

Control of brushless DC motors for healthcare equipment using PV-fed ZETA converters

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ABSTRACT

This paper proposes a zeta converter fed photovoltaic array as input power source for effective control of BLDC motor. The maximum power available from the SPV array is attained and it is conveniently utilized by the Zeta converter. The voltage source inverter (VSI) is used to perform electronic commutation of the BLDC motor and it plays a vital role in avoiding switching losses caused by the high frequency switching pulses. The output power of the zeta converter is used to drive the BLDC motor. The speed control of BLDC motor is resolved by governing the switching pulses of VSI by the electronic commutation of the BLDC motor. The suitability of proposed system at different possible operating conditions is exhibited through simulation results using MATLAB/ Simulink software.

Keywords: BLDC motor, SPV array, Zeta converter

INTRODUCTION

In current scenario, solar energy is an important non-conventional energy resource to meet the electrical load demand for the consumer and to supply the electricity for rural areas. Solar Photovoltaic system is one of the non – conventional energy sources which are used for various applications like lightening load, water pumping and fan etc. 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 accomplished by consuming Maximum power point tracking (MPPT) algorithm for better competence. Generally, in MPPT, Perturb and Observe (P&O) algorithm is widely adopted. In this, slide mode control is used for maximum power tracking.[12] While many researches have been done in an area of SPV array, joining various DC-DC converters and motor drives, the zeta converter in association with a permanent magnet brushless DC (BLDC) motor is not discovered accurately so far to develop such type of system. Though, the zeta converter has been used in certain new

SPV based applications [1-3]. 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 [4-6]. Belonging to a family of buck-boost converters, the zeta converter may be operated either to increase or to decrease the output voltage. This property is completely utilized for maximum power point tracking (MPPT) of a SPV array [7]. The MPPT can be performed with simple buck [8] and boost [9] converter if MPP occurs within certain described limits. Although consisting of same number of components as a Cuk converter [10], the zeta converter operates as non-inverting buck-boost converter unlike an inverting buck boost and Cuk converter. In this work Zeta converter is preferred when compare to the other conventional DC-Converters due to the advantages of soft starting, continuous output current, low ripple input and output currents [11]. In general, a zeta converter has many advantages over the conventional buck, boost, buck-boost converters and Cuk

converter when it is combined with SPV applications. In this work, speed of the BLDC motor is controlled through the variable link voltage, hence no additional sensors are required for speed control. Furthermore, the VSI is operated, by electronic commutation, with the pulses of fundamental frequency, which minimizes the switching losses.

CIRCUIT CONFIGURATION

The structure of this proposed system contains SPV array fed BLDC motor drive with zeta converter. It contains SPV array, zeta converter, MPPT with sliding mode controller, VSI, BLDC motor.

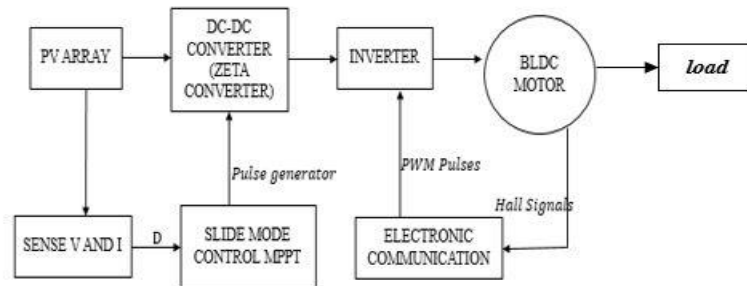


Fig. 1: Overall Design.

The structure of this proposed system contains SPV array fed BLDC motor drive with zeta converter. It contains SPV array, zeta converter, MPPT with sliding mode controller, VSI, BLDC motor. The implementation of zeta converter is used in order to extract the maximum power from solar PV array, soft starting and speed control of BLDC motor. This zeta converter is operated in continuous conduction mode results in a reduced accentuation in power devices and components. There are many techniques to maximize the (PV) power that transfer to various loads they are perturb and observe algorithm, the incremental conductance method, the open circuit voltage method, the short circuit voltage method. The P&O method is most widely used method. This algorithm is not suitable when there is a variation in the solar irradiation is high. The voltage never actually reaches an explicit value but perturbs around the maximum power point (MPP). From this it “perturbs” the terminal voltage of the solar panel by incrementing or decrementing it and compares the new calculated output

power to the previously calculated one. The algorithm is operated until the maximum power point (MPP) is achieved. In this, new control method for MPPT is used that is slide mode control method. The SPV array, zeta converter and BLDC motor are designed such that which exhibits the performance with the solar irradiance level.

