International Journal for Innovative Engineering and Management Research
A Peer Revieved Open Access International Journal
www.ijiemr.org

IJIEMR Transactions, online available on 8th Sept2017. Link :http://www.ijiemr.org/downloads.php?vol=Volume-6&issue=ISSUE-8

Title: **SPEED CONTROL OF BLDC MOTOR DRIVEN SOLAR PV ARRAY FED WATER PUMPING SYSTEM EMPLOYING ZETA CONVERTER**

Volume 06, Issue 08, Pages: 68– 78.

Paper Authors

DARABOINA RAMBABU, D. KIRAN KUMAR

Nova College of Engineering & Technology;Jupudi, Ibrahimpatnam, Krishna (DT), A.P, India.

International Journal for Innovative Engineering and Management Research
A Peer Revieved Open Access International Journal
www.ijiemr.org

SPEED CONTROL OF BLDC MOTOR DRIVEN SOLAR PV ARRAY FED WATER PUMPING SYSTEM EMPLOYING ZETA CONVERTER

[1]DARABOINA RAMBABU, [2]D. KIRAN KUMAR (M.TECH)

[1]M-tech Student Scholar,Department of Electrical & Electronics Engineering,Nova College of Engineering & Technology;Jupudi, Ibrahimpatnam, Krishna (DT), A.P, India.

[2]Assistant ProfessorDepartment of Electrical & Electronics Engineering,Nova College of Engineering & Technology;Jupudi, Ibrahimpatnam, Krishna (DT), A.P, India

ABSTRACT: In this paper a novel converter is designed for the applications of water pumping system driven by Brush less DC motor (BLDC). The photo voltaic (PV) system is proposed in this paper in order to replace the conventional energy sources like coal, nuclear, gas etc. BLDC motor is replaced with the commercial dc motor to achieve better performance, less maintenance and also less cost for water pumping applications. A zeta converter is utilized to extract the maximum available power from the SPV array through Incremental Conductance Maximum Power Point Tracking (MPPT) algorithm offers smooth and soft starting on BLDC motor. A voltage source inverter (VSI) is used to convert the output dc voltage into an ac voltage. The pulses for inverter are generated and the speed of the motor is adjusted with the help of PI controller. Finally an absolute model of water pumping system with the proposed inverter is implemented in Matlab/Simulink.

Key words: Brushless dc (BLDC) motor, incremental conductance maximum power point tracking (INC-MPPT), solar photovoltaic (SPV) array, voltage-source inverter (VSI), water pump, zeta converter.

I. INTRODUCTION

Renewable energy penetrations are increased in power sector to reduce dependency on fossil fuels [1]. Solar PV (Photo-Voltaic) systems are now well recognized for trapping solar energy. Solar energy has the greatest availability compared to other energy sources. It has been estimated that the amount of energy supplied to the earth in one day is sufficient to cater energy needs of the earth of one year [2]. For such solar PV systems, maximum power point tracking control is preferred for efficient operation [3]-[5]. Matsui et.al have presented a MPPT control system for solar PV system by utilizing steady state power balancing condition at DC link [6]. It has further improved by Mikihiko for sensor less application [7]. Integration of PV system with the grid fulfill standard power quality requirements and it have been reported in [8]-[10]. The solar PV system has found many potential applications such as residential, vehicular, space air craft and water pumping system. PV water-pumping is highly competitive compared to traditional energy technologies and best suited for remote site applications that have small to moderate power requirements. Most of the existing photovoltaic

International Journal for Innovative Engineering and Management Research
A Peer Revieved Open Access International Journal
www.ijiemr.org

irrigation systems offer a mechanical output power from 0.85 kW up to 2.2 kW. The efficiency of Induction motors are less compared to permanent magnet motors, whereas DC machines are not suitable for submersible installations. In recent years, the use of PMSM (Permanent Magnet Synchronous Motors) are increased for drives applications due to its high efficiency, large torque to weight ratio, longer life and recent development in permanent magnet technologies. It need power processor for effective control. This paper presents a standalone solar PV supplied BLDC drive for water pumping system. Pumping water is a universal need for agriculture and the use of PV panels is a natural choice for such applications. The performance of photovoltaic pumping system employing BLDC drive with proportional integrator controller is analyzed. response. In fact a Zeta converter can a little more power as compared to other converter. A BLDC motor is driven through an inverter interface. The hall sensor provides the required control strategy for driving the inverter. The speed is fed back to the inverter to make it a constant speed variable load motor. The first part of the paper deals with the modelling and simulation of PV module. The modelling of the system based on Matlab\Simulink has been proposed in many papers. The next is the modelling of the PI based MPPT and is followed by the Zeta converter fed BLDC motor simulation and analysis of the motor parameters is done.The existing literature exploring SPV array-based BLDC motor-driven water pump is based on a configuration shown in Fig.1. A dc–dc converter is used for MPPT of an SPV array as usual. Two phase currents are sensed along with Hall signals feedback for control of BLDC motor, resulting in an increased cost. The additional control scheme causes increased cost and complexity, which is required to control the speed of BLDC motor. Moreover, usually a voltage-source inverter (VSI) is operated with high-frequency PWM pulses, resulting in an increased switching loss and hence the reduced efficiency.

