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Torque Ripple Reduction Method for BLDC Motor for SPV fed Water Pumping System Employing Zeta Converter

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ABSTRACT: This paper proposes a simple, cost-effective, and efficient brushless dc (BLDC) motor drive for solar photovoltaic (SPV) array-fed water pumping systemwith torque ripple reduction.To extract maximum available power from SPV array a zeta converter is utilized.Phase current sensors are eliminated by the proposed control algorithmand uses a fundamental frequency switching of the voltage source inverter (VSI), thus the power losses due to high frequency switching are avoided.The cost and bulkiness of motor drive is reduced by the elimination of dc link capacitor but it results torque ripple to arise at the output of motor. A new method is proposed where the dc link capacitor is replaced by a ceramic capacitor and a switch to minimize the torque ripple.An appropriate control of zeta converter through the incremental conductance maximum power point tracking (INC-MPPT) algorithm offers soft starting of the BLDC motor. Simulations are performed using MATLAB/SIMULINK software and the results are presented.

KEYWORDS: Brushless Dc (BLDC) Motor, Solar Photovoltaic(SPV), Voltage Source Inverter(VSI), Incremental Conductance Maximum Power Point Tracking(INC-MPPT).

I.INTRODUCTION

The increasing growth on energy demand is mostly met by the use of fossil fuels. At the same time, it is responsible for many environmental hazards including global warming. Hence the concept of using renewable energy resources have received wide attention nowadays in many applications water pumping, irrigation, household applications etc. The use of solar PV water pumping system in remote areas are economical and have advantages like pollution free generation, no running cost and large abundance in nature

DC motors and AC motors are used for driving the water pumps. BLDC motors have several advantages over DC motors and induction motors like high efficiency, long operating life, high torque to weight ratio, less maintenance and better speed torque characteristics. To get constant voltage at the input of the inverter, a bulkier dc link capacitor is used. Operating temperature affects the life time of the dc link capacitor. And also the cost is about 5-15% of overall cost of BLDC motor drive. A method to reduce the torque ripple associated with the elimination of dc link capacitor is proposed in this paper. The advantages and desirable features of both zeta converter and BLDC motor drive contribute to develop a simple, efficient, cost-effective, and reliable water pumping system based on solar PV energy.

II.PROPOSED SYSTEM

Figure.1 shows the configuration of the proposed system. It consists of a solar PV array, a zeta converter, a VSI, BLDC motor and a water pump. The electric power demanded by the pump is generated by the SPV array. The dc voltage from the panel is stepped up or stepped down to a regulated dc voltage by the zeta converter.Switching pulses for the switch of the zeta converter is generated by the pulse generator through INC MPPT algorithm. The INC-MPPT algorithm uses voltage and current as feedback from SPV array and generates an optimum value of duty cycle. The actual switching pulse is generated by comparing the duty cycle with a high-frequency carrier wave.

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The dc output from a zeta converter is converted into ac by the VSI, 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.

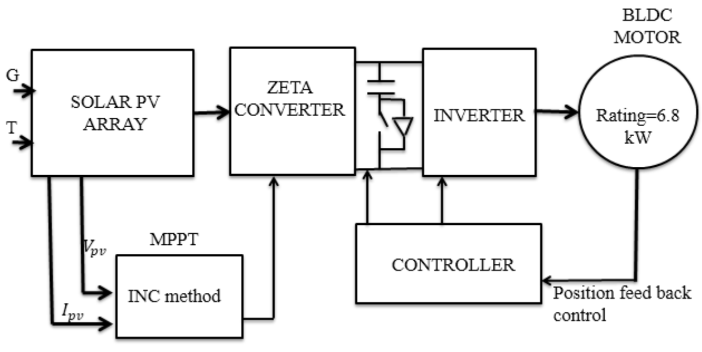

Fig.1 Configuration of the proposed system

A. MODELLING OF PV MODULE

Solar cells are the basic components of photovoltaic panels. Most are made from silicon even though other materials are also used. Solar cells take advantage of the photoelectric effect: the ability of some semiconductors to convert electromagnetic radiation directly into electrical current. The charged particles generated by the incident radiation are separated conveniently to create an electrical current by an appropriate design of the structure of the solar cell.

