specifications

Power Rating	930 W
Speed, N	3000 rpm
DC voltage	310 V
No. of poles	4
Moment of inertia	8 Kg.cm ²
Torque constant (K_t)	0.74485 Nm/A
Phase resistance, R_s	3.58 Ω
Phase inductor, L_s	9.13mH

4. THE CONTROL OF THE PROPOSED SYSTEM

In this work, controlling is employed in two stages, one to generate pulses for zeta converter topology to trace the peak power point through MPPT algorithm, another is to generate firing pulses for VSI through hall sensors.

P &O MPPT algorithm This algorithm is very simple to implement to track the maximum power and thus, it is most commonly used MPPT technique. Current (I_{pv}) & voltage (V_{pv}) of photovoltaic array is measured and the change in power is obtained by comparing it with previous state value. The opposite perturbation will be applied to get required value [3]. The system oscillates to near maximum power point as it reaches the MPP. Oscillations can be reduced by setting the suitable perturbation step size. Fig. 4 shows P&O MPPT algorithm flow chat.

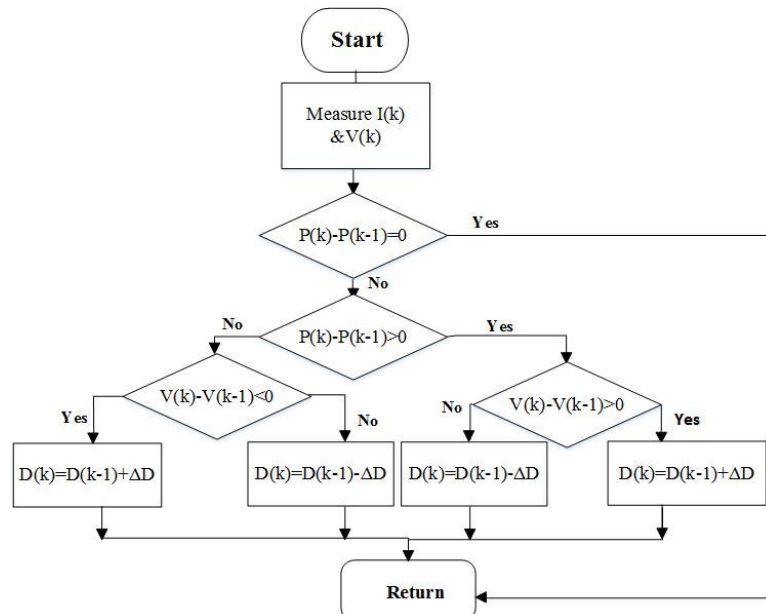


Fig.3: Flow chart of the perturb and observe MPPT algorithm

Electronic commutation of BLDC motor Gate signals for VSI to drive the BLDC motor is given by decoding the hall signals from the shaft mounted position sensors. For an interval of 60° rotor position hall signals combination are produced which determines the winding to commutate. The switching states for different combination of hall signals is shown in Table.3

Table.4: Switching states for VSI

Rotor position	Hall sensor signals			State of VSI switches					
	h_1	h_2	h_3	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6
NA	Low	Low	Low	Off	Off	Off	Off	Off	Off
0° - 60°	High	Low	High	On	Off	Off	On	Off	Off
60° - 120°	Low	Low	High	On	Off	Off	Off	Off	On
120° - 180°	Low	High	High	Off	Off	On	Off	Off	On
180° - 240°	Low	High	Low	Off	On	On	Off	Off	Off
240° - 300°	High	High	Low	Off	On	Off	Off	On	Off
300° - 360°	High	Low	Low	Off	Off	Off	On	On	Off
NA	High	High	High	Off	Off	Off	Off	Off	Off

5. SIMULATION RESULTS AND DISCUSSIONS

The proposed system performance is evaluated using MATLAB/Simulink for various operating conditions like temperature and irradiation. The comparison of starting inrush current of BLDC motor with boost and zeta converter is depicted in Fig.4. The performance of the BLDC motor at steady state operation is shown in Fig.5. The dynamic performance of the BLDC motor at varying temperature and irradiation is depicted in Fig.6 & Fig.7 respectively.