DESIGN OF PROPOSED SYSTEM

The suitable design of the system for the efficient operation under the unsure conditions. A BLDC motor of 1 HP 2000rpm power rating and solar PV array of 110V 5A 550 W peak power capacities are selected to design the system. The detailed design of SPV array, zeta converter and BLDC motor are described as follows.

Design of Photovoltaic System

Among all the renewable energy sources, the energy through the photovoltaic effect is the most essential of solar radiant energy.

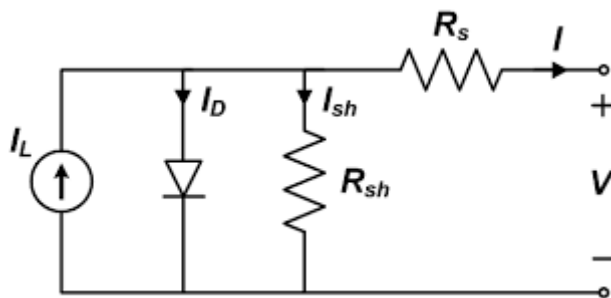


Fig. 2: Equivalent Circuit of a Solar Cell.

Solar cell is the building blocks of solar panel. The output of the current source is directly relative to the light falling on the cell. During darkness, the solar cell is not an active device; it acts as a diode.

In this I and V signifies the output current and voltage of solar cell. R_s And R_{sh} are the series and shunt resistances correspondingly. I_l and I_d are photo current and diode current. The characteristics are given by

$$I = I_l - I_0 \left(\exp\left(\frac{q(v + IR_s)}{AKT}\right) - 1 \right) - \frac{v + IR_s}{R_{SH}} \quad (1)$$

The electrical specifications of the solar panel is listed in table [1]

Table 1: Specifications of Solar PV Array.

Peak power, P_{pv} (watt)	1700
Open circuit voltage, V_0 (V)	17.2
Short circuit current, I_s (A)	5.45
Voltage at MPP, V_m (V)	68.4
Current at MPP, I_m (A)	4.95

Mathematical Modelling of Zeta Converter

A zeta converter is a fourth order nonlinear system being that, with concern to energy input, it can perceive as buck-boost-buck converter and with concern to the output, it can be understood as boost-buck-boost converter. The zeta converter is neighboring to the SPV array. This design consists of various components such as input inductor, L_1 , output inductor, L_2 , input capacitor, C_1 , output capacitor, C_2 . These

components are designed such that the zeta converter is operated in Continuous Conduction Mode.[14,15]

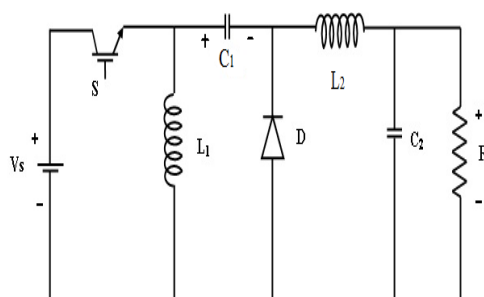


Fig. 3: Basic Zeta Converter Circuit.

The Duty Cycle D, initiates the design of zeta converter.

The output voltage is given by,

$$\frac{V_0}{V_{in}} = \frac{D}{1-D} \quad (2)$$

The duty cycle of zeta converter is given by,

$$D = \frac{V_0}{V_0 + V_{in}} \quad (3)$$

$$D = 0.52$$

The input inductor L_1 , output inductor L_2 , is given by,

$$L_1 = L_2 = \frac{NV_{in}DT_s}{\Delta I_0} \quad (4)$$

$$L_1 = 5.1 \mu H; L_2 = 5mH$$

The coupling capacitor C_1 , output capacitor C_2 is given by,

$$C_1 = \frac{1-D}{8 f_s^2 L_1 \Delta V_0} \quad (5)$$

$$C_2 = \frac{I_0 D}{0.5f \Delta V_{C2}} \quad (6)$$

$$C_2 = 6000 \mu F$$

where f is the switching frequency, ΔV_{C1} and ΔV_{C2} are the voltage ripples of two capacitors.

