ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
Vol 4, Issue 5, May 2018

Solar PV based BLDC Motor Driven Water Pumping System using Zeta Converter

[1] Deepak Saw, [2]Samar Anand, [3] Kartick Chandra Jana
[1][2] M. Tech Scholar, [3] Assistant Professor, Department of Electrical Engineering, IIT (ISM) Dhanbad

***Abstract*: This paper proposes an efficient and cost effective Brushless dc motor fed water pumping system for solar photovoltaic (PV) array. A zeta converter is utilized to draw the maximum power available from the Solar PV array. BLDC motor does not require any additional circuitry for speed control. Variable dc link voltage of voltage source inverter (VSI) is utilized to control the speed. The proposed technique comply fundamental switching frequency of VSI, results in reduction in power loss due to high switching frequency. A suitable control of zeta converter through INC-MPPT (incremental conductance maximum power point tracking) algorithm provides smooth starting of the BLDC motor. The water pumping system is developed and demonstrated through simulation using MALTAB/Simulink.**

Keywords: Photo Voltaic (PV), incremental conductance maximum power point tracking (INC-MPPT), brushless dc (BLDC) motor, voltage source inverter (VSI), zeta converter, electronic commutation

1. INTRODUCTION

Generation of power through conventional energy sources, environment pollution and annihilation of conventional energy resources are some of the major concern. So power generation is gradually shifting from conventional to renewable energy sources. Nowadays demand of energy is very huge and only ways to meet this requirement is solar energy. Solar PV array fed water pumping system is receiving huge attention these days for irrigation, industrial use, and household application. Generally, DC-DC converters are used with solar PV array fed water pump which suffers from several drawbacks [1]. So zeta converter in association with BLDC motor is utilized here [2]. Benefits of both zeta converter and BLDC motor can contribute to develop a solar PV array fed water pumping system which ensure satisfactory operation even under dynamic condition. Zeta converter shows following merits over conventional boost, buck, Cuk converter, and buck-boost converter.

1. Zeta converter belongs to family of buck-boost converter; it may be used to increase or decrease output voltage which results boundless region for MPPT of solar PV array.
2. Also this property offers smooth starting of the BLDC motor.
3. Output inductor of zeta converter is responsible for continuous current at output unlike conventional buck-boost converter.
4. Zeta converter operates in non-inverting mode unlike an inverting Cuk or buck-boost converter which eliminate requirement of circuits for negative voltage sensing.

To ensure that Solar PV array operates at MPP an incremental conductance MPPT algorithm is used. An efficient and cost effective Brushless dc motor fed water pumping system is used. A zeta converter is utilized to draw the maximum power available from the Solar PV array and ensure soft starting of BLDC motor. This converter offers continuous conduction mode (CCM) which results in reduction of stress on its switches and other components. The Solar PV array fed water pumping system is developed and demonstrated through simulation using MALTAB/Simulink [3].

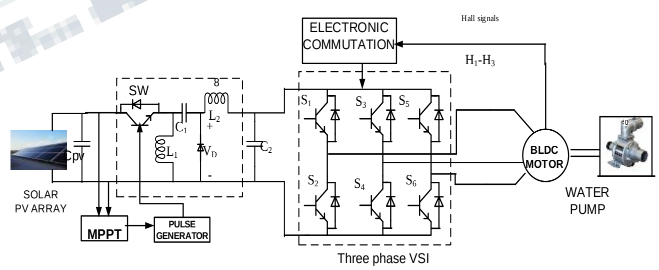

Fig. 1. Block diagram of proposed Solar PV based BLDC Motor Driven Water Pumping System.

II. DETAILED OPERATION OF PROPOSED SYSTEM

Electrical power generated by Solar PV array fed to the BLDC motor through zeta converter and VSI. Slightly less power is transferred to the VSI due to various losses

ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
Vol 4, Issue 5, May 2018

in the converter [4]. Switching pulses are generated from pulse generator through incremental conductance MPPT for IGBT. Incremental conductance uses voltage and current signals and produce duty cycle for the VSI and hence maximum power is extracted. Dc output of zeta converter is converted into ac from VSI to feed the BLDC motor which drives the water pump. An electronic commutation is used to operate VSI in fundamental switching frequency. BLDC have built-in encoder which eliminates high switching frequency losses leads to increase in efficiency.

