SPEED REGULATION FOR A BLDC MOTOR EMPLOYING A ZETA CONVERTER

A.Anjaiah[1]

A. Anjaiah, *Assistant Professor EEE, Tkr College of Engineering &Technology (Autonomous), India*

S. Goutam, *UG student, EEE, Tkr College of Engineering &Technology (Autonomous), India*

P. Ganesh, *UG student, EEE, Tkr College of Engineering &Technology (Autonomous), India*

R. Naveen Kumar, *UG student, EEE, Tkr College of Engineering &Technology (Autonomous), India*

S. Thilak Teja, *UG student, EEE, Tkr College of Engineering &Technology (Autonomous), India*

Abstract— The project presents the control of Brushless direct current (BLDC) motor with the help of the bidirectional DC-DC converter. The AC Source is fed to the Diode Bridge Rectifier (DBR). The output of DBR is fed to Zeta converter. The output of the Zeta (DC-DC) converter is fed to the three-phase voltage source inverter (VSI) to drive the motor. The Zeta Converter, known for its ability to efficiently regulate voltage in systems with wide input voltage ranges, presents a promising solution for BLDC motor speed control. Through advanced control of modulation techniques, the Zeta Converter facilitates precise speed control, achieving desired torque and speed characteristics with high efficiency. the utilization of Zeta Converter for BLDC motor speed control presents a promising avenue for achieving high-performance. To deliver feedback position to the pulse generators, the Hall-sensors are used. The MATLAB/Simulink software is employed to validate the aforementioned operations.

Keywords— Brushless dc motor (BLDC), Proportional-integral Controller (PI), Voltage Source Inverter (VSI), Diode Bridge Rectifier (DBR), Zeta Converter, Hall-sensors.

1. INTRODUCTION

In the past two decades, there has been a significant increase in energy consumption, particularly in electricity usage driven by both conventional and advanced appliances. This surge in energy consumption has raised environmental concerns and become a critical issue for communities worldwide. To address these challenges, improving energy efficiency techniques have become crucial in mitigating environmental impacts. The industrial sector accounts for more than two-thirds of the electricity consumed globally, with electric motors being a major contributor to this consumption. Electric motors, whether air-cooled or liquid-cooled, play a vital role in various applications such as ship propulsion, pipeline compression, and industrial machinery, where power ratings of up to 150 MW are required. Moreover, electric motors are extensively utilized in industrial fans, blowers, pumps, household appliances, power tools, and disk drives.

Among electric motors, Brushless DC (BLDC) motors have gained significant popularity due to their efficiency, quiet operation, reliability, wide speed range, and low maintenance requirements. Unlike conventional DC motors that use brushes for commutation, BLDC motors employ electronic commutation, making them ideal for various household appliances and low horsepower applications. However, BLDC motors still face challenges such as variable speed control and power quality issues, limiting their widespread adoption. To address these challenges, power factor correction converters like the zeta converter are being utilized. The zeta converter, a fourth-order DC-DC converter, operates as a step-up or step-down converter and aids in power factor correction. It consists of two inductors and two capacitors, which act as dynamic storage components, offering non-inverted output and effectively addressing power factor correction problems.

The zeta converter holds promise for numerous home appliances and industrial applications, including blenders, electric cutters, coffee machines, dishwashers, refrigerators, CNC machine tools, and heating systems. Various studies have explored BLDC motor speed control techniques, advancements in PMBLDC motor drives, and the implementation of innovative power converter models like the zeta converter to enhance power factor and speed control.

In this paper, we provide a detailed overview of BLDC motors in Section II and discuss the operation of the zeta converter in Section III. Section IV presents MATLAB/Simulation results, followed by the conclusion in Section V, summarizing the key findings and contributions of this work.

2. BLDC MOTOR OPERATION

2.1 WORKING OF BLDC MOTOR

When current flows through the coils of a BLDC motor, it generates a magnetic field. The arrangement of these field lines determines the polarity of the energized magnet's poles, which is contingent upon the direction of the current in the coil. In the operational diagram of a BLDC motor, depicted in Figure 1, three coils—named A, B, and C—are positioned within the stator slots. Upon energizing coil A with a DC supply, it becomes active and magnetizes the rotor's permanent magnet. Similarly, energizing coil B attracts a rotor permanent magnet, and this sequence continues until coil C is energized. Upon energizing coil C, coil A is subsequently charged with negative polarity.