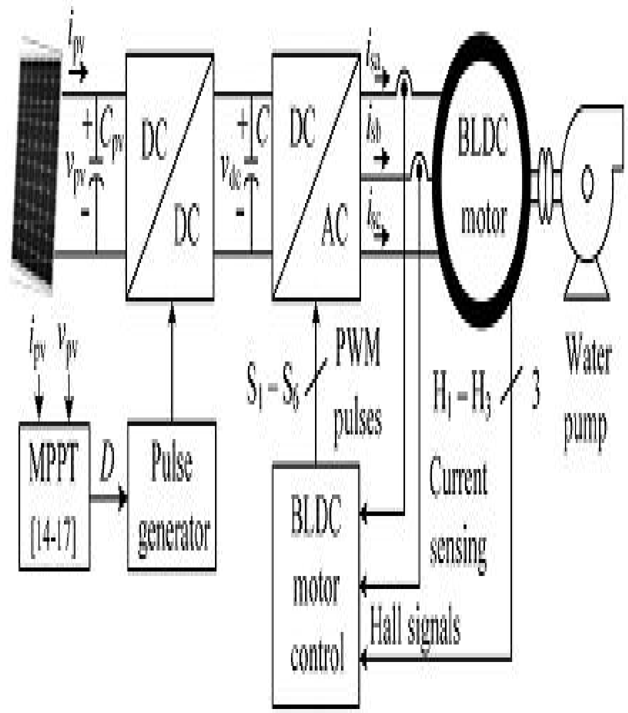


Fig.1. Conventional SPV-fed BLDC motor-driven water pumping system

II. CONFIGURATION OF PROPOSED SYSTEM

The structure of proposed SPV array-fed BLDC motor driven water pumping system employing a zeta converter is shown in Fig.2. The proposed system consists of (left to right) an SPV array, a zeta converter, a VSI, a BLDC motor, and a water pump. The BLDC motor has an inbuilt encoder. The pulse generator is used to operate the zeta converter. A step-by-step operation of

International Journal for Innovative Engineering and Management Research
A Peer Revieved Open Access International Journal
www.ijiemr.org

proposed system is elaborated in Section III in detail.

III. OPERATION OF PROPOSEDSYSTEM

The SPV array generates the electrical power demanded by the motor-pump. This electrical power is fed to the motor pump via a zeta converter and a VSI. The SPV array appears as a power source for the zeta converter as shown in Fig.2. Ideally, the same amount of power is transferred at the output of zeta converter which appears as an input source for the VSI. In practice, due to the various losses associated with a dc–dc converter, slightly less amount of power is transferred to feed the VSI. The pulse generator generates, through INCMPPT algorithm, switching pulses for insulated gate bipolar transistor (IGBT) switch of the zeta converter. The INC-MPPT algorithm uses voltage and current as feedback from SPV array and generates an optimum value of duty cycle. Further, it generates actual switching pulse by comparing the duty cycle with a high-frequency carrier wave. In this way, the maximum power extraction and hence the efficiency optimization of the SPV array is accomplished.The VSI, converting dc output from a zeta converter into ac, feeds the BLDC motor to drive a water pump coupled to its shaft. The VSI is operated in fundamental frequency switching through an electronic commutation of BLDC motor assisted by its built-in encoder. The high frequency switching losses are thereby eliminated, contributing in an increased efficiency of proposed water pumping system.

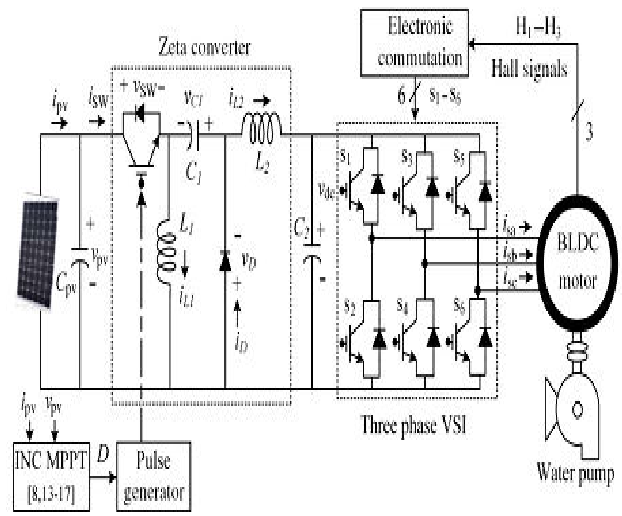


Fig.2. Proposed SPV-zeta converter-fed BLDC motor drive for water pump

IV. DESIGN OF PROPOSEDSYSTEM

Various operating stages shown in Fig.2 are properly designed to develop an effective water pumping system, capable of operating under uncertain conditions. A BLDC motor of2.89-kW power rating and an SPV array of 3.4-kW peak power capacity under standard test conditions (STC) are selected to design the proposed system. The detailed designs of various stages such as SPV array, zeta converter, and water pump are described as follows.

A. Design of SPV Array

As per above discussion, the practical converters are associated with various power losses. In addition, the performance of BLDC motor-pump is influenced by associated mechanical and electrical losses. To compensate these losses, the size of SPV array is selected with slightly more peak power capacity to ensure the satisfactory operation regardless of power losses. Therefore, the SPV array of peak power capacity of P_{mpp}=3.4 kW under STC (STC: 1000 W/m^2, 25^{o}C, AM 1.5), slightly

International Journal for Innovative Engineering and Management Research
A Peer Revieved Open Access International Journal
www.ijiemr.org

more than demanded by the motor-pump is selected and its parameters are designed accordingly. Solar World make Sun module Plus SW 280 mono SPV module is selected to design the SPV array of an appropriate size. Electrical specifications of this module are listed in Table.1 and numbers of modules required to connect in series/parallel are estimated by selecting the voltage of SPV array at MPP under STC as V_{mpp}= 187.2V.

