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Bridgeless Zeta Converter with Four Switch Three Phase Inverter for Sensorless BLDC Motor

Riya Augustin[1], Nithin S.Nair[2]

PG Student [Power Electronics], Dept. of EEE, Sree Narayana Gurukulam College of Engineering, Kadayiruppu, Kerala, India[1]

Assistant Professor, Dept. of EEE, Sree Narayana Gurukulam College of Engineering, Kadayiruppu, Kerala, India[2]

ABSTRACT: Brushless DC (BLDC) motors are becoming popular due to their advantages of high efficiency, high energy density, high torque/inertia ratio, variable speed operation and low electro-magnetic interference (EMI). They find applications in household appliances, medical equipment, robotics and automation, transportation and industrial tools. A diode bridge rectifier (DBR) with a high value of smoothening capacitor is generally used for feeding the BLDC motor. It draws a distorted supply current from AC mains due to uncontrolled charging and discharging of the DC link capacitor. Also 6-switch 3-phase inverters have been widely used for BLDC motor drives. This project proposes a bridgeless ZETA converter with four switch three phase inverter. ZETA converter is provides low ripple output voltage. The bridgeless configuration eliminates the front end diode bridge rectifier and reduces conduction losses. Similarly the four switch inverter configuration reduces the cost of the inverter, the switching losses, and the complexity of the control algorithms. This proposed system uses sensorless control operation. There are no hall sensors, therefore, the system becomes robust.

KEYWORDS: BLDC Motor, Diode Bridge Rectifier, Hall Sensor.

I.INTRODUCTION

For a reduced cost operations and high efficient motor drive we employ BLDC motors to fulfill the requirement. The applications of these motors are mainly for computer, aerospace, military, automotive, industrial and household products. The utilization of BLDC motors is increasing as these motors have features like high flux density with less maintenance and high speed. These are not only restricted to house hold applications but also for industrial tools, HVAC (Heating, Ventilation and Air Conditioning) systems and also for traction applications. The BLDC motors are normally controlled with variable voltage fed to the terminals of the motor i.e., the speed of the BLDC motor is controlled by adjusting the DC voltage supply given to the VSI (Voltage source inverter).A conventional Brushless DC motor is excited by a six switch three phase inverter (SSTPI) where commutation is achieved through an inverter and a position sensor placed 120° apart on the stator. Researchers are always conscious about their cost and are always exploring methods to bring in cost minimization.

Power supplies with active power factor correction (PFC) techniques are becoming necessary for many types of electronic equipment to meet harmonic regulations and standards, such as the IEC 61000-3-2. A BLDC motor when fed by a diode bridge rectifier (DBR) with a high value of dc link capacitor draws peaky current which can lead to a THD of supply current of the order of 65% and power factor as low as 0.8 . Hence, a DBR followed by a power factor corrected (PFC) converter is utilized for improving the power quality at ac mains.

A conventional BLDC motor drive is generally implemented via a six switch, three-phase inverter and three Hall-effect position sensors that provide six commutation points for each electrical cycle. Cost minimization is the key factor in an especially fractional horse-power BLDC motor drive for home applications. It is usually achieved by elimination of the drive components such as power Switches and sensors. In this project four switch, three-phase inverter (FSTPI) topology is used for a three-phase BLDC motor drive. Reduction in the number of power switches, dc power supplies,

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switching driver circuits, losses and total price are the main features of this topology. A Hall-Effect position sensor is used to sense the rotor position on a span of 60^0. A switching logic generates a switching states for the VSI to attain electronic commutation. To eliminate the requirement of Hall Effect position sensors for the overall cost reduction of the PFC drive system, a sensor less approach can be used. This project proposes a bridge less zeta converter with four switch three phase inverter based sensorless speed control of bldc motor. Thus a bridgeless zeta converter configuration provides power factor correction with elimination of the diode bridge rectifier circuit. The four switch three phase inverter have reduced switching losses compared to six switch three phase inverter .The sensor less speed control eliminates the hall effect sensors mounted on the stator.

