Design and Simulation of Zeta Converter for Speed Control of BLDC Motor

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Abstract – Now days the utilization of driving systems with variable speed are increasing in different applications like vehicle industries, domestic appliance and in manufacturing industries etc. And in product manufacturing companies motors with both variable speed and constant speed is required. For such requirement proposed circuit fed BLDC motor can be used effectively. This paper proposes sensored control of BLDC motor using Zeta converter. The proposed circuit operates in both openloop and closed loop. The sensored speed control scheme of BLDC motor is designed. Since brushes are absent in motor, for the commutation purpose voltage source inverter operating in 120 degree conduction mode is designed. Zeta converter is used for obtaining regulated dc output voltage. PSIM Simulation is used to simulate the designed model.

Index Terms – Zeta Converter, Brushless DC motor, PID controller, PSIM Software.

1. INTRODUCTION

Presently, the Brushless DC motor is getting enthusiasm in a vehicle industries, domestic appliances etc. And in product manufacturing companies where motors with both variable speed and constant speed is required. [1]. Additional to this BLDC motors don't contains brushes. Due to this electronically commutation takes place. Brushless DC Motor is having many advantages compared to brushed DC motor like improved speed versus torque characteristics ,better dynamic response, , noisefree operations , extended operating life, higher speed range etc..The basic dc-dc converters available are buck, boost, buck-boost, cuk, sepic and zeta converter. The zeta converter is presented in this paper. For purpose of voltage regulation zeta converter is proposed and having advantage of isolated structure and able to operate in both buck and boost mode. And using this proposed converter both power factor correction and voltage regulation can be achieved in single stage compared to other dc-dc converters.[2].

In the paper work section 1 gives introduction about the paper, section 2 deals with bldc motor structure ,in section 3 zeta converter and design of the proposed circuit is represented, section 4 presents the speed control methods ,in section 5 simulation results are tabulated along with waveforms and in the last section presents the conclusion of the work.

2. STRUCTURE OF BRUSHLESS DC MOTOR

Brushless dc motor are available in single phase, two phase and three phase configurations. Most type of motors used are of three-phase type. These are type of permanent magnet synchronous motor. The magnetic field created by stator and rotor rotate at the same frequency. It does not operate directly by dc voltage source. To supply power to stator windings it requires voltage source inverter. The rotor is made up of permanent magnets and stator is made up of windings. It is electronically commutated motor.. Some of the BLDC motor consists of position sensor like hall sensor. Hall sensors detects the rotor position. And based on its input commutation is performed

Stator: The stator present in the BLDC motor consists of stacked steel laminations slots, the windings are placed in these slots which axially cut along the inner periphery of the slot as in Figure 1. Windings of a stator can be arranged in two shapes which is a star connection (Y) or delta connection(Δ). BLDC motors are mostly have three stator windings connected in star connection. The stator windings can be classified into two types which is trapezoidal and sinusoidal motors

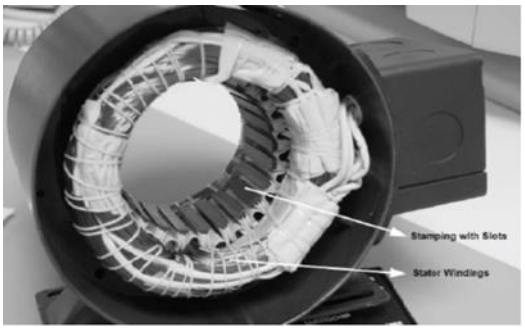

Figure 1.Stator Structure

Rotor: The BLDC motor rotor is made up of permanent magnets. Number of poles in the rotor varies and is chosen based on application requirements. As the number of poles increases it gives better torque but speed reduces. The maximum torque is also impacted by the material used for

construction of permanent magnet;the higher the flux density of the material, the higher the torque .

There are two commutation techniques of BLDC motor are available one is square-wave commutation and another is sine-wave commutation. And based on the method of rotor position present, there are two types, sensor control technique and sensorless control technique .The sensor control method deals with rotor position detection using the induced back emf. In this paper sensor control technique is proposed, in which hall sensors are used to detect the rotor position of BLDC motor.