TABLE 1
Specifications of Sun module plus SW 280monoSPV Module

Peak power, P_m (W)	280
Open circuit voltage, V_o (V)	39.5
Voltage at MPP, V_m (V)	31.2
Short circuit current, I_s (A)	9.71
Current at MPP, I_m (A)	9.07
Number of cells connected in series, N_{ss}	60

The current of SPV array at MPPI_{mpp} is estimated as

$$I_{mpp} = P_{mpp}/V_{mpp} = 3400/187.2 = 18.16 \text{ A} \quad (1)$$

The numbers of modules required to connect in series are as follows:

$$N_s = V_{mpp}/V_m = 187.2/31.2 = 6. \quad (2)$$

The numbers of modules required to connect in parallel are as follows:

$$N_p = I_{mpp}/I_m = 18.16/9.07 = 2. \quad (3)$$

Connecting six modules in series, having two strings in parallel, an SPV array of required size is designed for the proposed system.

B. Design of Zeta Converter

The zeta converter is the next stage to the SPV array. Its design consists of an estimation of various components such as input inductorL_1, output inductor L_2, and intermediate capacitor C_1. These components are designed such that the zeta converter always operates in CCM resulting in reduced stress on its components and devices. An estimation of the duty cycle D initiates the design of zeta converter which is estimated as [6]

$$D = \frac{V_{dc}}{V_{dc} + V_{mpp}} = \frac{200}{200 + 187.2} = 0.52 \quad (4)$$

Where V_{dc} is an average value of output voltage of the zeta converter (dc link voltage of VSI) equal to the dc voltage rating of the BLDC motor.

An average current flowing through the dc link of the VSII_{dc} is estimated as

$$I_{dc} = P_{mpp}/V_{dc} = 3400/200 = 17 \text{ A}. \quad (5)$$

Then, L_1, L_2, and C_1 are estimated as

$$L_1 = \frac{DV_{mpp}}{f_{sw}\Delta I_{L1}} = \frac{0.52 \times 187.2}{20000 \times 18.16 \times 0.06} = 4.5 \times 10^{-3} \approx 5 \text{ mH} \quad (6)$$

$$L_2 = \frac{(1-D)V_{dc}}{f_{sw}\Delta I_{L2}} = \frac{(1-0.52) \times 200}{20000 \times 17 \times 0.06} = 4.7 \times 10^{-3} \approx 5 \text{ mH} \quad (7)$$

$$C_1 = \frac{DI_{dc}}{f_{sw}\Delta V_{C1}} = \frac{0.52 \times 17}{20000 \times 200 \times 0.1} = 22 \text{ μF} \quad (8)$$

Where f_{sw} is the switching frequency of IGBT switch of the zeta converter; ΔI_{L1} is the amount of permitted ripple in the current flowing throughL_1, sameasI_{L1}=I_{mpp}; ΔI_{L2} is the amount of permitted ripple in the current flowing through L_2, same as $I_{L2} = I_{dc}$; ΔV_{C1} is

International Journal for Innovative Engineering and Management Research
A Peer Revieved Open Access International Journal
www.ijiemr.org

permitted ripple in the voltageacrossC_1, same as $V_{C1} = V_{dc}$.

C. Estimation of DC-Link Capacitor of VSI

A new design approach for estimation of dc-link capacitor of the VSI is presented here. This approach is based on a fact that sixth harmonic component of the supply (ac) voltage is reflected on the dc side as a dominant harmonic in the three-phase supply system. Here, the fundamental frequencies of output voltage of the VSI are estimated corresponding to the rated speed and the minimum speed of BLDC motor essentially required pumping the water. These two frequencies are further used to estimate the values of their corresponding capacitors. Out of these two estimated capacitors, larger one is selected to assure a satisfactory operation of proposed system even under the minimum solar irradiance level.

The fundamental output frequency of VSI corresponding to the rated speed of BLDC motor ω_{rated} is estimated as

$$\omega_{\text{rated}} = 2\pi f_{\text{rated}} = 2\pi \frac{N_{\text{rated}} P}{120} = 2\pi \times \frac{3000 \times 6}{120} = 942 \text{ rad/s.} \quad (9)$$

The fundamental output frequency of the VSI corresponding to the minimum speed of the BLDC motor essentially required to pump the water (N= 1100r/min) ω_{min} is estimated as

$$\omega_{\min} = 2\pi f_{\min} = 2\pi \frac{NP}{120} = 2\pi \times \frac{1100 \times 6}{120} = 345.57 \text{ rad/s} \quad (10)$$

Where f_{rated} and f_{min} are fundamental frequencies of output voltage of VSI corresponding to a rated speed and a minimum speed of BLDC motor essentially required to pump the water, respectively, in Hz; N_{rated} is rated speed of the BLDC motor; P is a number of poles in the BLDC motor.