Specifications of BLDC Motor

The specifications of BLDC motor for this work is given in table. [2]

Table 2: Specifications of BLDC Motor.

Power rating	1 HP (746 W)
Speed , N	2000 rpm
DC voltage	48 V
No. Of. Poles	4
Torque constant	0.75Nm/A
Stator phase resistance, R_s	0.2 ohm
Stator phase inductor, L_s	0.1245e-3

METHODOLOGY OF PROPOSED SYSTEM

The SPV array brings about electrical power from the solar irradiance. This electrical power is fed to the BLDC motor via a zeta converter and a VSI. The SPV array acts like a power source for the zeta converter. The output voltage of the zeta converter appears as a power source of the VSI. In many cases, various losses are associated with DC-DC converters so there will be low amount of power is equipped and it is deliver to VSI. The pulse generator generates pulses via sliding mode control of MPPT, switching pulses for MOSFET (Metal-Oxide-Semiconductor Field Effect Transistor) switching the zeta converter. The MPPT uses the voltage and current as feedback from SPV array and generates optimum value for the duty cycle. The VSI, DC-AC converter which is used for converting DC output from the zeta converter to AC that is fed to BLDC motor. The VSI is mainly operating under the fundamental frequency switching through an electronic commutation of BLDC motor. The proposed system is controlled by two stages. This proposed system employs two techniques. They are

- MPPT using Slide Mode Control
- Electronic commutation of BLDC motor

MPPT

A maximum power point tracker (MPPT) is used for extracting the maximum power from the solar PV module and transferring that power to the motor. The peak power is got with the help of a DC-DC converter by modifying its duty cycle such that the resistance resultant to the peak power is attained.

There are various approaches used for maximum power point tracking some of them are listed below:

- Perturb and Observe method
- Incremental Conductance method
- Parasitic Capacitance method
- Constant Voltage method
- Constant Current method

Sliding mode control

Sliding Mode Control (SMC) is a nonlinear control technique. This method is robust, accurate and easy for tuning. The implementation of this method is very effective [13]. The two main advantages of sliding mode control is the dynamic characteristics of the system by particular choice of the sliding function and it plays an important role in making closed loop response. The analysis and design of a SMC focused at performing a fast MPPT action on grid-connected PV systems using a single control stage. This method avoids the dependency between cascade controllers, by decreasing the number of

controllers and avoids the use of linearized models to deliver global stability in all the operating ranges. In this method, even the use of a PWM is not needed. Such a compact design also reduces the system cost and complexity.

The main application of the SMC for MPPT is the inductor current of a DC-DC converter is governing by using sliding mode controller.

Electronic Commutation of BLDC Motor

Brushless DC motor also recognized as electronically commutated motors which might be powered by a DC given via an inverter switching power supply, which creates an AC electric signal to drive the motor. DC brushless motors are controlled with switching commutation logic. The higher efficiency, reliability, maintenance free properties of BLDC motor attracts the attention to apply in solar powered application. An electronic commutation of BLDC motor stands for commutating the

currents sinuous through its windings in a predefined sequence using decoder logic. It symmetrically put the DC input current at the center of each phase voltage for 120°. Six switching pulses are generated by several likely combinations of three Hall-effect signals. These three Hall-effect signals are produced by an encoder according to rotor positions. The particular combination of hall-effect signals is produced for each specific range of rotor position at an interval of 60°.the switching sequence using hall signal angle of switching done in two modes 60° angle & 120° angle mode. When hall signal h_c is high the switch S4-S5 conducts similarly sequence is S4-S5, S2-S3, S2-S5, S1-S6, S1-S4 and S3-S6. A 3 phase BLDC motor requires three Hall sensors to detect the rotor’s position. Grounded on the physical position of the Hall sensors, there are two types of output a 60° phase shift and a 120° phase shift. Joining these three Hall sensor signals can determine the accurate commutation sequence.

Table 3: Switching States for Electronic Commutation for BLDC Motor.

