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Engineering

DESIGN AND MODELING OF ZETA CONVERTER AND BLDC MOTOR FOR WATER PUMPING APPLICATION

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ABSTRACT In this paper, the design and modeling of zeta converter and brushless dc motor is done for water pumping application due to its advantages over others. Zeta Converter is devised to drive the brushless dc motor. This converter is used because it has high fast response, simplicity and very large range of power tracking. In another way, the Brushless DC (BLDC) motor is a good substitute for other commercial motors on account of its high reliability, high efficiency, high torque inertia ratio, less commutation losses, low radio frequency interference, low electromagnetic interference (EMI) and noise and also it requires less maintenance in compared with DC motor and induction motor. By merging different DC-DC converters and motor drives, the zeta converter in connection with the Brushless DC (BLDC) motor is feasible to form an effectual water pumping system. The simulation of Brushless DC (BLDC) motor and zeta converter was done in MATLAB/Simulink Software.

KEYWORDS : Brushless DC (BLDC) motor, Zeta Converter, Electromagnetic Interference (EMI), DC-DC Converter, Water Pump.

INTRODUCTION

In pumping application, a brushless dc motor (BLDC) drive shows good performance than other commercial motors on account of its better efficiency and reliability, low electromagnetic interference (EMI) and noise, maintenance free, high speed range and long operating life. The induction motor is commonly used machine for water pumping application because of its durability, less cost, high efficiency, and availability in local markets. But this motor suffers from complex control requirements and overheating problems. Hence, in this paper a brushless dc motor is selected for water pumping system.

In this paper, zeta converter is used to drive the brushless dc motor. The reason behind of choosing this converter is its essential properties of fast response, simple circuit, very large range of power tracking efficiency etc. The other developed topologies of DC-DC converters have more number of components which results in the efficiency degradation, high cost, weight and size. These problems motivates to use a zeta converter in this work.

ZETA CONVERTER BASED WATER PUMPING SYSTEM

The basic block diagram of the proposed system is shown in Fig. 1. It comprises of a PV panel, zeta converter, three phase four switch inverter, brushless dc motor and the pump. The voltage from the PV panel is given to the zeta converter which steps up the voltage to the desired value. The zeta converter is designed to perform in continuous conduction mode, in this the current flow is continuous and this helps to minimize the voltage and current stress on the semiconductor devices and components. The output voltage of the panel is tracked by MPPT that is used to harness maximum power from photovoltaic array. Here the conventional three phase six switch inverter is replaced by three phase four switch inverter. The output of the zeta converter is given to the three phase four switch inverter which converts the DC output power from the zeta converter into AC power feeds the BLDC motor to drive the centrifugal pump coupled to its shaft.

Figure 1: Block Diagram of the Proposed System

DESIGN OF ZETA CONVERTER

Zeta converter is a DC-DC converter which will give positive output voltage from an input voltage that varies above and below the output voltage. It can be worked either in buck or boost mode based on the duty cycle. For a duty cycle lower than 50%, the zeta converter performs as a buck converter and for a duty cycle higher than 50%, the zeta performs as a boost converter. The zeta converter contains two inductors and a series capacitor. Due to a single switch, this converter has very good efficiency and offers boundless region for maximum power point tracking. D is the duty ratio and the output of the zeta converter can be controlled by adjusting the duty ratio.

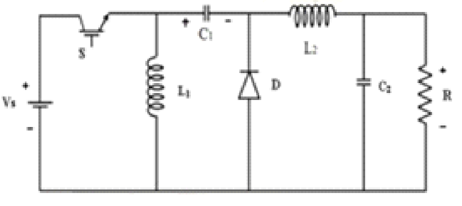

Figure 2: Circuit of Zeta Converter [4]

Mode 1: In this mode, when the switch is ON and the diode is in OFF position. During this period, the current through the inductor L_1 and L_2 are drawn from the source voltage, Vs. The inductor current I_{L1} and I_{L2} increases linearly. Also the discharging of C_1 and charging of C_2 takes place. This mode of operation is also known as charging mode.

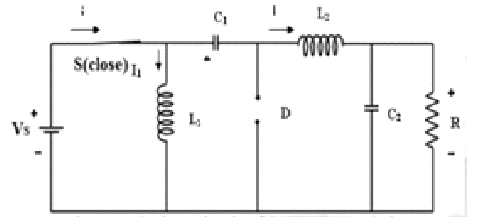

Figure 3: Zeta Converter in ON State [4]

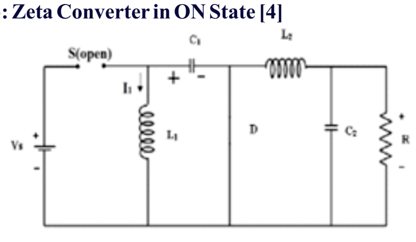

Figure 4: Zeta Converter in OFF State [4]

Mode 2: In this mode, when the switch is OFF and the diode is ON position. During this period the energy stored in the inductors discharged through capacitors C1 and C2. The current in the inductors decreases linearly. This mode of operation is known as discharging mode.

$$D = \frac{Vdc}{Vin+Vdc} = \frac{203}{185+203} = 0.52 \qquad (1)$$

Where, V_{dc} is the average value of output voltage of the zeta converter which is equal to the DC voltage rating of the BLDC motor.