The value of dc link capacitor of VSI at ω_{rated} is as follows:

$$C_{2,\text{rated}} = \frac{I_{\text{dc}}}{6 \times \omega_{\text{rated}} \times \Delta V_{\text{dc}}} = \frac{17}{6 \times 942 \times 200 \times 0.1} = 150.4\ \mu\text{F}. \quad (11)$$

Similarly, a value of dc link capacitor of VSI at ω_{min} is as follows:

$$C_{2,\min} = \frac{I_{\text{dc}}}{6 \times \omega_{\min} \times \Delta V_{\text{dc}}} = \frac{17}{6 \times 345.57 \times 200 \times 0.1} = 410\ \mu\text{F} \quad (12)$$

Where ΔV_{dc} is an amount of permitted ripple in voltage across dc-link capacitorC_2.Finally, C_2= 410μF is selected to design the dc-link capacitor.

D. Design of Water Pump

To estimate the proportionality constant K for the selected water pump, its power–speed characteristics [26], [27] is used as

$$K = \frac{P}{\omega_r^3} = \frac{2.89 \times 10^3}{(2\pi \times 3000/60)^3} = 9.32 \times 10^{-5} \quad (13)$$

Where P = 2.89 kW is rated power developed by the BLDC motor and ω_r is rated mechanical speed of the rotor (3000r/min) in rad/s.

A water pump with these data is selected for proposed system.

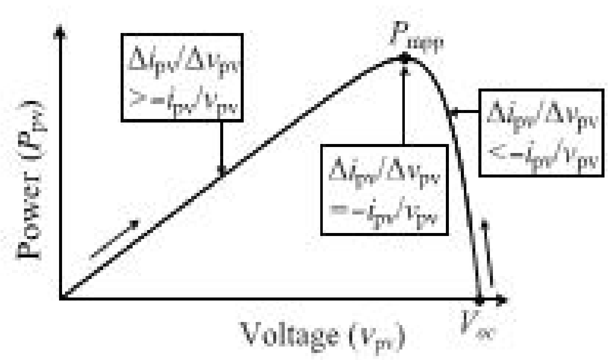


Fig.3. Illustration of INC-MPPT with SPV array P_{pv}–v_{pv} characteristics.

International Journal for Innovative Engineering and Management Research
A Peer Revieved Open Access International Journal
www.ijiemr.org

TABLE.2
Switching States for Electronic Commutation of BLDC Motor

Rotor position θ (°)	Hall signals			Switching states					
	H_3	H_2	H_1	S_1	S_2	S_3	S_4	S_5	S_6
NA	0	0	0	0	0	0	0	0	0
0–60	1	0	1	1	0	0	1	0	0
60–120	0	0	1	1	0	0	0	0	1
120–180	0	1	1	0	0	1	0	0	1
180–240	0	1	0	0	1	1	0	0	0
240–300	1	1	0	0	1	0	0	1	0
300–360	1	0	0	0	0	0	1	1	0
NA	1	1	1	0	0	0	0	0	0

V. CONTROL OF PROPOSED SYSTEM

The proposed system is controlled in two stages. These two control techniques, viz., MPPT and electronic commutation, are discussed as follows.

A. INC-MPPT Algorithm

An efficient and commonly used INC-MPPT technique [8], [13] in various SPV array based applications is utilized in order to optimize the power available from a SPV array and to facilitate a soft starting of BLDC motor. This technique allows perturbation in either the SPV array voltage or the duty cycle. The former calls for a proportional-integral (PI) controller to generate a duty cycle [8] for the zeta converter, which increases the complexity. Hence, the direct duty cycle control is adapted in this work. The INC-MPPT algorithm determines the direction of perturbation based on the slope of $P_{pv} - v_{pv}$ curve, shown in Fig.3. As shown in Fig.3, the slope is zero at MPP, positive on the left, and negative on the right of MPP, i.e.,

$$\left.\begin{aligned} \frac{dP_{pv}}{dv_{pv}} &= 0; && \text{at mpp} \\ \frac{dP_{pv}}{dv_{pv}} &> 0; && \text{left of mpp} \\ \frac{dP_{pv}}{dv_{pv}} &> 0; && \text{right of mpp} \end{aligned}\right\} \quad (14)$$

Since

$$\frac{dP_{pv}}{dv_{pv}} = \frac{d(v_{pv} * i_{pv})}{dv_{pv}} = i_{pv} + v_{pv} * \frac{di_{pv}}{dv_{pv}} \cong i_{pv} + v_{pv} * \frac{\Delta i_{pv}}{\Delta v_{pv}} \quad (15)$$

Therefore, (14) is rewritten as

$$\left.\begin{aligned} \frac{\Delta i_{pv}}{\Delta v_{pv}} &= -\frac{i_{pv}}{v_{pv}}; && \text{at mpp} \\ \frac{\Delta i_{pv}}{\Delta v_{pv}} &> -\frac{i_{pv}}{v_{pv}}; && \text{left of mpp} \\ \frac{\Delta i_{pv}}{\Delta v_{pv}} &< -\frac{i_{pv}}{v_{pv}}; && \text{right of mpp} \end{aligned}\right\} \quad (16)$$

Thus, based on the relation between INC and instantaneous conductance, the controller decides the direction of perturbation as shown in Fig.3, and increases/decreases the duty cycle accordingly. For instance, on the right of MPP, the duty cycle is increased with a fixed perturbation size until the direction reverses. Ideally, the perturbation stops once the operating point reaches the MPP. However, in practice, operating point oscillates around the MPP.As the perturbation size reduces, the controller takes more time to track the MPP of SPV array. An intellectual agreement between the tracking time and the perturbation size is held to fulfill the objectives of MPPT and soft starting of BLDC motor. In order to achieve soft starting, the initial value of duty cycle is set as zero. In addition, an optimum value of perturbation size (ΔD=0.001) is selected, which contributes to soft starting and also minimizes oscillations around the MPP.