Starting inrush current The stator current of BLDC motor using Boost and Zeta converter is depicted in Fig.4. From the simulation plot it is very clearly found that the stator current during starting (0-0.2 sec) is very less with zeta converter when compared to the traditional boost converter which ensures the soft starting of BLDC motor.

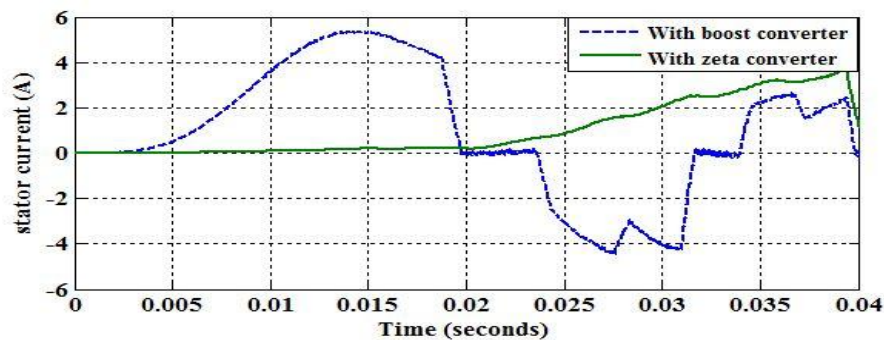
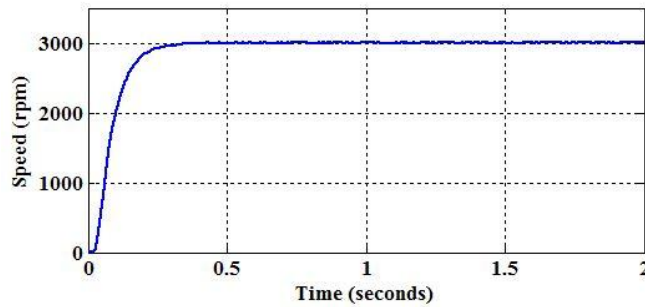
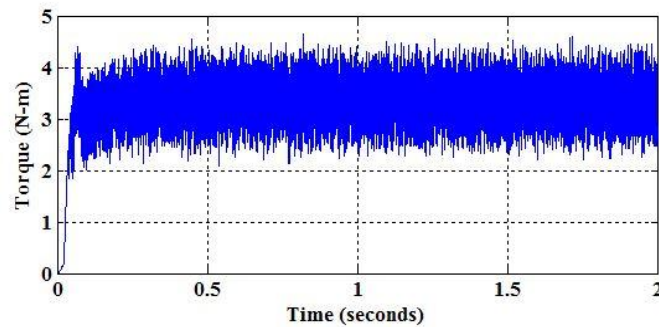


Fig. 4: Stator currents of BLDC motor with boost converter and zeta

Steady State operation at STC The performance of the BLDC motor Speed (N) and electromagnetic torque (T_e) at rated speed of 3000 rpm and standard temperature (25°C) & irradiance 1000w/m^2 is shown in Fig. 5(a) & (b).



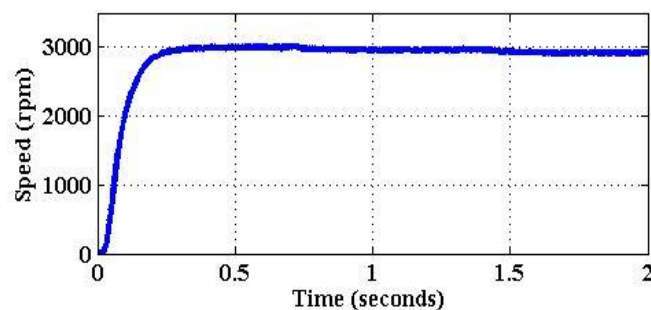
5(a)



5(b)

Fig. 5(a): Rotor speed,(b): Torque for irradiation of 1000W/m^2
Dynamic Performance

Change in temperature at constant irradiation The performance of the BLDC motor Speed (N) and electromagnetic torque (T_e) at various temperature conditions, like step change in temperature from 25°C to 30°C at 0.8sec and 30 to 35°C at 1.4 sec is applied at constant irradiance 1000w/m^2 and is shown in Fig. 6(a),6 (b) respectively.