III. DESIGN OF VARIOUS STAGES OF PROPOSED SYSTEM

Various stages as shown in Fig. 1 are designed as follows

A. Design of Solar PV Array

Various power losses are associated with the practical converters. Also some electrical and mechanical losses are present in the BLDC motor pump. To overcome these losses,

Table I. Specification of Solar PV Module

Power at MPP, P_{mpp} (w)	248.9
Open circuit voltage V_o (v)	39.5
Voltage at MPP, V_m (V)	31.2
Short circuit current Is (A)	9.71
Current at MPP, Im (A)	9.07
Cells per Module (N_{cell})	60

the size of Solar PV array with slightly more peak power capacity is selected to ensure satisfactory operation despite power losses. The equivalent circuit of PV cell which consist of a diode, a current source I_{ph}, a shunt resistance R_{sh} and a series resistance R_{se}. The values of series and shunt resistance is zero and infinite for ideal PV cell. Eq. (1) and Eq. (2) shows the output current of PV cell:

$$I_{pv} = I_{ph} - I_d - I_{sh} \qquad (1)$$

$$I_{pv} = I_{ph} - I_o e^{\left(\frac{qV}{akT} - 1\right)} - \frac{V_{pv}}{R_{sh}} \qquad (2)$$

where I_o is the leakage or reverse saturation current of the diode, k is the Boltzmann constant (1.3806503 × 10^{-23} J/K), q is the electron charge (1.60217646 × 10^{-19} C), T (in K) is the temperature of the p-n junction and a is the diode ideality factor [5].

PV cells are connected in parallel and series combinations to increase the output current and output voltage respectively. The Solar PV array of peak capacity P_{mpp} = 2.48 KW which is more than power demanded by the pump motor is considered with suitable parameters. 1Soltech 1STH-FRL-4H-250-M60-BLK module is considered to design the suitable size of Solar PV array. Specifications of the module are mentioned in Table I.

Let us consider N_s and N_p are the number of cells connected in series and parallel. Hence the equation of the output current will be:

$$I_{pv} = N_p I_{ph} - N_p I_o \left(e^{\frac{qV}{N_s akT}} - 1 \right) \qquad (3)$$

B. Design of Zeta Converter

Zeta converter is next stage to the Solar PV array as indicated in Fig. 1. Designing of Zeta converter necessitate computation of numerous components such as inductor L_1 at input side, inductor L_2 at output side and intermediate DC link capacitor C_1. DC-DC converter is required to readjust and control the intermittent output of Solar panel. Determination of duty cycle D leads to the design of zeta converter estimated as [6]

$$D = \frac{V_{dc}}{V_{dc} + V_{mpp}} \qquad (4)$$

where V_{dc} is dc link voltage at the output of zeta converter.

The above parameters are designed as to ensure that zeta converter always perform in continuous conduction mode (CCM).

C. Design of Voltage Source inverter (VSI)

To employ the renewable energy sources in efficient manner inverter is most relevant device. Also BLDC motor is controlled utilizing an inverter which is operated by an electronics commutation of BLDC motor for commutating the alternating currents in harmony with the rotor position to generate the required torque. An equivalent circuit of 3 ph. VSI is indicated in Fig. 1. The prime objective of this circuit is to generate sinusoidal output voltage with suitable magnitude and frequency.

ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
Vol 4, Issue 5, May 2018

D. Design of Water Pump

Designing of Water Pump require calculation of proportionality constant which is obtained from its power-speed characteristics [7] as

$$K = \frac{P}{\omega_r^3} \quad (5)$$

E. Calculation of DC Link filter capacitor of inverter

Rated speed of the BLDC motor for water pump is calculated from the fundamental frequency at the output of VSI [8]. Further this frequency is utilized to estimate the value of DC link filter capacitor.

$$\omega_{rated} = 2\pi f_{rated} = 2\pi \frac{PN_{rated}}{120} \quad (6)$$

$$C_{2,\text{rated}} = \frac{I_{dc}}{\Delta V_{dc} \times \omega_{rated} \times 6} \quad (7)$$

In same manner minimum speed of the BLDC motor and capacitor value corresponding to the minimum speed is also obtained from the fundamental frequency at the output of VSI.

$$\omega_{\min} = 2\pi f_{\min} = 2\pi \frac{PN_{\min}}{120} \quad (8)$$

$$C_{2,\min} = \frac{I_{dc}}{\Delta V_{dc} \times \omega_{\min} \times 6} \quad (9)$$

Finally, capacitor with larger value is selected to ensure the proper operation of the proposed system even at minimum irradiance.