B. Electronic Commutation of BLDC Motor

The BLDC motor is controlled using a VSI operated through an electronic commutation of BLDC motor. An electronic commutation of BLDC motor stands for commutating the currents flowing through its windings in a

International Journal for Innovative Engineering and Management Research
A Peer Revieved Open Access International Journal
www.ijiemr.org

predefined sequence using decoder logic. It symmetrically places the dc input current at the center of each phase voltage for 120^o. Six switching pulses are generated as per the various possible combinations of three Hall-effect signals. These three Hall-effect signals are produced by an inbuilt encoder according to the rotor position.A particular combination of Hall-effect signals is produced for each specific range of rotor position at an interval of 60^o [5], [6]. The generation of six switching states with the estimation of rotor position is tabularized in Table II. It is perceptible that only two switches conduct at a time, resulting in 120^oconduction mode of operation of VSI and hence the reduced conduction losses. Besides this, the electronic commutation provides fundamental frequency switching of the VSI; hence, losses associated with high-frequency PWM switching are eliminated. A motor power company makes BLDC motor [28] with inbuilt encoder is selected for proposed system and its detailed specifications are given in the Appendixes.

VI. BLDC MOTOR SPEED CONTROL

In servo applications position feedback is used in the position feedback loop. Velocity feedback can be derived from the position data. This eliminates a separate velocity transducer for the speed control loop. A BLDC motor is driven by voltage strokes coupled by rotor position. The rotor position is measured using Hall sensors. By varying the voltage across the motor, we can control the speed of the motor. The speed and torque of the motor depend on the strength of the magnetic field generated by the energized windings of the motor, which depend on the current through them. Hence adjusting the rotor voltage and current will change motor speed. Commutation ensures only proper rotation of the rotor. The motor speed depends only on the amplitude of the applied voltage. This can be adjusted using PWM technique. The required speed is controlled by a speed controller. This is implemented as a conventional proportional-Integral controller. The difference between the actual and required speeds is given as input to the controller. Based on this data PI controller controls the duty cycle of the PWM pulses which correspond to the voltage amplitude required to maintain the desired speed. When using PWM outputs to control the six switches of the three-phase bridge, variation of the motor voltage can be achieved easily by changing the duty cycle of the PWM signal. In case of closed loop control the actual speed is measured and compared with the reference speed to find the error speed. This difference is supplied to the PI controller, which in turn gives the duty cycle. BLDC motor is popular in applications where speed control is necessary and the current must be controlled to get desired torque. Figure .shows the basic structure for closed loop control of the BLDC motor drive. It consists of an outer speed control loop, an inner current control loop for speed and current control respectively. Speed loop is relatively slower than the current loop.

VII. MATLAB/SIMULATION RESULTS

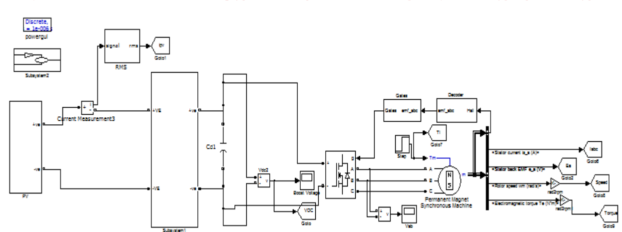
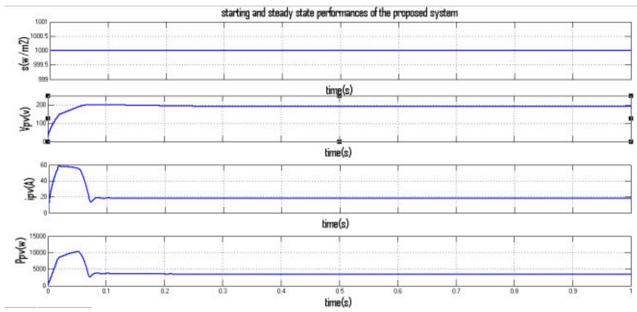
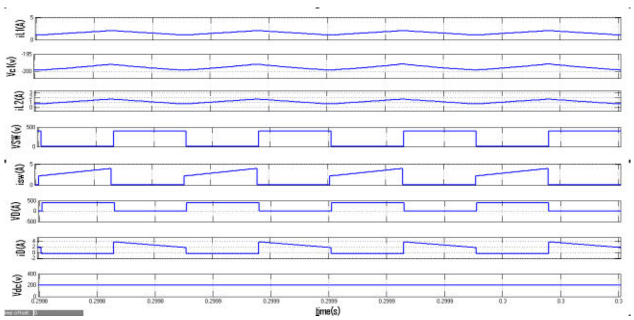


Fig.4 Matlab/Simulink circuit of Starting and steady-state performances of the proposed SPV array based zeta converter-fed BLDC motor drive for water pump