Rotor position $\theta(^{\circ})$	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

SIMULATION RESULTS AND DISCUSSIONS

The performance of the proposed system is designed, modelled and simulated using MATLAB/ simulations in MATLAB R2016b software.

The performance of the solar PV array is under the conditions at 1000w/m². The MPP is tracked by SMC. The optimal maximum voltage obtained by MPP is 340v. The irradiance that is utilized to obtain the voltage at MPP is 800w/m². The outputs are shown in the following figures (4) and (5).

Design and Performance of Solar PV Array

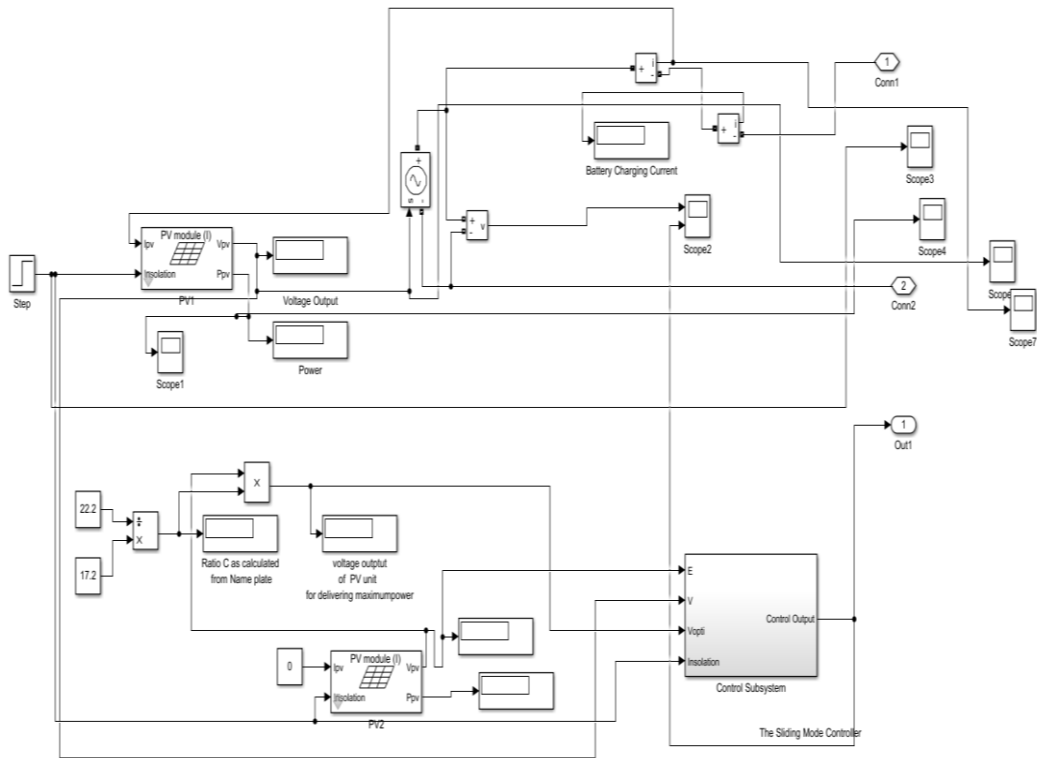


Fig. 4: Simulation of PV Array.