II.PROPOSED SYSTEM

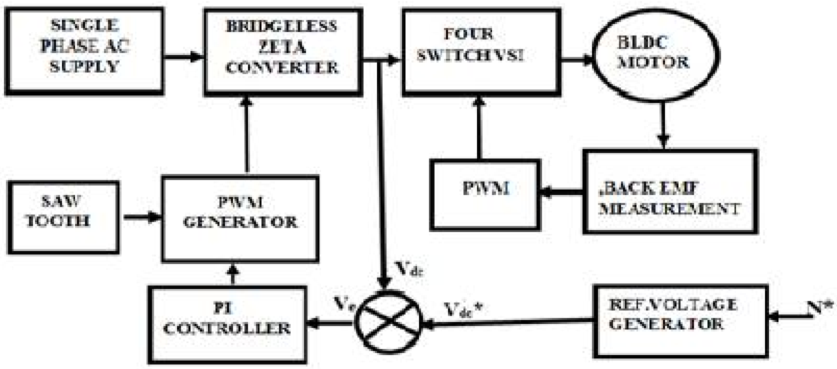

Fig 1 Block diagram representation of bridgeless zeta converter with four switch three phase inverter fed sensor less bldc motor drive

Fig 1 shows the block diagram of bridgeless zeta converter with four switch three phase inverter fed sensor less bldc motor drive .The single phase ac supply is given to a bridgeless zeta converter, the output of this converter is dc.The dc supply is given to a four switch voltage source inverter, which is then fed to BLDC motor. In order to produce electronic commutation back emf detection method is used. The switches in the bridgeless zeta converter is controlled through PI controller.

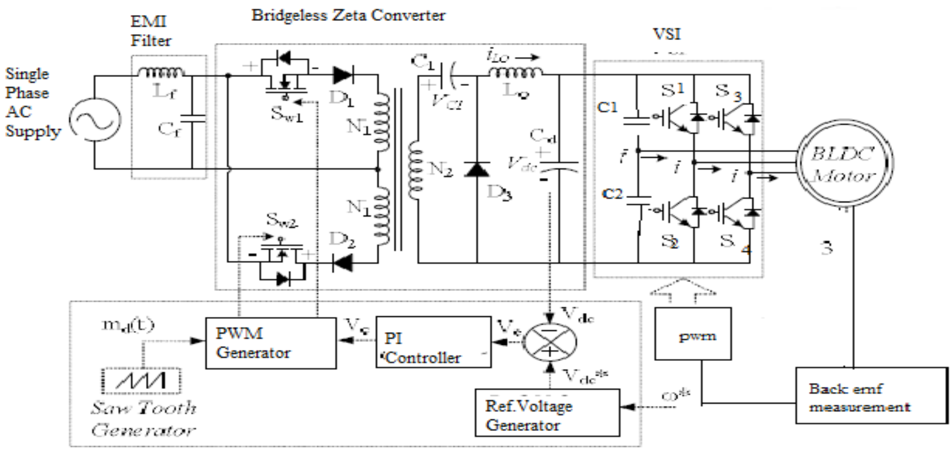

Fig.2 Circuit diagram representation of bridgeless zeta converter with four switch three phase inverter fed sensor less bldc motor drive

A bridgeless topology is designed such that two switches conduct independently for the positive and negative half cycle of the supply voltage. The conduction losses of the DBR are reduced to half as compared to conventional topology due

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to the bridgeless configuration. Moreover, this also improves the thermal utilization of switches since switch rms current is divided into two switches. Switch Sw_1 and diode D_1 conduct for the positive half cycle of the supply voltage and diode D_2 remains reversed biased during this period. Similarly for the negative half cycle of the supply voltage, switch Sw_2 and diode D_2 conduct and no current flows through switch Sw_1 and diode D_1.

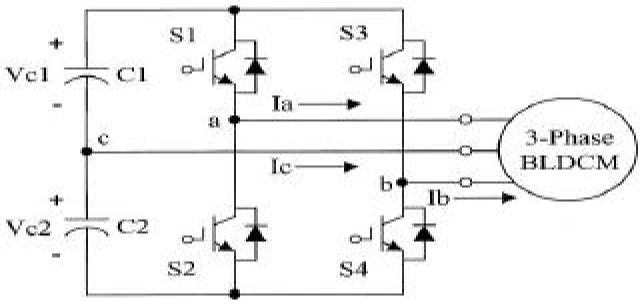

Fig 3 Circuit Diagram of four switch bldc motor drive

For a BLDC motor to generate maximum and constant output torque, their phase currents should be rectangular with 120°conducting and 60° non-conducting intervals. Also at each operating mode, only two phases are conducting and the other phase remains silent.