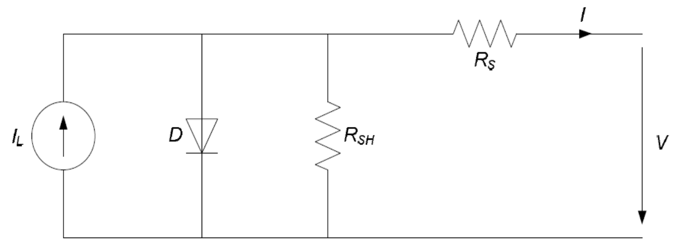

Fig.2 Equivalent Circuit of Solar Cell

Asolarcellcanberepresentedbyacurrentsource parallel withadiode,ahighresistanceandserieswithasmall resistance. Figure 2 shows the equivalent circuit of a solar cell.
The output current-voltage characteristic of a PV panel is expressed by equation (1), where $n_p$and $n_s$are the number of solar cells in parallel and series respectively.

$$I = n_p\, I_{PH} - n_p\, I_O\,(e^{\frac{q(V-IRs)}{AkTns}} - 1) \qquad (1)$$

$$I_{PH} = [I_{SC} + K_i(T-T_{ref})]\,\frac{B}{1000} \qquad (2)$$

I is the load current, I_{PH} / I_L is the photocurrent , I_S / I_O is the diode current , q is the electron charge , V is the terminal voltage of the cell , N is the diode ideality factor , K is the Boltzmann constant, T is the cell temperature , R_S and R_{SH} is the series and shunt resistance respectively.Where Isc is the short circuit current of the PV cell, T is the current atmospheric temperature andT_{ref} is the temperature at nominal condition (25oC and 1000W/m2), G is the current irradiancelevel.Maximum power capacity of array is 7 kW to drive a 6 kW pump. A 250 W PV module is simulated

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and themodules are connected in series and parallel to attain a 7 kW PV array. Table I shows the parameters of the pv module.

TABLE I
PV MODULE PARAMETERS

ELECTRICAL PARAMETERS	VALUE
Maximum Power (P_{max})	250 W
Open Circuit Voltage (V_{OC})	37.6 A
Short Circuit Current (I_{SC})	8.66 A
Number of Series Cells (N_s)	60

We make use of maximum power point techniquesto utilize the trapped power from the available power from the sun. The implementation of technique can be done on the dc-dc converter to change its duty ratio, so as to obtain the required voltage at the output of converters.Of the different MPPT techniques, Incremental conductance method is used here. The method senses voltage and current of the PV panel. At maximum power point, the slope of PV curve is zero(dP/dV=0). Slope of PV curve increases on positive of MPP and decreases on negative of MPP.

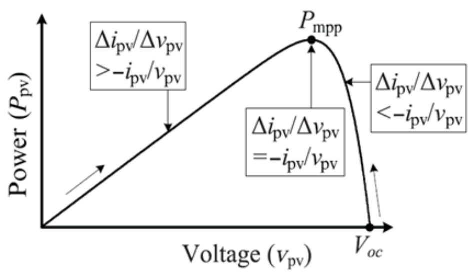

Fig.3.Illustration of INC-MPPT with SPV array P_{pv}–V_{pv} Characteristics.