3. ZETA CONVERTER

The Zeta converter is a type of dc-dc converter in which output voltage is greater than or less than input voltage .It is used for obtaining regulated output voltage. The output voltage polarity is non-inverted.The circuit consists of diodes, solid switching device ,inductors and capacitors. The values of inductor and capacitor determines output efficiency and ripple voltage. For the variation in output voltage value this converter exchanges energy between inductor and capacitor. The switching device S(MOSFET) controls the transfer of energy. Its circuit diagram is shown in Figure 2.

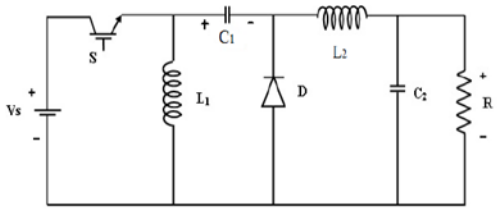

Figure 2.Zeta converter circuit diagram

3.1 States of Operation

There are two modes of zeta converter operation i.e mode1 and mode2

Mode1:

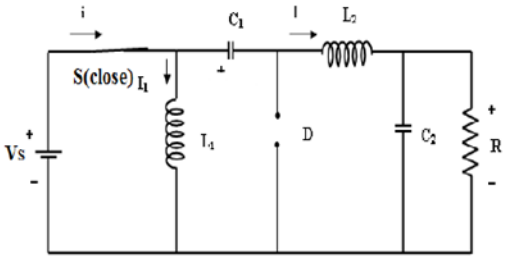

Figure 2.1.Circuit Diagram with switch Closed

In mode1 the switch is closed and circuit is shown in Figure2.1.When switch is turned on the diode is reverse baised .It is represented as open circuit for diode and short circuit for switch. The reverse voltage the diode is equal to $-(V_s + V_o)$.In this period inductor L_1&L_2 are in state of charging condition. The current through both inductors starts increasing.The voltage across capacitorC_1will be equal to output voltage V_0 .Capacitor $C_1$and inductor L_2 both are series connection. Addition of both inductor current flows through switch S.

Mode2:

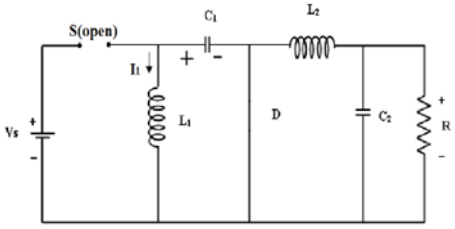

Figure 2.2 .Circuit Diagram of switch Open

In mode2 the switch is in open condition and is shown in Figure 2.2 .When switch is opened the diode is forward baised. This is shown as open for switch and short circuit for diode. Inductor L_1.& L_2 will be in discharging state. The polarity of inductor changes and diode will be in conducting state.

3.2 Design of Proposed Converter

The formula for output voltage of zeta converter is given as

$$V_0 = \frac{V_{in}\, D}{(1-D)} \qquad (1)$$

in the equation-1 V_{in} the output voltage value of diode bridge rectifier.

The expression for output voltage diode bridge rectifier is

$$V_{in} = \frac{2\sqrt{2}V_s}{\pi} \qquad (2)$$

V_s is equal to supply voltage

The expression for inductor L_1& capacitor C_1 is given as below

$$L_1 = \frac{DV_{in}}{f_s \Delta IL_1} \qquad (3)$$

Where ΔIL_1 is a ripple content present in inductor current and f_s switching frequency.

$$C_1 = \frac{DI_{DC}}{f_s \Delta V_{C1}} \qquad (4)$$

And ΔV_{C1} is mentioned ripple voltage in C_1 capacitor and I_{DC} is output current.