Under a balanced condition, the three-phase currents will satisfy the following condition:

$$Ia + Ib + Ic=0 \quad (1)$$

This can also be written as

$$Ic=- (Ia + Ib) \quad (2)$$

In an ac induction motor drive, at any instant there are always three phase currents flowing as

$$Ia\neq0;\ Ib\neq0;\ Ic\neq0 \quad (3)$$

TableI: Switching Sequence of Four Switch Converter

MODES	ACTIVE PHASES	SILENT PHASES	SWITCHING DEVICES
Mode 1	Phase B and C	Phase A	S_4
Mode 2	Phase A and B	Phase C	S_1 and S_4
Mode 3	Phase A and C	Phase B	S_1
Mode 4	Phase B and C	Phase A	S_3
Mode 5	Phase A and B	Phase C	S_2 and S_3
Mode 6	Phase A and C	Phase B	S_2

for a BLDC motor (3) is not valid anymore. Due to the characteristics of BLDC motor, only two phases need to be controlled by the four switches using the hysteresis current control method during each operating mode. Hence this scheme is called the Direct Current Controlled PWM scheme.The switching sequence is shown in tableI.

For controlling the brushless dc motors they generally require a rotor position sensor for starting and for providing the proper commutation sequence to control the inverter. These position sensors can be Hall sensors, resolvers, or absolute position sensors. Those sensors will increase the cost and the size of the motor, and a special mechanical arrangement needs to be made for mounting sensors. Particularly, Hall sensors are temperature sensitive limiting the operation of the motor below about 75°C.On the other hand, they could reduce the system reliability because of the components wiring.

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In some applications, it even may not possible to mount any position sensor on the motor. Therefore, sensor less control of BLDC motor has been receiving great interest in recent years.

When the BLDC motor rotates, each winding will generates the voltage known as back electromotive force or simply back EMF .which opposes the main voltage supplied to the windings according to the Lenz law. The polarity of this back EMF is in opposite direction to that of the energized voltage, back EMF mainly depends on three factors
(1) Angular velocity of the motor
(2) Magnetic field generated by the rotor magnets
(3) The number of turns in the stator windings.

Back EMF is expressed as
Back EMF=N l r B ω 1.1 Where
N is the no of windings per phase
l is the length of the rotor
r is the internal radius of the rotor

B is the rotor magnetic field density and ω is the motor’s angular velocity.From the above equation the only variable term is the rotor angular speed ,therefore the back EMF is directly proportional to the rotor speed ,as speed increases the back EMF increases and vice versa.

Back emf zero crossing detection method is one of the simplest methods of back EMF sensing techniques for obtaining the rotor position information and is based on the detection of the detection of zero crossing of the back EMF waveform. In the typical operation of the BLDC motor, the phase current and back EMF should be aligned to generate the constant torque. At any instant only two phases will conduct current, leaving the third phase floating in order to produce maximum torque. The Direct current (DC) voltage source is applied to the three phase inverter which consist of four MOSFET switches used for the commutation of the current this converter will convert the DC into Alternating current(AC) which is required to run the BLDC Motor. ZCD consist of the operational amplifier which is programmed to detect the zero crossing of the back EMF signal. Whenever the back EMF wave crosses zero the op amp will give a signal which is purely a square wave required for the controller to perform the pulse generating function. Depending on the signal given by the ZCD, controller reads the captures (signals equivalent to the hall sensor signals) and the corresponding PWM pulses are generated in the Controller.