B.ZETA CONVERTER

The PV array is followed by a zeta converter. Figure 4 shows the circuit diagram of the zeta converter. The converter gives a positive regulated voltage at the output. The output voltage depends on the duty ratio of converter. The converter have two modes of operation. In the first mode , switch is ON and diode is OFF. Current will be drawn from the voltage source. And hence charging mode. In the second mode switch is OFF and diode is ON. Since all the energy stored in L_2 is transferred to the load, this mode is called discharging mode.
An estimation of the duty cycle D initiates the design of zeta converter which is given as

$$D = \frac{Vdc}{Vdc + Vmpp} = \frac{200}{200 + 187.2} = 0.52 \quad (3)$$

$$Idc = \frac{Pmpp}{Vdc} = \frac{3400}{200} = 17A \quad (4)$$

$$L1 = \frac{DVmpp}{fsw\,\Delta I_{L1}} = \frac{0.52 \times 187.2}{20000 \times 18.16 \times 0.06} = 4.5e-3 \approx 5mH \quad (5)$$

$$L2 = \frac{(1-D)Vdc}{fsw\Delta I_{L2}} = \frac{(1-0.52) \times 200}{20000 \times 17 \times 0.06} = 4.7e-3 \approx 5mH \quad (6)$$

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$$C_1 = \frac{DIdc}{fsw\Delta Vc1} = \frac{0.52 \times 17}{20000 \times 200 \times 0.1} = 22\mu F \quad (7)$$

$$C2 = \frac{Idc}{6 \times wmin \times \Delta Vdc} = \frac{17}{6 \times 345.57 \times 200 \times 0.01} = 410\mu F \quad (8)$$

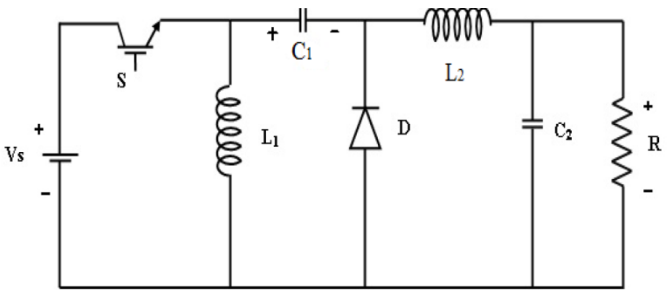

Fig.4. Circuit Diagram of Zeta Converter

C.MODELLING OF BLDC MOTOR

BLDC motors are synchronous motors, which work on the same principle of dc motors. They are electronically commutated motors. Energization of stator windings in a sequence to make rotor running is called commutation. Motor consists of three phase stator windings which are connected in star fashion, rotor made of permanent magnets and a hall sensor. Hall sensors are used to sense the position of rotor so as to know which winding will energize next. A 3 phase,star connected trapezoidal back emf type BLDC motor is used for the mathematical modeling. For simplifying equations and the model, it is assumed that eddy current and hysteresis losses are neglected, armature reaction is not considered and stator windings are symmetrical and concentrated [3].The matrix equation of phase voltages is:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} p \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (10)$$

where R is the resistance of each phase (Ω), L is the self-inductance of each phase (H), M is the mutual inductance between any two phases, Va, Vb, Vc are the stator phase voltages (V), ia, ib, ic are the stator phase currents in (A), e_a, e_b, $e_c$are the back emf signals (V) of BLDC motor and p is the differential operator.

In a three phase BLDC motor back emf is related to as a function of rotor position. Rotor position function is a unit function generator which has a maximum value of +1 or -1 which have a phase difference of 120° between each phase[5]

$$e_a = k_w f(\theta_e)\omega \quad (11)$$
$$e_b = k_w f(\theta_e - 2\pi/3)\omega \quad (12)$$
$$e_c = k_w f(\theta_e + 2\pi/3)\omega \quad (13)$$

Where k_w is back EMF constant of one phase [V/rad.s^{-1}],θ_e is electrical rotor angle [° el.],ω is rotor speed [rad. s^{-1}]
The electromagnetic torque is ;

$$T_e = \frac{e_a i_a + e_b i_b + e_c i_c}{\omega} \quad (14)$$

The mechanical torque is given by

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$$T_e - T_l = J\frac{d\omega}{dt} + B\omega \quad (15)$$

where T_l is load torque [Nm], J is inertia of rotor and coupled shaft [kgm^2],B is friction constant [Nm.s.rad^{-1}].
The parameters of the motor is shown below in Table II