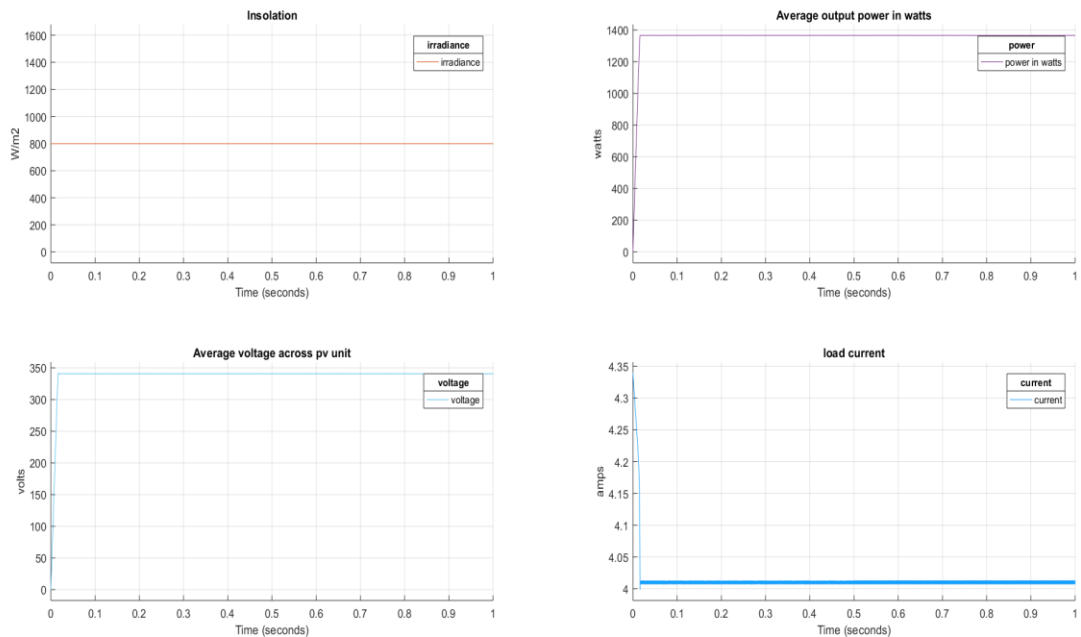


Fig. 5: Results of PV Array.

Design and Simulation of Zeta Converter

The design and operation of the converter is mostly depending upon the irradiance level of the solar PV. The Zeta converter is a buck –boost converter so it has the

capability to change its mode of operation from buck to boost or its vice-versa according to the irradiance level and the duty cycle. The simulation results are shown in figures (6) and (7).

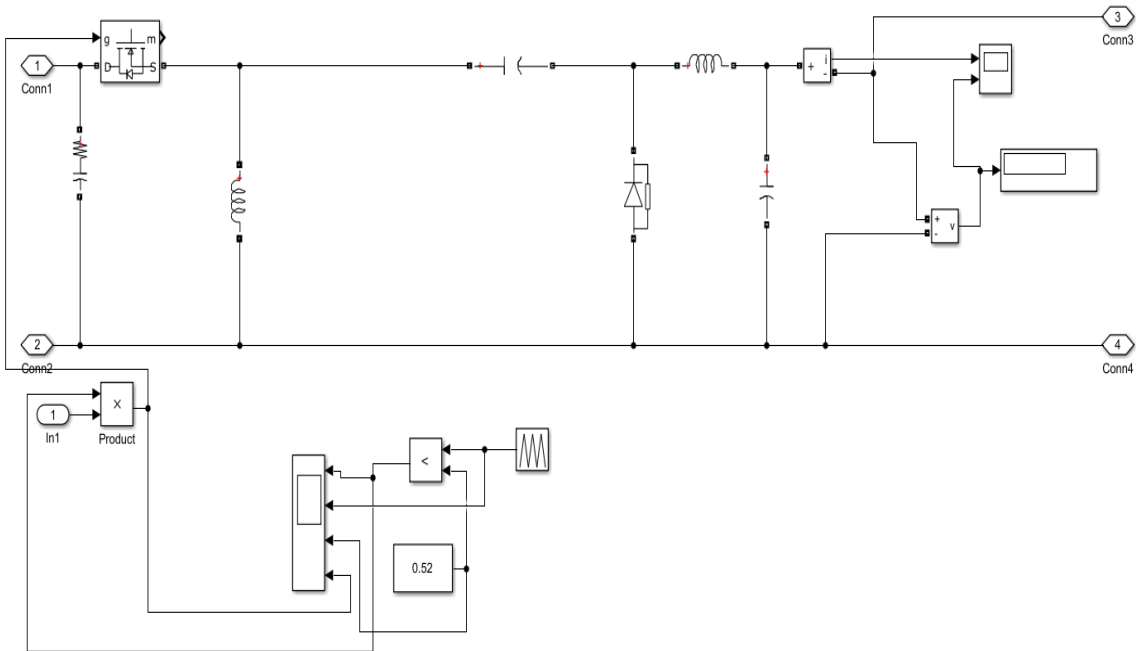


Fig. 6: Simulation of Zeta Converter.