The design equations used for designing the bridgeless zeta converter is given below. Let,

Input supply voltage V_{in}
DC link voltage V_{dc}
Line frequency f_L
Transformation ratio of HFT N2:N1 =1:2

Duty ratio D is calculated as $D = \frac{V_{dc}}{V_{dc} + \left(\frac{N2}{N1}\right) Vin}$ (4)

The value of output inductor L_o is calculated as

$$L_o = \frac{V_{dc}(1-D)}{f_s \Delta^{i}_{Lo}} \quad (5)$$

The value of intermediate capacitor C_1 is calculated as

$$C_1 = \frac{V_{dc} * D}{f_s V_{in} R_l} \quad (6)$$

The value of DC link capacitor is given and calculated as

$$C_d = \frac{I_{dc}}{2\omega_L \Delta^{V}_{dc}} \quad (7)$$

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III.SIMULATION ANALYSIS

The simulation is carried out for a input voltage V_{in} = 220V and a dc link voltage V_{dc} = 130V.The reference speed is set as 500rpm.Fig 4 shows the simulation model of bridgeless zeta converter with four switch three phase inverter fed BLDC motor drive.

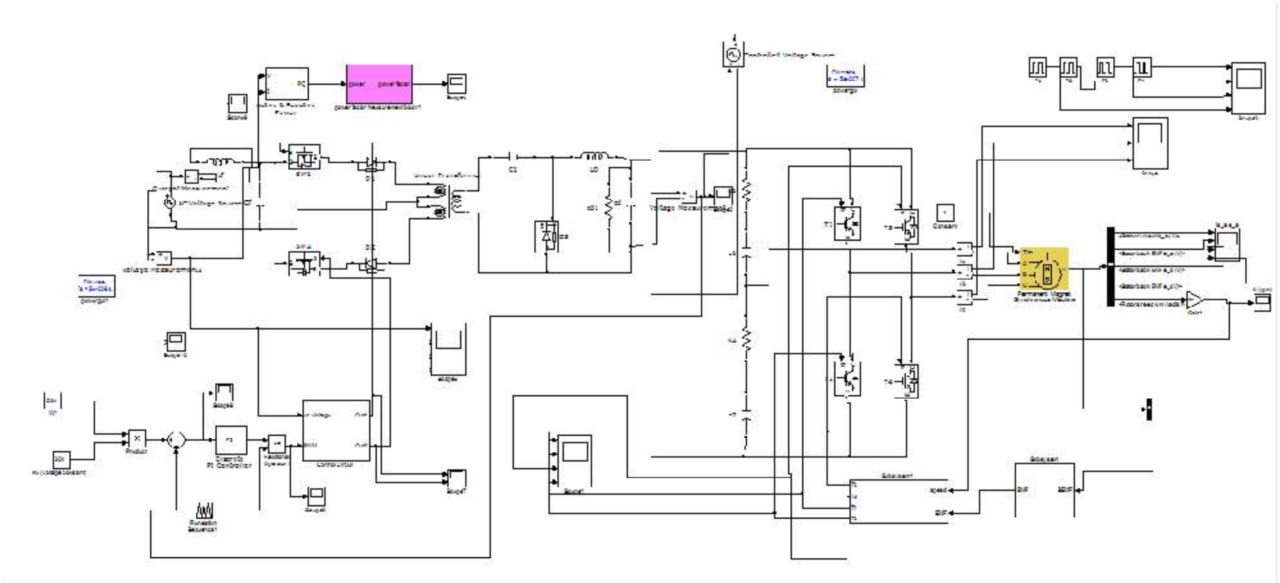

Fig 4: simulation model of bridgeless zeta converter with four switch three phase inverter fed BLDC motor drive

TableII: Simulation Parameters of bridgeless zeta converter with four switch three phase inverter for sensorless BLDC motor

COMPONENT	VALUE
Output inductor L_o	3.247mH
Intermediate capacitor C_1	156nF
DC link capacitor C_d	2500mF
Inverter capacitor C_{1a}	2000µ*F*
Inverter capacitor C_{2a}	2000µ*F*

Table II shows the simulation parameters of bridgeless zeta converter with four switch three phase inverter for sensorless BLDC motor.

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Figure 7 shows the simulation result of rotor speed in rpm. The reference speed is set to 500 rpmand the real speed is about 490 rpm.Brushless DC motor with their trapezoidal back EMF profile requires six discrete rotor position information to properly perform the phase commutation and /or current control.