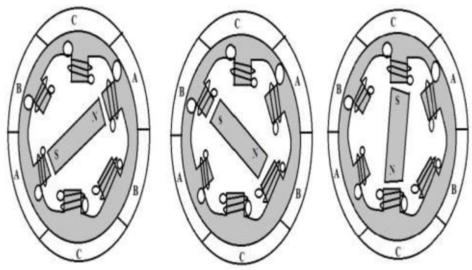

Fig.2.1.1. Working of the BLDC motor

This process repeats with the other coils exhibiting negative polarity. This sequential rotation continues, causing the rotor to rotate continuously. At any given instant, one phase remains positive, another phase is negative, and the third phase remains idle.

2.2 Speed-Torque Characteristics of BLDC motor

There are two torque variables: peak torque and rated torque, as shown in figure 2. At rated speed, the torque must remain uniform. Once the rated speed doubles, the motor operates at maximum speed, but subsequently, the torque begins to decrease [13]. When the load torque increases, the speed decreases accordingly. The phase resistance and torque are directly proportional to the speed decrease. Heat transfer and temperature rise are determined by the continuous limit. The highest ratings of semiconductor devices of the controller are determined by the intermittent limit.

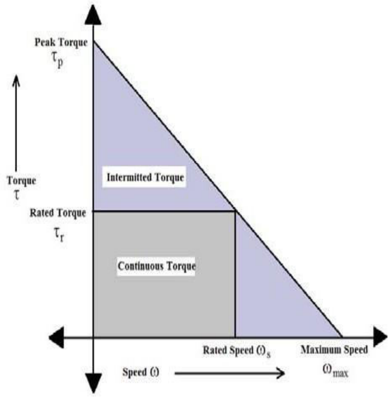

Fig.2.2.1. Speed-Torque characteristics graph of BLDC motor

2.3. Motor Operation with inverter

To enhance efficiency and minimize power usage, one can employ an inverter control technique. The inverter, comprising six switching devices denoted as T1 to T6, operates to generate each phase voltage wave symmetrically with a 120-degree phase shift in the DC input. At any given moment, two switches are activated: one from the upper group and another from the lower group. The motor's inverter operation is illustrated in Figure 2.3.1.

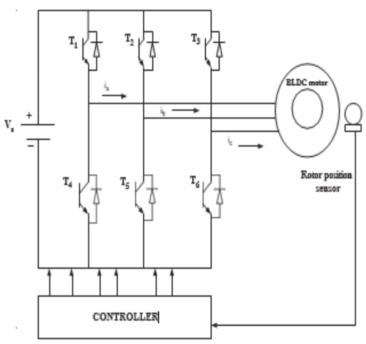

Fig 2.3.1: Inverter operation of BLDC motor

Let's consider an instant, denoted as t1, where the supply current Id flows through phases A and B. At this moment, switches T1 and T4 are activated, resulting in a positive current in phase A and a negative current in phase B. After a 60-degree interval, when phase A is at its midpoint, the current Id becomes negative in phase B. At this point, switch T2 is turned on while T6 is off, ensuring continuous conduction for T1 over the full 120-degree angle [13]. The position of coils is determined using a Hall sensor, which communicates with the controller to energize the coils based on the sensor's feedback. These sensors detect any changes in the magnetic field, and their activation is synchronized with the rotor magnets. A signal conditioner provides a compatible pulse, characterized by sharp edges, when combined with a Hall switch, utilizing Transistor-Transistor Logic (TTL).

Positioned at 120-degree intervals fixed on the stator frame, the Hall sensors generate digital signals to detect the rotor's position. Table I outlines the inverter process as indicated by the following hall-sensor truth table.

3. ZETA CONVERTER FED BLDC MOTOR

The central component of the entire system is the zeta converter, which significantly enhances the power quality of the model. This converter block begins with an input supply of 227V, which is initially rectified from AC to DC by a diode bridge rectifier. The resulting DC output is then directed to the zeta converter circuit. To address any ripples and harmonic distortions present in the DC supply, a low-pass filter Cc within the converter is employed to mitigate these issues. Operating as a single-stage process in Continuous Conduction Mode (CCM), it effectively manages voltage regulation and Power Factor Correction (PFC). Figure 3.1 illustrates the zeta converter circuit diagram showcasing various parameters.