IV. CONTROLLING TECHNIQUES

A. INC- MPPT Algorithm

To facilitate smooth starting of BLDC motor an efficient INC-MPPT technique[9] is utilized to optimize the available power of Solar PV array. In this technique perturbation is allowed in either duty cycle or Solar PV array voltage. Previously a Proportional-integral (PI) controller is used to generate duty cycle for zeta converter, which results increase in complexity. Hence to avoid complexity direct duty cycle control is used in this paper. In INC-MPPT algorithm as shown in the Fig. 3 slope of $P_{pv} - V_{pv}$ curve is decided by the direction of perturbation, shown in Fig. The slope is positive on left of MPP, zero at MPP, and negative on right of MPP as shown in Fig. 2.

$$\frac{I}{V} = \frac{dI}{dV}$$

where $\frac{I}{V}$ is the instantaneous conductance and $\frac{dI}{dV}$ incremental conductance.

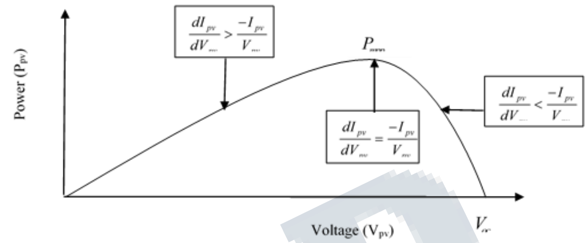

Fig. 2. Illustration of INC-MPPT with SPV array $P_{pv} - V_{pv}$ characteristics.

$$\frac{dP}{dV} = 0$$

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

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

MPP is reached when $\frac{dP}{dV} = 0$ and

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

$$\frac{dI}{dV} = -\frac{I}{V}$$

$$\frac{dP}{dV} > 0 \text{ then } V_p < V_{mpp}$$

$$\frac{dP}{dV} = 0 \text{ then } V_p = V_{mpp}$$

$$\frac{dP}{dV} < 0 \text{ then } V_p > V_{mpp}$$

Hence, based on the above relations between instantaneous conductance and INC, the direction of change of voltage or duty cycle is decided by the controller [2].

B. Electronic commutation of Brushless DC Motor

According to the position of rotor three hall-effect signals are produced by decoder logic [6] which is inbuilt in the motor. These three hall-effect signals converted into three EMF signals. Then six switching pulses are generated according to the various combination of three EMF signals. Now these six switching pulses are fed to the six switches of VSI which in turns control the BLDC motor. Block diagram of Electronic commutation is shown in Fig. 4. The various combination of hall-effect signals, switching pulses with the range of rotor position are shown in the table II. There are two switches conduct at a time, results in 120° mode of conduction of VSI and therefore cause reduction in the conduction losses. Besides, because of fundamental switching frequency of VSI, losses due to high switching frequency of PWM can be eliminated.

V. SIMULATED PERFORMANCE OF PROPOSED SYSTEM

Performance evaluation of proposed Solar PV array-fed BLDC motor-driven water pump employing a zeta converter is carried out using simulated results. The starting and steady-state behaviors of the BLDC motor pump at 1000 W/m2 is shown in Fig. 6. All the motor indices such as the back EMF e_a, the stator current i_{sa}, the speed N, the