To reduce the ripple in the output voltage of the zeta converter filter is designed. The inductance of the ripple filter reduces the inductor peak-to-peak ripple current (ΔIL_1) within a specified value for the given switching frequency (fs), and the capacitance (C2) value is calculated for the allowed ripple in the output voltage (ΔVc2).

The values of the ripple filter inductor and capacitor are given as

$$L_2 = \frac{DV_{IN}}{f_s \Delta I L_2} \quad (5)$$

$$C_1 = \frac{I_{DC}}{2w\Delta V_{C2}} \quad (6)$$

Table 1 . Parameters of Zeta converter fed BLDC drive

Input Voltage	12 v
Output Voltage	24v
Frequency	20khz
Duty cycle	68%
L1 & L2	39.6mH
C1	275uF
C2	1mF

Table 2.BLDC Motor ratings

Rated Voltage	24v
Rated Speed	3000rpm
Resistance(phase to phase)	0.363
Inductance (phase to phase)	0.049m
Speed Constant	120
Torque Constant	7.85m
Number of poles	4

4. SENSORED SPEED CONTROL METHOD

In automotive applications most generally utilized voltage levels are 48V, 24V and 12V. The motor manufactures indicates the working voltage level and speed run. In sensor control method ,the speed of motor is directly propotional to the applied voltage. Utilizing Pulse Width Modulation (PWM) by exchanging the MOSFET on and, off, a varying voltage can be applied to the motor. This average DC voltage decides the motor speed. There are two speed control schemes are possible and they are open loop speed control method and closed loop speed control method.

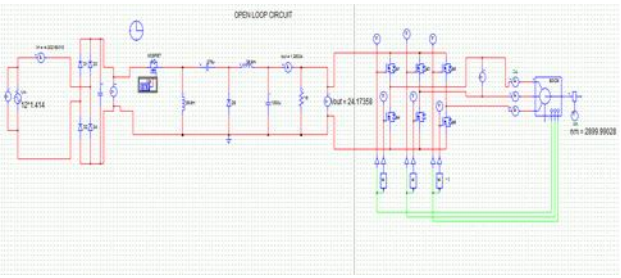

Figure 3.Simulation diagram of open loop method

The simulation circuit of open loop speed method is shown in Figure 3.In this method supply to BLDC motor given through diode bridge rectifier and zeta The AC to DC conversion takes place in diode bridge rectifier and to reduce large pulsation in the output capacitor is inserted and this capacitor produces increased THD in input ac supply current and larger peak value of input current and results in poor power factor ,due to this zeta converter can be employed. Since bldc motor does not contain brushes and hence for the purpose of commutation voltage source inverter operating in 120 degree conduction mode is designed.

In open loop method by the variation of duty cycle of zeta converter which in turn varies the dc output voltage of converter due to this speed variation of the bldc motor can be obtained.

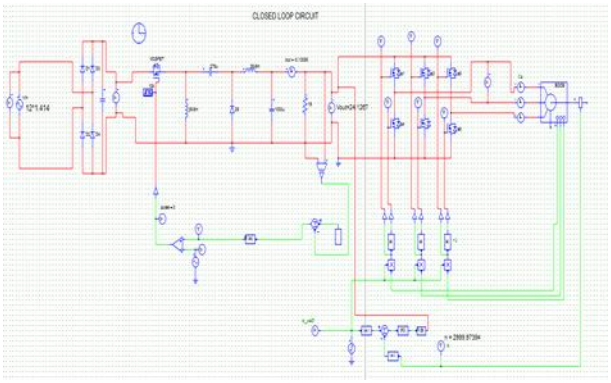

Figure 4. Closed loop simulation circuit

In some application where constant speed is needed for this purpose closed loop is implemented as shown in Figure 4.In closed loop method control in the speed of BLDC motor is obtained by comparing actual speed with reference speed(desired speed).By this method speed in wide range can be controlled and it is possible to obtain constant speed.

5. SIMULATION RESULTS

The Figure 5 shows the open loop voltage and current of Zeta converter. It contains ripple contents.