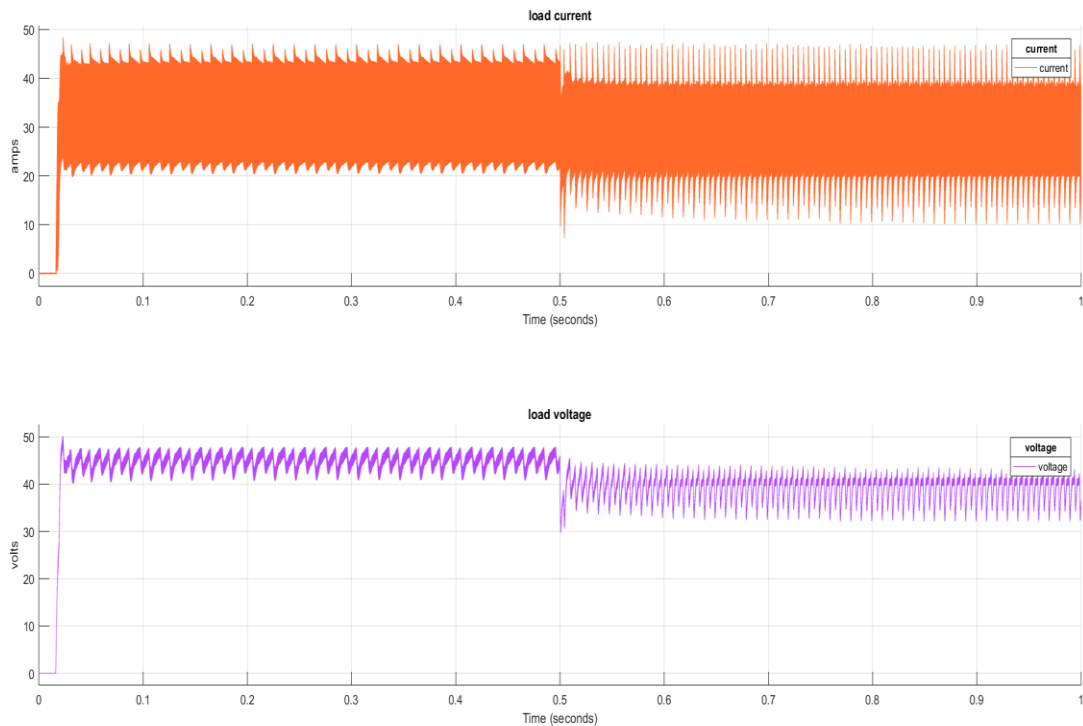


Fig. 7: Results of Zeta Converter.

Performance of BLDC Motor and its Results

The BLDC motor has the rated values of 1-HP (746 watts),2000rpm motor draws

power from solar PV array. Thus the torque and speed is estimating from the performance of the BLDC motor and it is mentioned in the figures (8) and (9).