TABLE II
MOTOR PARAMETERS

Motor Parameters	Values
Stator inductance per phase	2.55 m H
Stator resistance per phase	0.43Ω
Moment of inertia, J	0.0689 kgm^2
Friction coefficient, B	0.05 $Nm.s.rad^{-1}$
Rated speed	3000rpm
Rated power	6.8kW
Back emf constant	0.51 $V/rad.s^{-1}$

D. DESIGN OF WATER PUMP

For water pumping application, a centrifugal pump is coupled to the shaft of the motor.The requirement of water to be pumped is given as the load torque to the BLDC motor.Motor runs in different speed according to the load requirement of the centrifugal pump.A centrifugal pump of 6 kW power rating is selected for proposed system. An outputpower, P of a centrifugal water pump is given as,

$P= k_w w_m^2$ (16)

Where k_w is a constant in $Watt/(rad/sec)^3$and w_m is the mechanical speed in of rotorin rad/sec.Constant k_w is calculated using the torque-speedcharacteristics of a centrifugal pump[4] as,

$k_w = T_L / w_m^2$(17)

E. TORQUE RIPPLE COMPENSATION

The idea to eliminate the bulkier dc link capacitor causes the introduction of torque ripples at the output of motor. Hence a new method proposed is a low value inexpensive capacitor (ceramic capacitor) and a switch connected between the converter and the inverter. The ceramic capacitor used to reduce the torque ripple has a value of 25 µF which replaces a 470 µF dc link capacitor. A switch with antiparallel diode is used to provide the required current to run the motor. The motor drive is fed with a voltage between 0 to 325 V without a dc link capacitor. The build-up of phase current is possible when rectified mains voltage is greater than back emf. With the compensation technique, capacitor is charged when input voltage is less than back emf. Energy stored in capacitor is discharged when Vm< E, so that current in motor is maintained at current reference [7]. Discharge of capacitor can be controlled by gating pulse applied to the switch. Controller is developed in such a way that gating pulse is generated based on value of back emf and rectified mains voltage.

$T=\frac{1}{2\pi f}\sin^{-1}\frac{E}{Vm}$(18)

where T is the time taken for Vin(t) to reach E from 0 V.Vmis peak value of voltage (V) .

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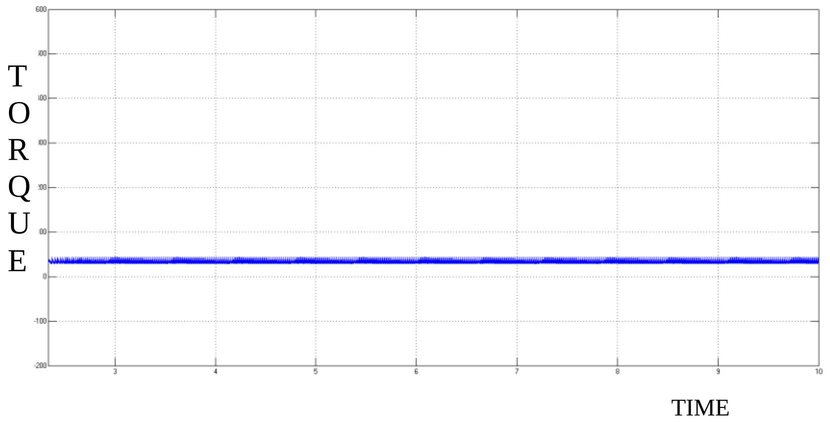
f is the frequency of input supply voltage (Hz) At E =100 V,Vm=310 V,The value of C_{DC} is selected such that it is capable to provide the required reference current when Vm<E to maintaincurrent at reference. The minimum value of capacitance that is required to provide current at reference is