TABLE – 1DESIGN VALUES OF ZETA CONVERTER

Variables	Values
Input Inductor, L_1	5mH
Output Inductor, L_2	5mH
Intermediate Capacitor, C_1	22F
DC link capacitor, C_2	410F
Switching Frequency	20 kHz

MODELLING OF BLDC MOTOR

MODELLING EQUATIONS

In this paper, three-phase BLDC motor in star connection is proposed. With the assumption that $R_a = R_b = R$ due to symmetry of three-phase BLDC motor and $L_a=L_b=L_C=L=L_S$, the equivalent circuit is arranged as shown in Figure 5. Here, the small letters a, b and c denotes the phases of the BLDC motor. The following assumptions are made with the intent of simplifying equations and overall model:

Assumptions

- The motor is three phase and symmetric.
- Magnetic circuit saturation and mutual inductance are eliminated.
- Stator resistance and self-inductance of all the phases are equal and constant.
- Hysteresis and eddy current losses are identical.
- All semiconductor switches are identical.
- Back emfs are identical.

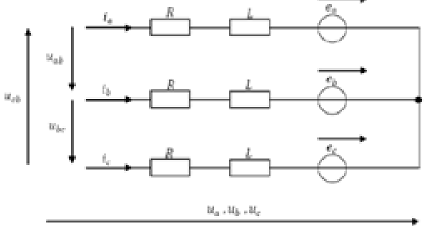

Figure 5: The equivalent circuit of three- phase motor star-connection

The electrical and mechanical mathematical equations of brushless dc motor are given in this section. The stator voltage equations are:

$$V_a = Ri_a + L\frac{di_a}{dt} + e_a \quad (2)$$

$$V_b = Ri_b + L\frac{di_b}{dt} + e_b \quad (3)$$

$$V_c = Ri_c + L\frac{di_c}{dt} + e_c \quad (4)$$

The equations of back EMF can be given as

$$e_a = K_e\omega_m F(\theta_e) \quad (5)$$

$$e_b = K_e\omega_m F(\theta_e - \frac{2\pi}{3}) \quad (6)$$

$$e_c = K_e\omega_m F(\theta_e + \frac{2\pi}{3}) \quad (7)$$

The equations of torque can be given as

$$T_a = K_t i_a F\theta_e \quad (8)$$

$$T_b = K_t i_b F(\theta_e - \frac{2\pi}{3}) \quad (9)$$

$$T_c = K_t i_b F(\theta_e + \frac{2\pi}{3}) \quad (10)$$

Resultant torque equation is given as

$$T_e = T_a + T_b + T_c \quad (11)$$

Mechanical equation can be derived as

$$T_e - T_l = J\frac{d^2\theta_m}{dt^2} + \beta\frac{d\theta_m}{dt}\theta_e \quad (12)$$

Electrical position and mechanical speed is given as

$$\theta_e = \frac{p}{2}\theta_m \quad (13)$$

$$\omega_m = \frac{d\theta_m}{dt} \quad (14)$$

TABLE – 2 DESIGN VALUES OF BLDC MOTOR

Rated Power, P	2.89 KW
Rated Speed, N	3000 rpm
Rated Torque, T	9.2 Nm
Voltage, V	200 V
Rated Current, I	18.9 A
Moment of inertia, J	17.5 $Kgcm^2$
Friction Coefficient, B	0.02949
Phase Resistance, R_s	0.36 Ω
Phase Inductance, L_s	1.3 mH
Poles	6

SIMULATIONS AND RESULTS

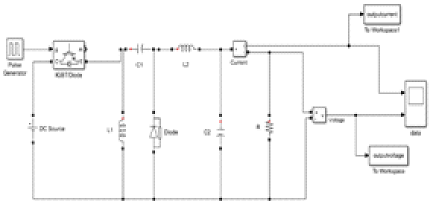

Figure 6: Simulink model of zeta converter

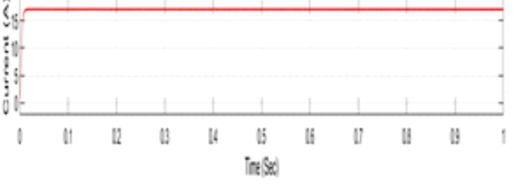

Figure 7: Output Current of zeta converter

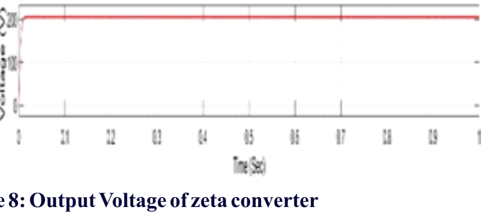

Figure 8: Output Voltage of zeta converter

Figure 7 and 8 shows the output current and voltage of zeta converter respectively. The voltage is obtained up to 203V and current is obtained up to 17 A.