6(a)

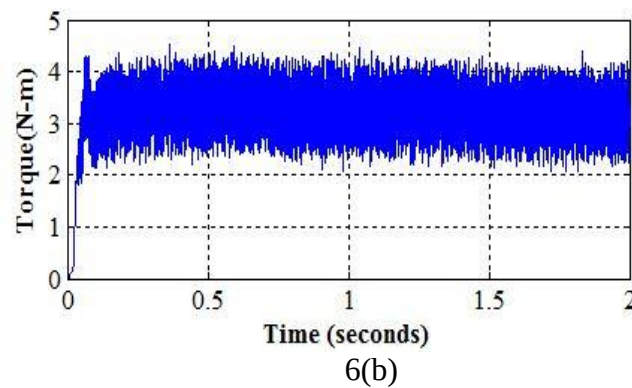


Fig. 6(a): Rotor speed, (b): Torque (for temperature of 25°C(0-0.8s), 30°C(0.8-1.4s), 35°C(1.4-2s))

Change in irradiation at constant temperature The performance of the BLDC motor Speed (N) and electromagnetic torque (T_e) at various irradiation conditions, like step change in irradiation from 600W/m² to 200W/m² at 0.7s and 200 W/m² to 1000 W/m² at 1.4s is applied at constant temperature 25 °C is shown in Fig. 7(a),7(b) respectively.

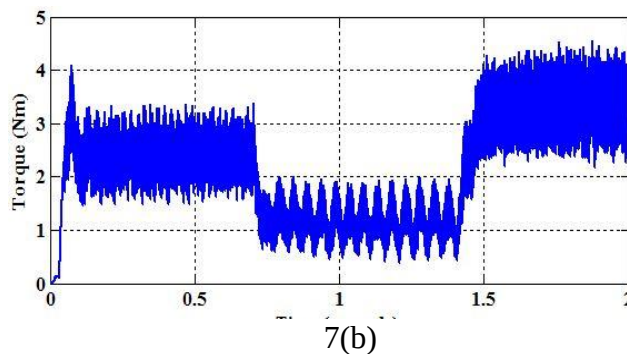
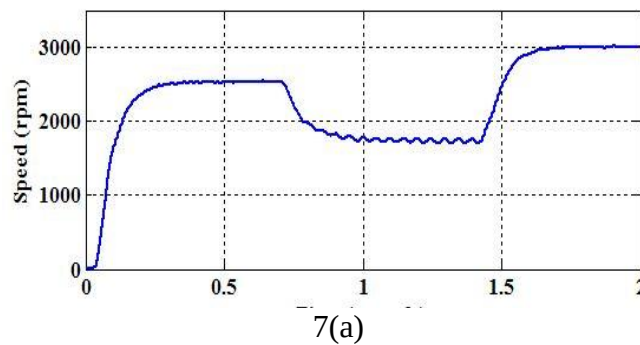


Fig. 7(a) : Rotor speed, (b) :Torque (for irradiation of 600W/m² (0-0.7s), 200W/m² (0.7-1.4s), 1000W/m² (1.4-2s))

6. CONCLUSION

Solar photovoltaic array powered brushless DC motor with zeta converter topology as a peak power tracer is modelled, designed and simulated. Proposed model is evaluated for constant irradiation & temperature and also for variable atmospheric conditions using

MATLAB/Simulink. The performance of BLDC motor with zeta converter shows satisfactory results and is suitable for for fan load which can be used for agriculture (post harvesting) and small scale industries.

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