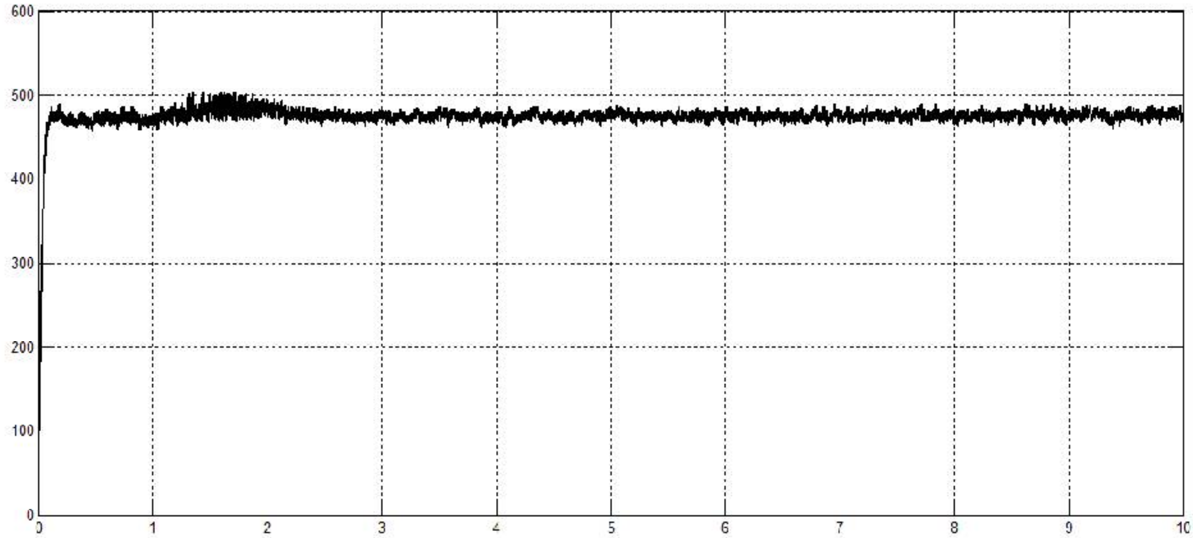

Fig 7 The Simulation Result of Rotor Speed in Rpm

IV.HARDWARE IMPLIMENTATION

The experimental prototype mainly consist of the bridgeless zeta converter, four switch three phase inverter ,BLDC motor and the controlling section. The controller used is ATmega16.Figure 8 shows the hardware implementation of bridgeless zeta converter with four switch three phase inverter for BLDC motor.

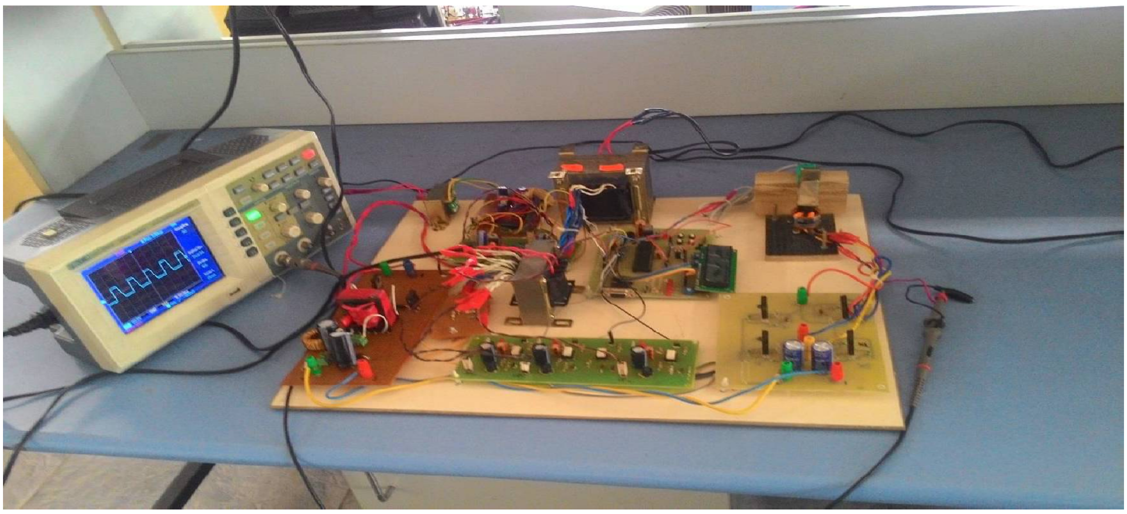

Fig 8 :The hardware implementation of bridgeless zeta converter with four switch three phase inverter for BLDC motor.