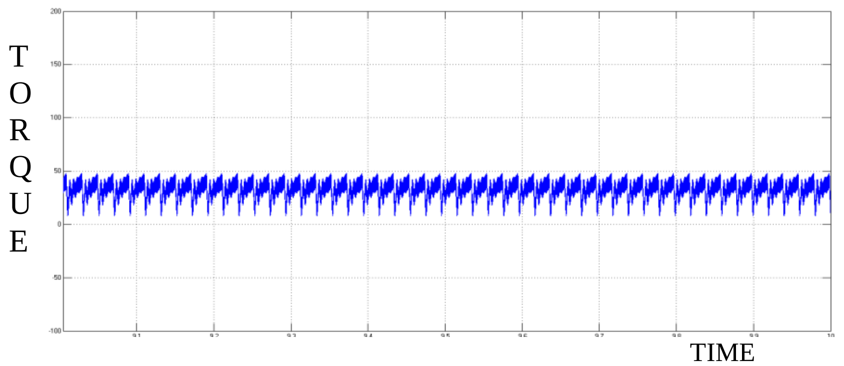
$$C_{DC} = 2T\, I_{avg}/(Vm-E) \quad (19)$$

III. RESULT AND DISCUSSION

The modelling of proposed system with compensation capacitor is carried out inMATLAB/SIMULINK. The simulation is carried out for an irradiance of 1000 W/m^2 to compare the torque rippleat the output of BLDC motor with and without a compensation capacitor.Fig. 5(a) shows the electromagnetic torque ofa 6.8 kW BLDC motor with compensation capacitor. The result is compared with another BLDC motor of same ratingwithout a compensation capacitor whose electromagnetic torque is as shown in Fig5(b).At 1000 W/m^2, motor has arated current of 25A at rated torque of 25 N-m.



(a)



(b)

Fig.5.Electromagnetic torque output of a BLDC motor for a step load torque of 25 N-m for G=1000 W/m^2 (a)with compensation capacitor (b)without compensation capacitor

Motor has a peak current of 30 A and a speed of 2800 rpm at this irradiance level.Figure 6 shows the speed of the motor at G=1000W/m^2 and at a load torque of 25N-m.

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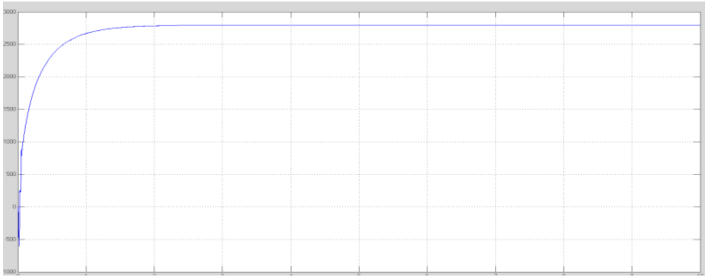
Speed