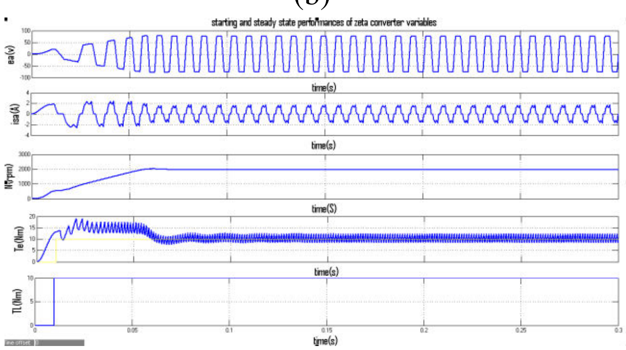
International Journal for Innovative Engineering and Management Research
A Peer Revieved Open Access International Journal
www.ijiemr.org



(a)



(b)



(c)

Fig.5 Starting and steady-state performances of the proposed SPV array based zeta converter-fed BLDC motor drive for water pump. (a) SPV array variables. (b) Zeta converter variables. (c) BLDC motor-pump variables.

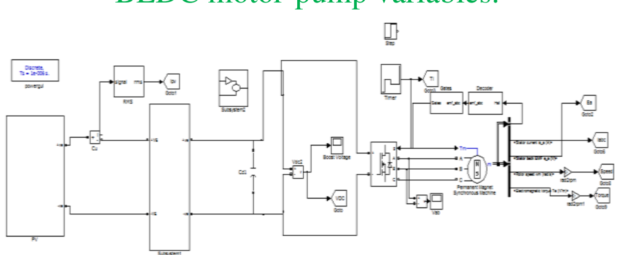
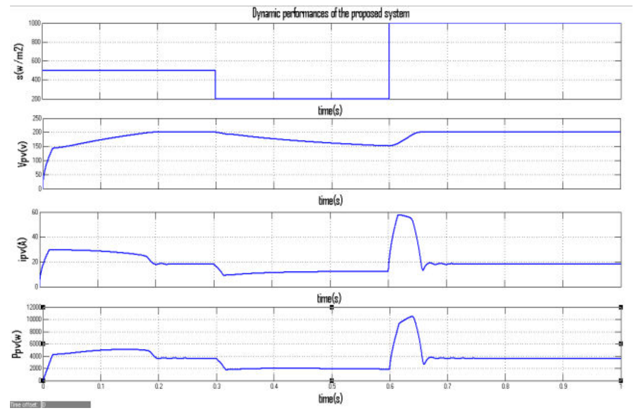
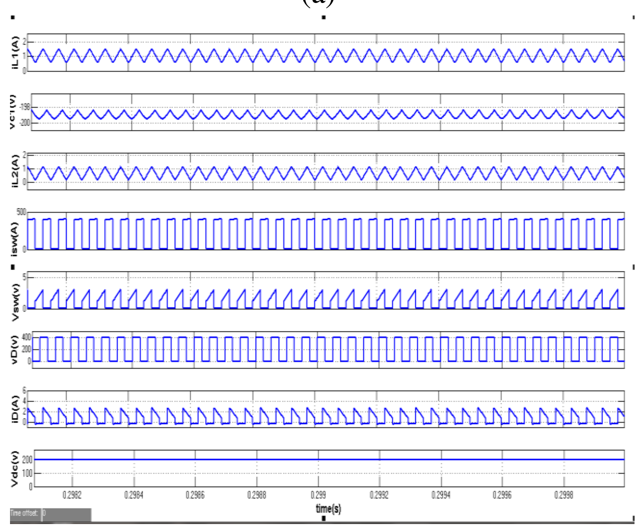


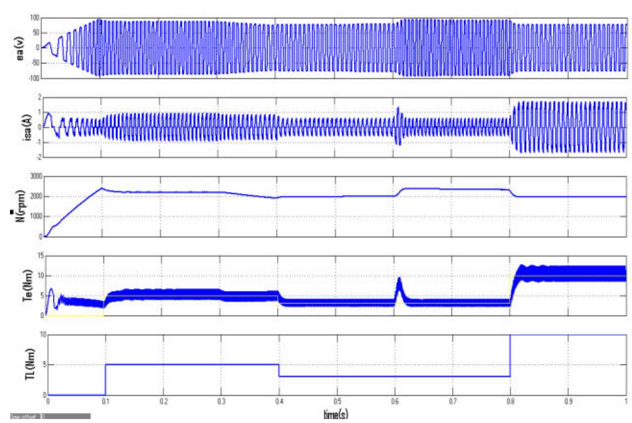
Fig.6 Matlab/Simulink circuit for Dynamic performance of SPV array-based zeta converter-fed BLDC motor drive for water pump



(a)



(b)



(c)

Fig.7 Dynamic performances of the proposed SPV array-based zeta converter-fed BLDC motor drive for water pump. (a) SPV array variables. (b) Zeta converter variables. (c) BLDC motor-pump variables.