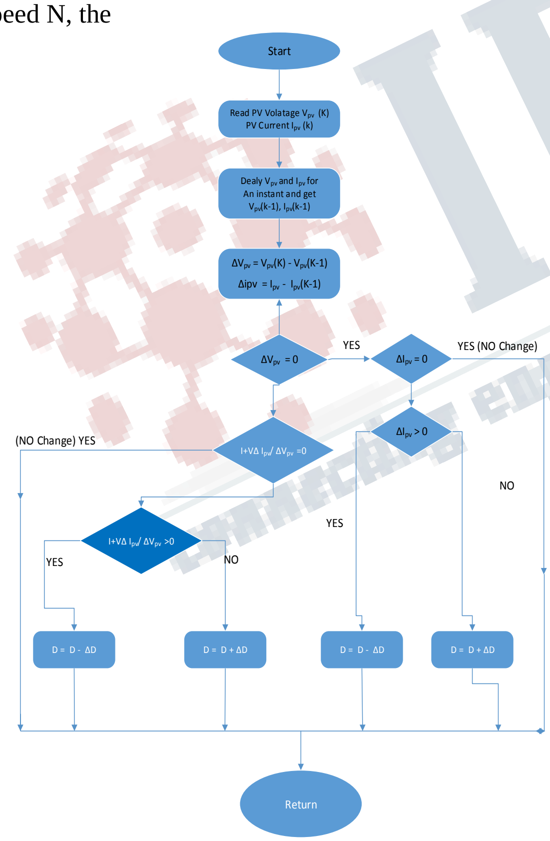

Fig. 3. Block diagram of algorithm of INC-MPPT

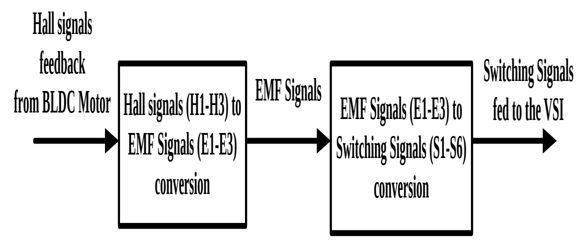

Fig. 4. Block diagram of Electronic commutation of BLDC Motor

Table II. Switching States for Electronic Commutation of BLDC Motor

Rotor postion(θ)	Hall Signals			Switching States					
	H_a	H_b	H_c	S_1	S_2	S_3	S_4	S_5	S_6
NA	0	0	0	0	0	0	0	0	0
0-60	0	0	1	0	0	0	1	1	0
60-120	0	1	0	0	1	1	0	0	0
120-180	0	1	1	0	1	0	0	1	0
180-240	1	0	0	1	0	0	0	0	1
240-300	1	0	1	1	0	0	1	0	0
300-360	1	1	0	0	0	1	0	0	1
NA	1	1	1	0	0	0	0	0	0

electromagnetic torque developed T_e, and the load torque T_L reach their corresponding rated values under steady state condition. The soft starting along with the stable operation of motor-pump is observed and hence the successful operation of proposed system is verified. However, a small pulsation in Te results due to the electronic commutation of the BLDC motor. The BLDC motor always attains a higher speed than 1100 r/min, a minimum speed required to pump the water at a minimum solar irradiance level of 200W/m2.

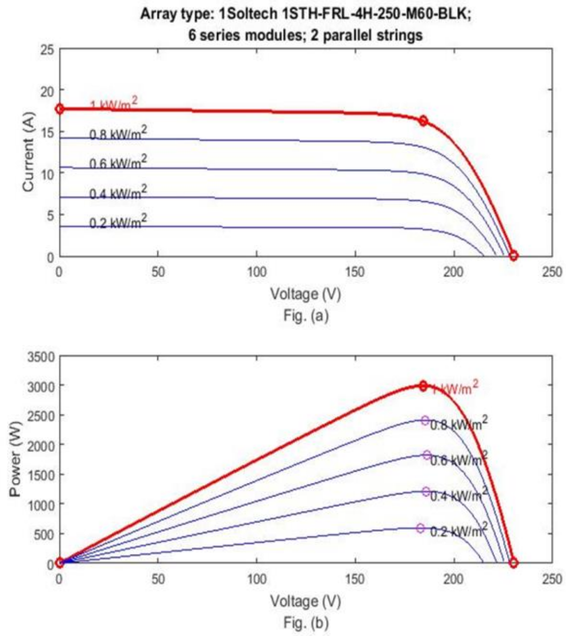

Fig.5. Curves plotted at specified temperature of 25 (in degree C) for different values of irradiance (in KW/m^2). (a) I-V curve (b) P-V curve

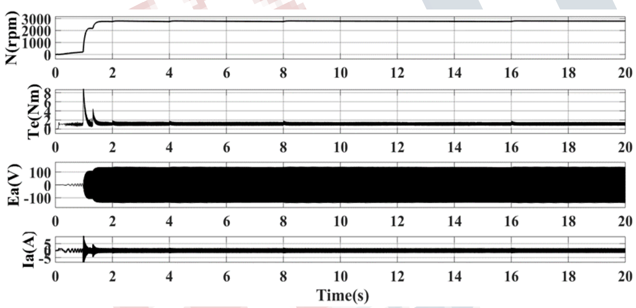

Fig. 6. Starting and steady state performance of the proposed BLDC motor for water pump