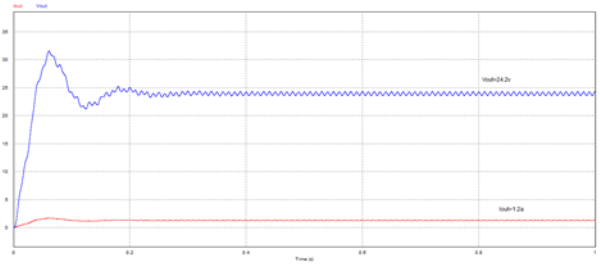

Figure 5.Open loop output voltage and current

PID Controller is used to reduce ripple in the output voltage and closed loop output waveform is shown in Figure 6.

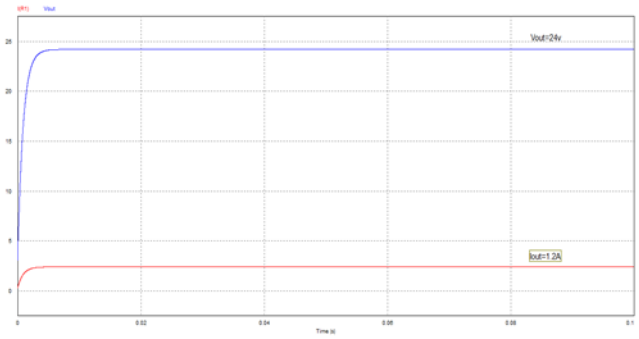

Figure 6.Closed loop output voltage & current

The speed waveforms obtained in open loop and closed loop conditions are shown in Figure 7 and Figure 8

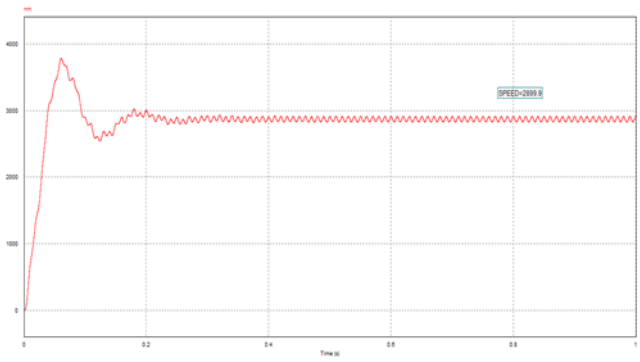

Figure 7.Speed waveform in open loop method

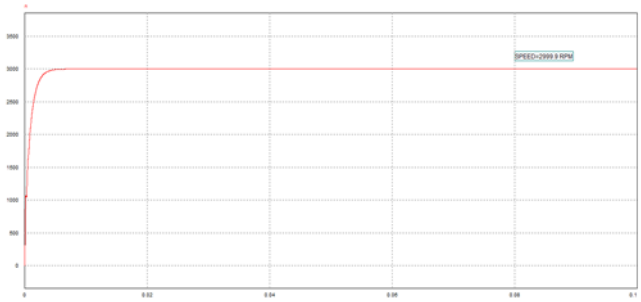

Figure 8. Speed waveform in closed loop method

Table 3 represents the variations in the speed range of BLDC motor obtained by varying duty cycle in open loop method. And Table 4 represents the controlled values obtained in closed loop method.

Table 3.Performance in Open-loop method

Duty Cycle (in %)	Speed (rpm)
60	1980
62	2170
64	2360
66	2632
68	2900

Table 4.Controlled Values of Speed in closed loop method

Refrence Speed(rpm)	Obtained Speed(rpm)
1500	1499.9
2000	1999.7
2500	2500.2
3000	2999.4

6. CONCLUSION

The paper discusses sensored control of BLDC motor using zeta converter in both open-loop scheme and closed-loop feedback system.. Initially, the construction and advantages of brushless DC motor was presented. Zeta converter is designed to obtain regulated dc voltages. Open loop method variations in speed of BLDC motor. This method of implementation is useful variable application. Wide speed range of BLDC motor is obtained by closed loop method. The complete system is simulated in PSIM Software.

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