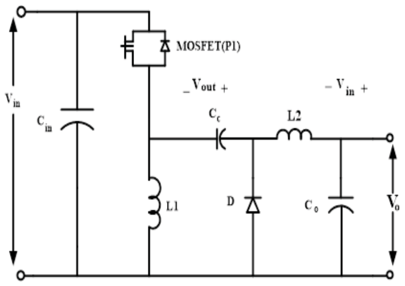

Fig 3.1: Circuit diagram of zeta converter

Where,
Cc = AC coupling capacitor
Cin = An input capacitor
Co = The output capacitor
L1 and L2 = Coupling inductors P1 = Power MOSFET
D = Diode
Vout = Output voltage
Vin = Input voltage

Coupling capacitor Cc is in parallel along with Cout, thus Cc is charged up to the output voltage, Vout through steady-state CCM. Vo displays the voltages through L1 and L2 during CCM operation.

3.1. Mode I (PI = ON)

Figure 3.1.1 shows the zeta converter operation when P1 is ON.

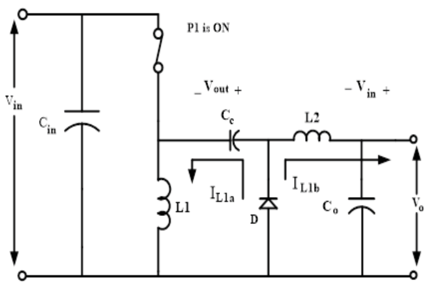

Fig 3.1.1: When P1 is ON

Coupling capacitor *CC* charge up the *Vout* and remains connected in series with *L2*. Therefore the voltage across *L2* is *+Vin* and diode D gets *Vin +Vout.*

3.2. MODE II (P1 = OFF)

The voltage across L1 must align with Vout. This places it in parallel with Cout, which is already charged to Vout. Consequently, across P1, there exist voltages of Vin + Vout. This leads to a voltage across L1 that is -Vout relative to the voltage across P1. Figure 3.2.1 illustrates the zeta converter's operation when P1 is in the ON state.

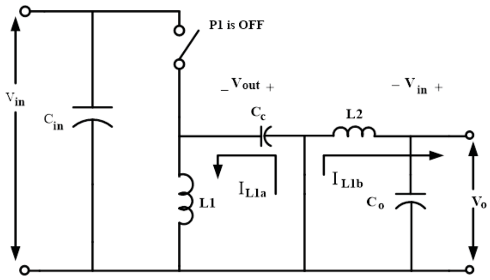

Fig 3.2.1: When P1 is OFF

It is noted that during Q1's activation, L1b supplies Iout. When Q1 deactivates, L1a sustains the current flow, delivered via CC, while L1b subsequently supplies Iout again. Energy from the input supply is stored in L1a, L1b, and CC.

Advantages of the zeta converter:

- It provides a non-inverted output.
- Ensures a stable output response.
- Exhibits minimal transients in the output response.
- Offers comprehensive control over the circuit, demonstrating its effectiveness.

3.3 Calculation of duty cycle

By assuming 100% efficiency, the duty cycle which is represented by D, operating during CCM for a zeta converter is presented by,

$$D = \frac{Vout}{V_{in}+V_{out}}$$

Where,

Dmax Occurs at Vin (min)

Dmin Occurs at Vin (max)

Vin = 227V

Vout = 268.5V

By substituting these values into D, the duty cycle can be determined. In continuous conduction mode (CCM), the duty cycle for the zeta converter is calculated to be 0.54, equivalent to 54%.

4. SIMULATION RESULTS

The block diagram depicting the simulation model is presented in Figure 4.1. Utilizing this block diagram, the proposed model can be simulated effectively.

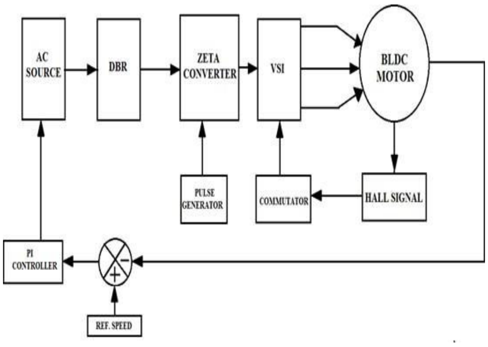

Fig 4.1: Block diagram representation of Simulink process

The AC input supply is first passed through a circuit and rectified by a diode bridge rectifier. The resulting DC supply is then directed to the zeta converter. The rectified DC is subsequently transferred to a voltage source inverter, where it is converted back into AC. This AC output is then supplied to the BLDC motor. The driver circuit sends gate pulses through MOSFET to control motor operation. Additionally, a PI controller automatically regulates the motor speed, adjusting it to match a reference speed.