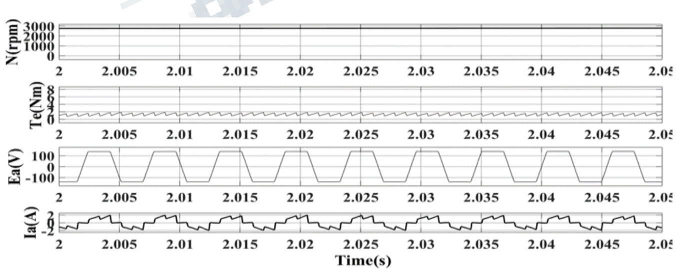

Fig. 7. Steady state performance of the proposed BLDC motor for water pump

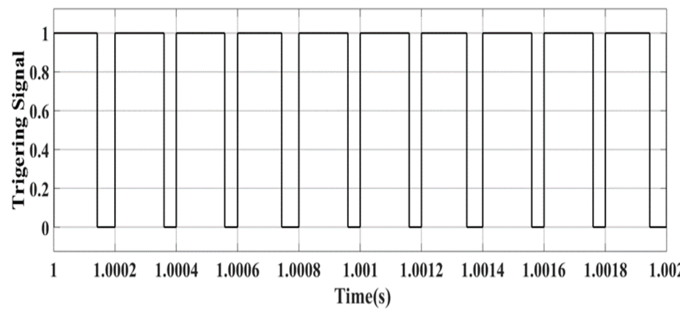

Fig. 8. Triggering signal for IGBT from MPPT

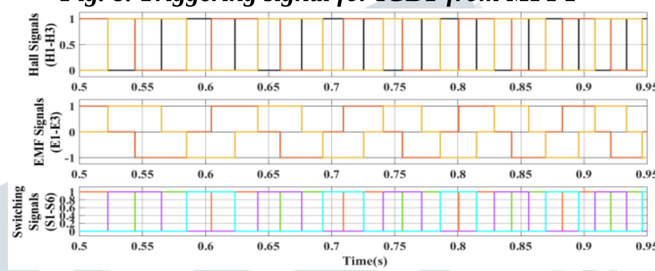

Fig. 9. Hall signals (H_1-H_3), EMF signals (E_1-E_3), Switching signals (S_1-S_6) of BLDC Motor

VI. CONCLUSION

The Solar PV based BLDC Motor Driven Water Pumping System using Zeta Converter has been investigated and its relevancy has been testified through simulated results. The evaluated performance has justified the combination of Brushless DC motor and zeta converter for solar PV based water pump. The starting and steady state performance of Brushless DC motor has been studied here. This paper shown various desirable functions such as extraction of maximum power of solar PV array, fundamental switching frequency of VSI which results in reduction in switching losses, smooth starting of BLDC motor, elimination of additional control, phase current and sensing of dc link voltage in speed control of Brushless DC motor which results in reduced cost and complexity.

REFERENCES

[1] M. Uno and A. Kukita, “Single-Switch Voltage Equalizer Using Multistacked Buck #x2013;Boost Converters for Partially Shaded Photovoltaic Modules,” *IEEE Trans. Power Electron.*, vol. 30, no. 6, pp. 3091–3105, 2015.

ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
Vol 4, Issue 5, May 2018

[2] S. Satapathy, K. M. Dash, and B. C. Babu, "Variable step size MPPT algorithm for photo voltaic array using zeta converter - A comparative analysis," *2013 Students Conf. Eng. Syst. SCES 2013*, 2013.

[3] R. Kumar and B. Singh, "BLDC Motor-Driven Solar PV Array-Fed Water Pumping System Employing Zeta Converter," *IEEE Trans. Ind. Appl.*, vol. 52, no. 3, pp. 2315–2322, 2016.

[4] A. Shahin, A. Payman, J. P. Martin, S. Pierfederici, and F. Meibody-Tabar, "Approximate novel loss formulae estimation for optimization of power controller of DC/DC converter," *IECON Proc. (Industrial Electron. Conf.*, pp. 373–378, 2010.

[5] M. Villalva, J. Gazoli, and E. Filho, "Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays," *IEEE Trans. Power Electron.*, vol. 24, no. 5, pp. 1198–1208, 2009.

[6] B. Singh and V. Bist, "Power quality improvements in a zeta converter for brushless DC motor drives," *IET Sci. Meas. Technol.*, vol. 9, no. 3, pp. 351–361, 2015.

[7] W. V. Jones, "Motor selection made easy: Choosing the right motor for centrifugal pump applications," *IEEE Ind. Appl. Mag.*, vol. 19, no. 6, pp. 36–45, 2013.

[8] K. H. Ahmed, M. S. Hamad, S. J. Finney, and B. W. Williams, "DC-side shunt active power filter for line commutated rectifiers to mitigate the output voltage harmonics," *Energy Convers. Congr. Expo. (ECCE), 2010 IEEE*, pp. 151–157, 2010.

[9] X. Zhou, D. Song, Y. Ma, and D. Cheng, "The simulation and design for MPPT of PV system based on incremental conductance method," *Proc. - 2010 WASE Int. Conf. Inf. Eng. ICIE 2010*, vol. 2, no. 50877053, pp. 314–317, 2010.