International Journal for Innovative Engineering and Management Research
A Peer Revieved Open Access International Journal
www.ijiemr.org

Case: 1 BLDC Motor with constant speed

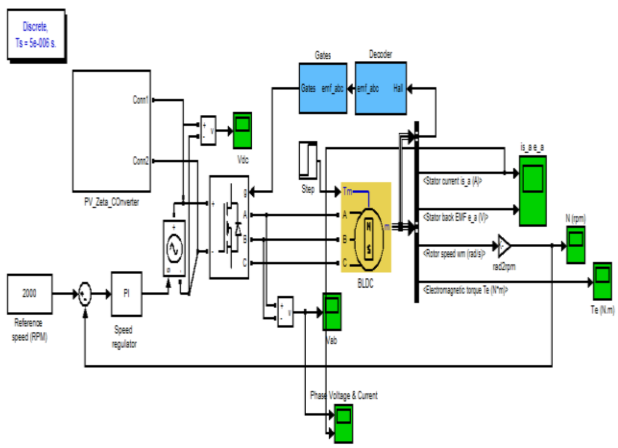
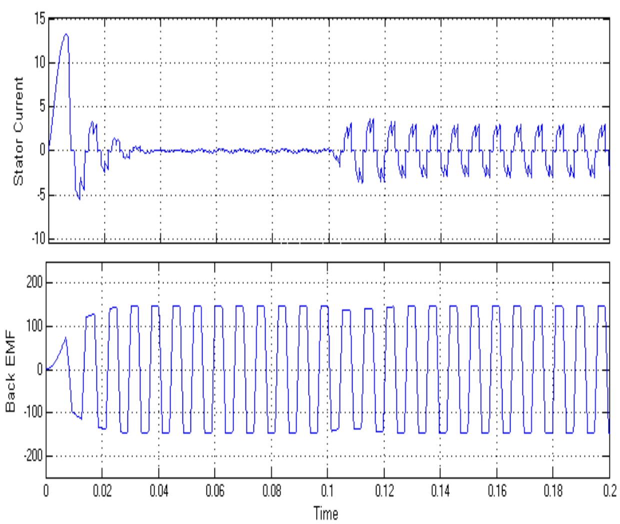
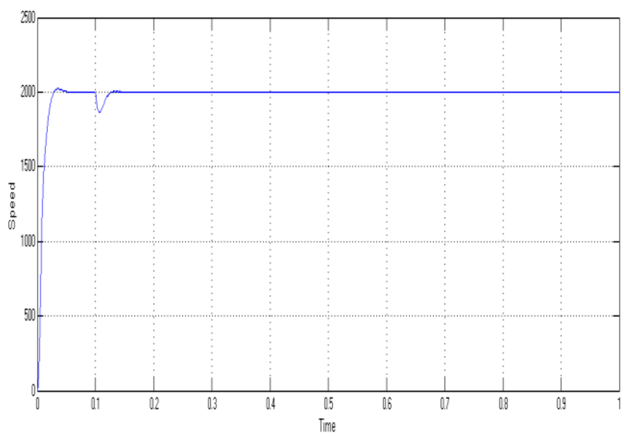


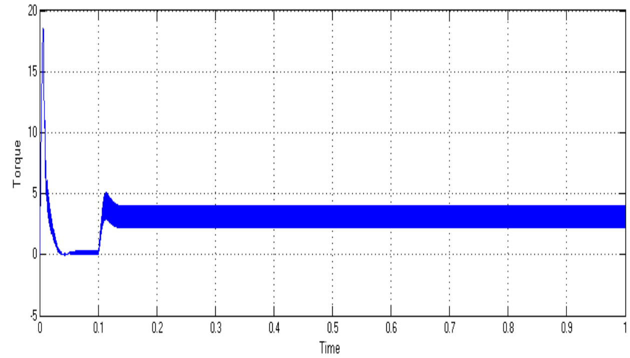
Fig.8 Simulink model of BLDC motor Drive with constant speed



(a)



(b)



(c)

Fig.9 (a) Stator Current and back EMF (b) Speed of the BLDC motor
(c) Torque characteristics of BLDC motor

Case: 1 BLDC Motor with variable speed

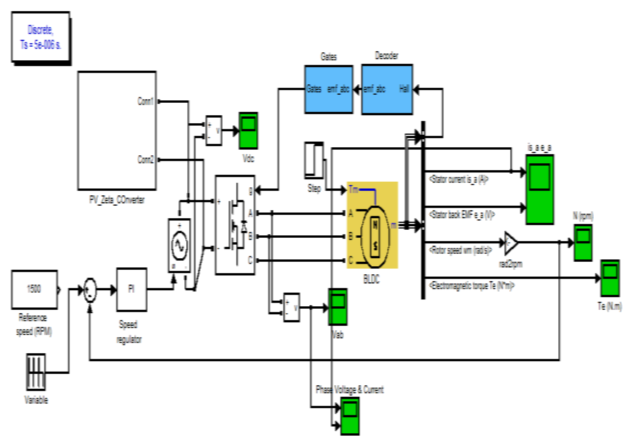
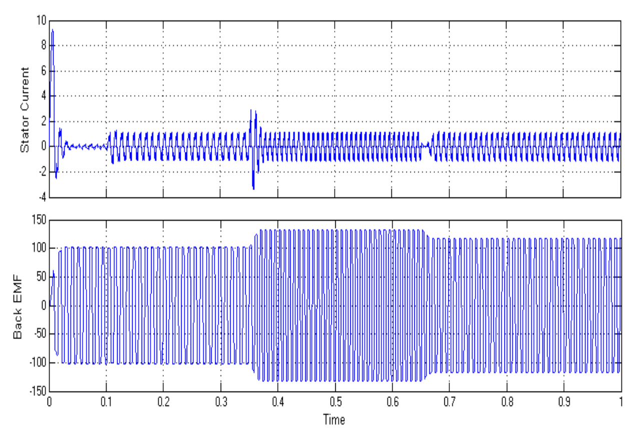
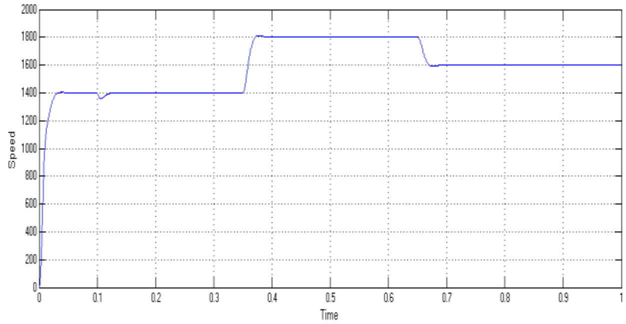