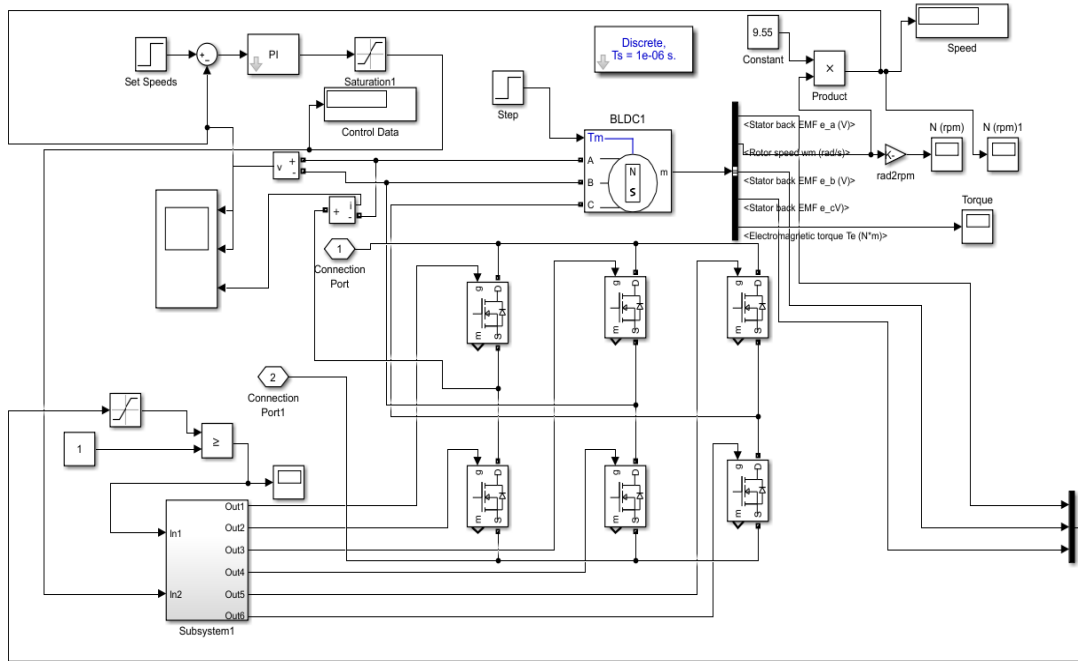


Fig. 8: Simularion of BLDC Motor.

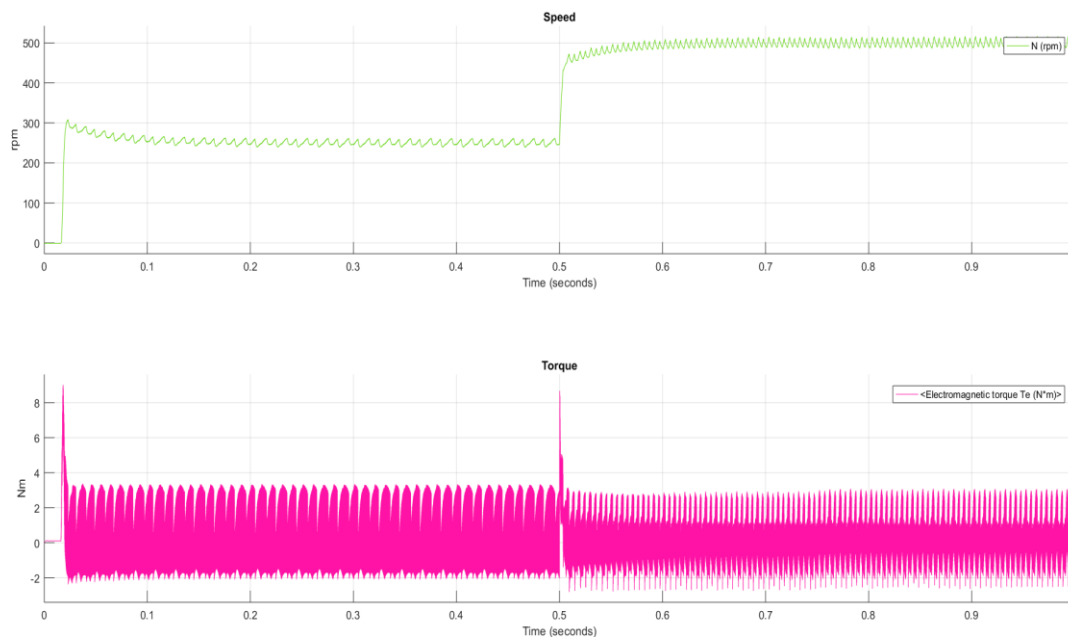


Fig. 9: Results of BLDC Motor.

PERFORMANCE ANALYSIS OF EXISTING AND PROPOSED SYSTEM OF BLDC PUMP SYSTEM

Table 4: Performance Analysis of Existing System.

Sw/m ²	P _{pV} (watts)	P _m (watts)	η(%)
700	535	438	78
800	1172	938	79
1000	1488	1190	80

Table 5: Performance Analysis of Proposed System.

Sw/m ²	P _{pv} (watts)	P _m (watts)	η(%)
700	1191	938	78
800	1366	1190	87
1000	1703	1512	88

CONCLUSION

The Solar PV array Zeta converter fed VSI –BLDC motor has been designed through the simulation results .In this maximum power point is tracked by using slide mode controller . The speed and the torque of the motor is estimated and the switching pulses for VSI is obtained by electronic commutation of BLDC motor is achieved.The efficiency of the BLDC motor is tabulated at different levels of irradiances.

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