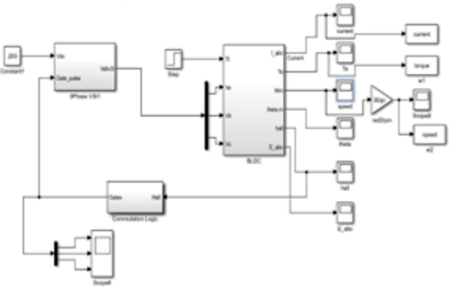

Figure 9: Simulink Model of BLDC Motor

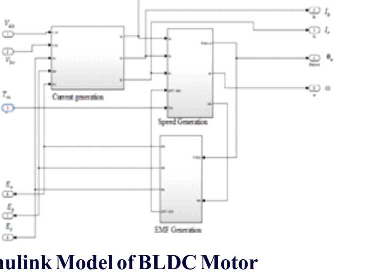

Figure 10: Simulink Model of BLDC Motor

The base model of brushless DC (BLDC) motor is shown in Figure 10. The base model of BLDC motor consists of a current generation part, speed generation part and an EMF generation part.

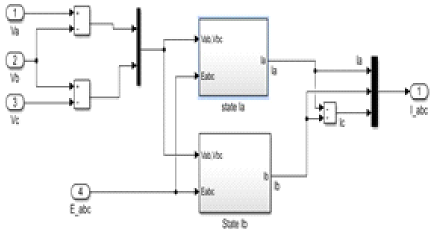

Figure 11: Simulink Model of current generation block

Figure.11 shows the expanded current generation block. . The phase voltages (V_{ab} and V_{bc}) and back emf (E_a, E_b, E_c) is given as input for current generation block. The outputs of current generation blocks are I_a, I_b, I_c.

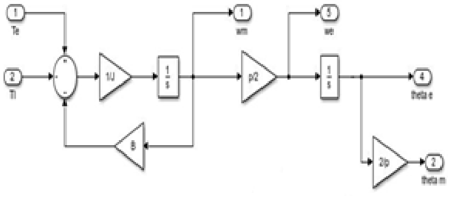

Figure 12: Simulink Model of speed generation block

Figure.12 shows the expanded speed generation block. The generated currents (I_a, I_b, I_c), torque and gate signals from emf generation block is given to speed generation block.

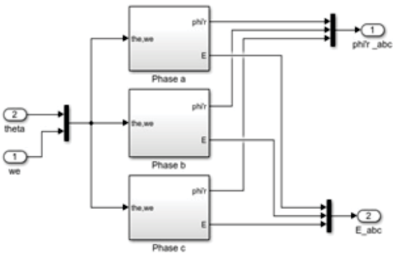

Figure 13: Simulink Model of EMF generation block

Figure.13 shows the expanded EMF generation block. The rotor position (θ) and electrical speed (ω_e) is given as input to emf generation block for generating back emf and gate signals for the inverter.

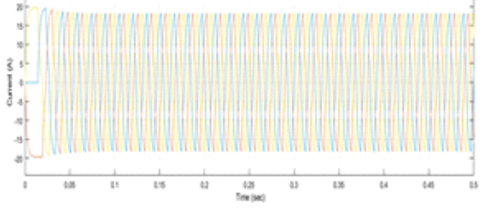

Figure 14: Time vs Current waveform of BLDC Motor

Figure. 14 shows the current characteristics of BLDC motor and the rated current obtained as 18 A. Due to the presence of trapezoidal back emf, the current waveform cannot be exact sinusoidal.

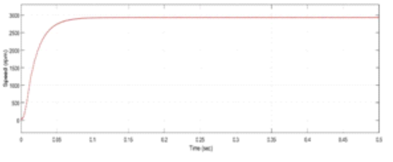

Figure 15: Time versus Speed waveform of BLDC Motor

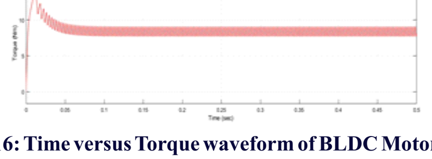

Figure 16: Time versus Torque waveform of BLDC Motor

The speed and torque response of the BLDC machine is shown in figure. 15 and 16 respectively. The rated speed of the machine is 3000 rpm and the machine attains the steady state at 0.08 sec. The rated torque of the machine is 9.2 Nm.

CONCLUSIONS

In this paper, the modeling and simulation of zeta converter and BLDC motor was done and studied the results. Brushless dc motors are most commonly used in high-performance applications because of their higher efficiency, higher torque in low-speed range, high power density, low maintenance and less noise than other motors. In this paper BLDC motor mathematical model is developed. Finally the performance of BLDC motor and zeta converter is verified by using Matlab/Simulink Software and simulation results are presented. The combination of zeta converter and BLDC motor provides an efficient performance for water pumping applications.

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