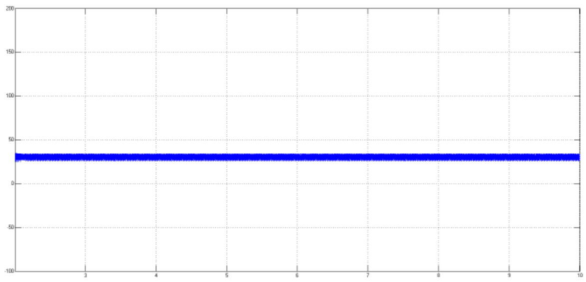


Time

Fig.6.Speed of a BLDC motor at G=1000W/m^2 and a load torque of 25 N-m

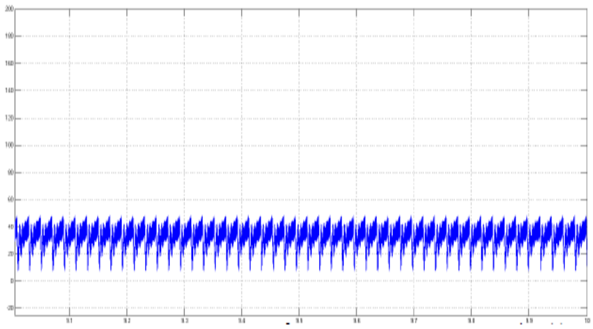
Irradiation is changed from 1000 W/$m^2$to 400 W/m^2 to demonstrate the performance of motor.When the solarirradiance is changed from 1000 W/$m^2$to 400 W/m^2 , as amount of tracked energy is less, the converter output voltageis less due to which the electromagnetic torque and stator current decreases.Torque generated with 400 W/m^2 is less than that generated with 1000 W/m^2. There is a comparable reduction in ripple in the electromagnetic torque withcompensation capacitor shown in figure 7(a) when comparing with the torque generated in a BLDC motor of samerating without compensation capacitor as shown in figure 7(b).Speed corresponding to the irradiation 400W/m^2 is shown in figure 8

Torque



(a) Time

Torque



(b)Time

Fig.7.Electromagnetic torque output of a BLDC motor for a load torque of 25 N-m for G=400 W/m^2

(a)with compensation capacitor (b)without compensation capacitor.

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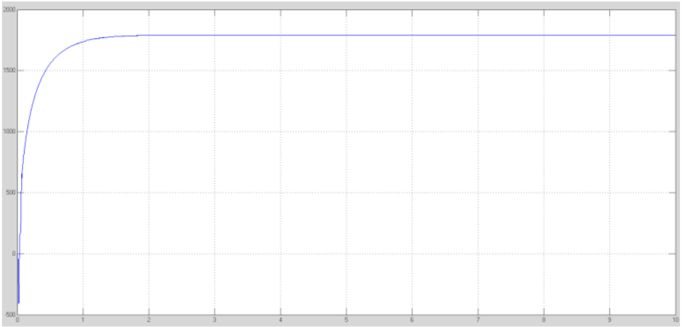
Speed



Time

Fig.8 Speed of a BLDC motor at G=400W/m^2 and a load torque of 25 N-m

IV.CONCLUSION

A compensation technique for the torque ripple reduction in a BLDC motor operated without dc link capacitor isproposed. The new technique is analysed for a BLDC motor which is fed from a solar PV array using ZETA converter. INC MPPT method is used to extract maximum power and to maintain a constant dc link voltage for a particular irradiance level. Performance ofmotor with compensation technique was analysed for irradiance level of 1000 W/^{2}and 400 W/m^2. Torque ripple wasreduced in both cases by using this compensation technique. With the use of the compensation capacitor of low value,the motor is able to operate in the rated speed and torque.The method can be used for water pumping applications.The proposed system has operated successfully even under minimum solar irradiance.

REFERENCES

[1] 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, May 2015.
[2] I. H. Altas, and A.M. Sharaf,” A Photovoltaic Array Simulation Model for Matlab-Simulink GUI Environment,”
[3] Swathikumari, A. Y. Lakxminarayana and S. Tarakalyani, “Modeling and Simulation of BLDC Motor for Aiding and Opposing Loads,” IOSR Journal of Electrical and Electronics Engineering, vol. 7, no. 4, pp. 59-67, Oct 2013.
[4] 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, Nov./Dec. 2013.
[5] S. Rambabu, “Modeling and Control of a Brushless DC Motor,” M. Eng. thesis, National Institute of Technology, Rourkela, India, May. 2007.
[6] M. A. Elgendy, B. Zahawi, and D. J. Atkinson, “Assessment of the incrementalconductance maximum power point tracking algorithm,” IEEE Trans. Sustain. Energy, vol. 4, no. 1, pp. 108–117, Jan.2013.
[7] H. K. SamithaRansara and U. K. Madawala, “A Torque ripple compensation technique for a low cost Brushless dc motor drive,” IEEE Trans. Industrial Electron., vol. 62,no. 10, pp. 6171–4182, Oct 2015.