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The input ac voltage is vin=32V which is given to the bridgeless zeta converter. The output of converter is dc. Which is given as input to the inverter. The output of inverter is fed to bldc motor. The controller used is ATmega16 it is a 40 pin IC. Initially the different modes of operation is programmed in the microcontroller. Since sensorless speed control using back emf detection method is used, the backemf is feedbacked through a potential divider.Which is then given to a zero crossing detector. Whenever theback EMF wave crosses zero the op amp will give a signal which is purely a square wave required for the controller to perform the pulse generating function. Depending on the signal given by the ZCD, controller reads the captures (signals equivalent to the hall sensor signals) and the corresponding PWM pulses are generated in the Controller.Figure 9 shows the output voltage waveform of bridgeless zeta converter

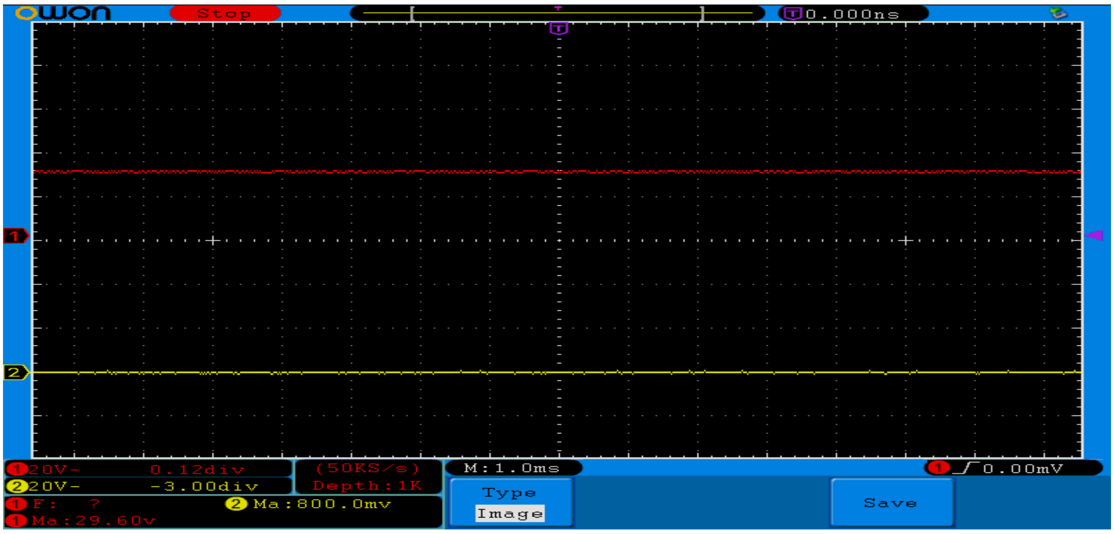

Figure 9 The output voltage waveform of bridgeless zeta converter

Figure 10 shows the speed regulation which is displayed in the LCD display.In the figure the set speed is 479rpm and the real speed 400 rpm.

Fig 10:The Speed Regulation(LCD Display)

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VI.CONCLUSION

Brushless dc (BLDC) motors have been desired for small horsepower control motors due to their high efficiency, silent operation, compact form, reliability, and low maintenance .A pfccuk converter fed bldc motor drive was designed and analysed. In this the single phase ac supply is given to a diode bridge rectifier with a high value of smoothening capacitor It draws a distorted supply current from AC mains due to uncontrolled charging and discharging of the DC link capacitor. Also the bldc motor is fed from a six switch three phase inverter. As the number of switching devices increases the conduction losses increases. Here in order to control the motor hall sensors are used. These sensors, particularly Hall sensors, are temperature sensitive, limiting the operation of the motor to below about 750C. On the other hand, they could reduce the system reliability because of the components and wiring. In order to overcome these difficulties bridgeless zeta converter with four switch three phase inverter for sensorless BLDC motor is proposed. Simulation of the circuit is carried out in MATLAB SIMULINK for analyzing the performance.The hardware of the same is implemented and the output of the hardware is checked. Both simulation and

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