Fig.10 Simulink model of BLDC motor Drive with variable speed

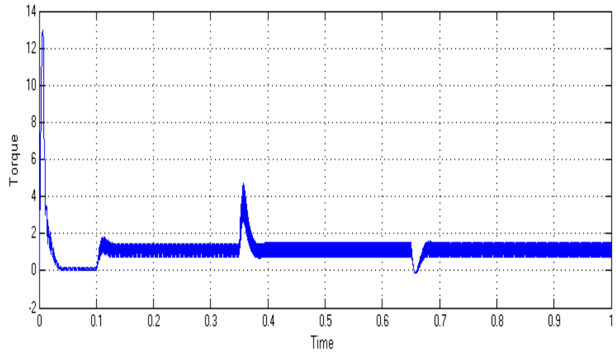


(a)

International Journal for Innovative Engineering and Management Research
A Peer Revieved Open Access International Journal
www.ijiemr.org



(b)



(c)

Fig.11 (a) Stator Current and back EMF (b) Speed of the BLDC motor
(c) Torque characteristics of BLDC motor

VIII CONCLUSION

The simulation of a PV based Brushless DC Motor was done. In order to extract the maximum possible power from the PV module, a PI based MPPT technique along with a Zeta converter was modelled and evaluated. The modeling and performance analysis of BLDC motor under different operating speed conditions has been presented. It helps in simulation of various operating conditions of BLDC drive system. The performance analysis of BLDC motor under different operating speed conditions are presented it shows that, such a modeling is very useful in studying the drive system before taking up the dedicated controller design, accounting the relevant dynamic parameters of the motor.

REFERENCES

[1] Menka Dubey, Shailendra Sharma, “Solar PV Stand-Alone Water Pumping System Employing PMSM Drive” Member IEEE and Rakesh Saxena Electrical Engineering Department 2014 IEEE Students’ Conference on Electrical, Electronics and Computer Science

[2] Hamza Bouzeria etal “Speed Control of Photovoltaic Pumping System” international journal of renewable energy research, vol.4, no.3, 2014

[3] R. Teodorescu, M. Liserre and P. Rodriguez, Grid Converters for Photovoltaic and Wind Power Systems, 1st edition, John Wiley, United Kingdom, 2011.

[4] M.G Villalva, J.R. Gazoli and E.R. Filho, “Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays,” IEEE Trans. Power Electronics, vol. 24, no. 5, pp. 1198-1208, Mar. 2009.

[5] W. J. A. Teulings, J. C. Marpinard, A. Capel, and D. O’Sullivan, “A new maximum power point tracking system,” Proc. IEEE 24th Annu. Power Electron. Spec. Conf., Jun. 1993, pp. 833–838.

[6] T. Esram and P. L. Chapman, “Comparison of photovoltaic array maximum power point tracking techniques,” IEEE Trans. Energy Conversion, vol. 22, no. 2, pp. 439-449, June 2007.

[7] F. Mayssa , F. Aymen and S. Lassaad, “ Influence of photovoltaic DC bus voltage on the high speed PMSM drive,” Proc. IEEE IECON Conf., Oct. 2012 , pp. 4489 - 4494.

[8] H. Moussa, M. Fadel and H. Kanaan, “A single stage DCAC boost topology and control for solar PV systems supplying a PMSM,” in Proc REDEC Conf., Nov.2012, pp.1-7.

[9] J. M. Shen, H. L. Jou and J. C. Wu, "Novel transformer less grid connected power converter with negative grounding for photovoltaic generation system," IEEE Trans. Power Electronics, vol. 27, no. 4, pp. 1818-1829, Apr. 2012.

[10] A. K. Verma, B. Singh and T. Shahani, "Grid interfaced solar photovoltaic power generating system with power quality improvement at ac mains," Proc IEEE ICSET Conf., Sep. 2012, pp. 177-182.

[11] H. Moussa, M. Fadel and H. Kanaan, "A single-stage DCAC boost topology and control for solar PV systems supplying a PMSM," in Proc REDEC Conf., Nov. 2012, pp. 1-7.

[12] W. Lawrance, B. Wichert and D. Langridge, "Simulation and performance of a photovoltaic pumping system," Proc. Power Electronics and Drive systems Conf., vol. 1, Feb. 1995. pp. 513–518.

[13] S. Henneberger, S. V. Haute, K. Hameyer and R. Belmans, "Submersible installed permanent magnet synchronous motor for a photovoltaic pump system," Proc. IEEE Electric Machines and Drives Conf., May 1997, pp. WB2/10.1 - WB2/10.3.

[14] P. Vas, Sensor less Vector and Direct Torque Control, Oxford University Press, 1998.

[15] B. K. Bose, Power Electronics and Variable Frequency Drives Technology and Application, IEEE Press, New York, 1996.