4.1 Closed loop speed regulation of BLDC motor with zeta converter

In MATLAB Simulink, the motor speed is compared by the PI controller. In this particular model, the values of Kp are set to 0.1 and Ki to 0.05. A reference speed of 1500 rpm is provided, and eventually, a constant speed of 1516 rad/s is attained. The output voltage of phase a and b of the inverter is measured at 268V. Figure 4.2.1 illustrates the closed-loop control of the motor utilizing a PI controller and zeta converter.

4.2 Motor Specification

No. of Phase - 3

Back-EMF waveform - Trapezoidal

Rotor type - Round

Mechanical Input - Torque (5 N.m.)

Stator phase resistance - 0.0485 ohm

Stator phase inductance - 0.0085 H

Flux linkage - 0.1194

Reference speed - 1500 rpm

Input voltage - 227 V

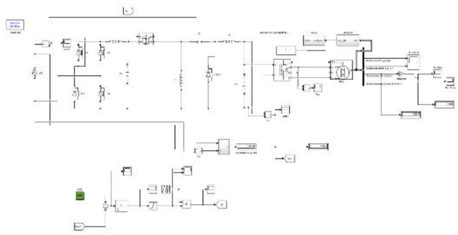

Fig 4.2.1: Speed regulation of motor with PI controller and zeta converter in closed-loop

Steady state response

In Figure 4.2.2, the initial graph illustrates a constant current. The second waveform depicts a stable back-EMF of the motor. Following this, the third graph displays a constant speed, measured at 1516 rad/s. Finally, the fourth graph illustrates the torque waveform, transitioning from 3 N.m. to 7 N.m.

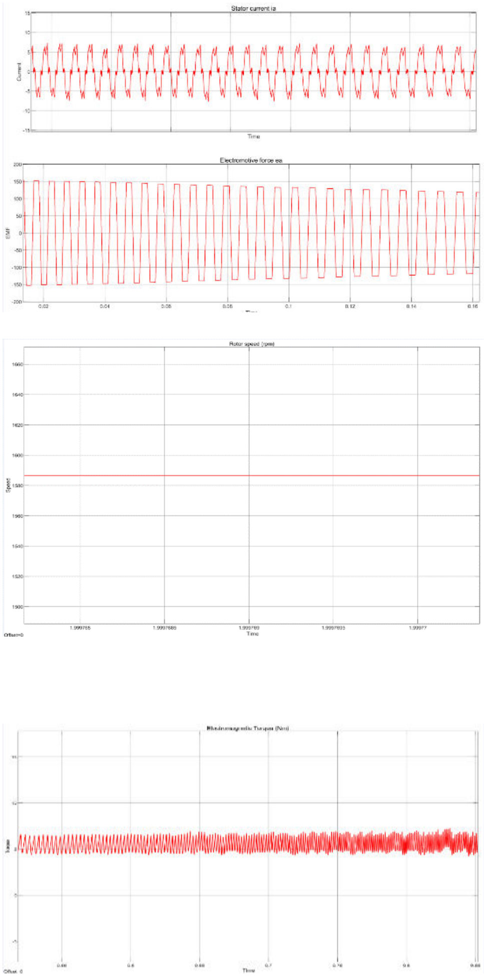

Fig 4.2.2: Steady state of BLDC motor fed zeta converter

5. CONCLUSION

In this project, A comparative analysis is done between open-loop and the closed-loop system feedback in steady-state condition. The utilization of a Zeta converter for speed control of BLDC motors offers several advantages, including improved efficiency, reduced electromagnetic interference, and enhanced controllability. By implementing pulse width modulation (PWM) techniques, the Zeta converter effectively regulates the voltage and current supplied to the BLDC motor, enabling precise speed control across a wide range of operating conditions. Furthermore, the inherent characteristics of the Zeta converter, such as its ability to operate in both step-up and step-down modes, make it well-suited for various BLDC motor applications, ranging from low-power household appliances to high-performance industrial systems.

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