3rd International Conference on
Robotics Automation and Non-Destructive Evaluation,
Chennai, India, 23 April 2022.
https://doi.org/10.13180/RANE.2022.23.04.37

DESIGN AND IMPLEMENTATION OF 1.5KW BLDC MOTOR SPEED CONTROL FOR E-VEHICLE

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Abstract— This paper deals about the design and development of 1.5kW BLDC motor in Ansys Design software. This software helps to design the BLDC Motor and make some testing of BLDC Motor li0.64ke heat loss, material cost, type material used. From the result we can predict the efficiency of the motor and some other properties of the motor. In proposed model 1.5kW BLDC motor was designed and various test result was taken from Ansys software. Hardware design developed for 48V BLDC Motor by using microcontroller for speed controlling. PWM technique used for the speed control of BLDC Motor.

Keywords— BLDC, Ansys, Microcontroller, MOSFET Driver, Speed Control.

1 INTRODUCTION

Brushless DC motor (BLDC) has more advantages than all other motors, such as Induction motors, DC motorsdue to compact size, higher efficiency, quiet operation, higher dynamic, long life and electronic switching. Due to these advantages, they are used in numerous areas such as aerospace, motion control, and robotics, transport. BLDC motor is synchronous three phase motor consisting of a three-phase stator concentrated windings and permanent rotormagnets. It has no mechanical brushes and commutator layout wears out on brushes and spark problems are eliminated. Detect rotor position it is very important to generate the correct switching sequences of the three-phase inverter. Afteroperating the BLDC motor at the three-phase inverter is implemented in hardware in this document. Initially BLDC Motor is designed in ANSYS software. In this ANSYS we can take many tests result This drive system can change the motor speed as good. We can use this motor for the smooth operation of e-vehicle, and also, we can use motor for any other e-vehicle. The overview of this paper is to develop a BLDC motor for E-vehicle application with speed control and smooth movement of the vehicle.

2 ANSYS RMXPRT

ANSYS Maxwell is a high-performance, low frequency electromagnetic field simulation interactive software package that uses finite element analysis (FEA) to solve electromagnetic problems by solving Maxwell's equations in a finite region of space with appropriate boundary, electromagnetic and electromechanical devices, including motors, transformers, coils. AN-SOFT Maxwell uses the accurate FEM to solve static, frequency-domain, and time- varying electromagnetic and electric fields.

(RMxprt) Rotating Motor Expert is a template-based design tool of the ANSYS – Maxwell suite used to create a customized Motor design flow to meet demand for higher efficiency. Using classical analytical motor theory and equivalent magnetic circuit methods, RMxprt can calculate Motor performance, make initial sizing decisions and perform numerous "what if" analyses. RMxprt is able to automatically set up a complete Maxwell project (2-D/3-D) including geometry, materials and boundary conditions. The set up includes the appropriate symmetries and excitations with coupling circuit topology for electromagnetic transient analysis. Fig.1 shows the basic BLDC motorstructure.

3 48 SLOTS, 22 POLES BLDC MOTOR IN ANSOFT

The text below describes the RMxprt design of a 48 Slot, 22 Pole with the aim to maximize performance at ratedparameters.

3.1 Motor & Circuit

The general Motor and circuit parameters are as follows,

Parameter	Value	Unit
Number of Poles	22	
Frictional Loss	10	W
Windage Loss	20	W
Reference Speed	380	Rpm
Lead angle of trigger	0	°
Trigger Pulse Width	120	°
Transistor/Diode Drop	2	V
Circuit Type	Y3	

Figure. 1 General motor & circuit data

3.2 Stator Data

The general data for the stator is tabulated below,

Parameter	Value	Unit
Outer Diameter	240	mm
Inner Diameter	140	mm
Stacking Factor	0.95	
Length	50	mm
Steel Type	M100-23P	
Number of Slots	48	
Slot Type	4	
Skew Width	1	Slots

Figure.2 Stator Data

3.3 Slot Design

The selected slot type 4 in RMxprt is based on the research done by [14]. Its design are Data are depicted and tabulated below.

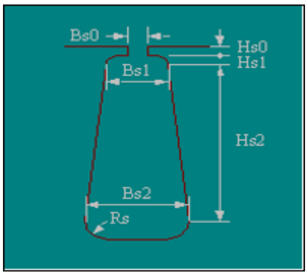

Figure. 3 Slot Design (Type 4)

3.4 Winding Design

The stator winding data and geometry along with its end terminations and insulations is depicted and tabulated below,the coil pitch is kept minimum to reduce eddy current losses and end extensions.

Parameter	Value	Unit
Winding Layers	2	
Winding Type	Whole Coiled	
Parallel Branches	1	
Conductors per slots	12	
Coil Pitch	1	
Number of Strands	6	
Wire Wrap	0.2	mm
Wire Size (Diameter)	1.369	mm

Figure. 4 Winding Data

Parameter	Value	Unit
End Extension	4	mm
Base Inner Radius	0.5	mm
Tip Inner Diameter	1	mm
End Clearance	1	mm
Slot Liner	0.5	mm
Wedge Thickness	0.3	mm
Layer Insulation	0.1	mm
Limited Fill Factor	0.75	

Fig. 5 End / Insulation Data

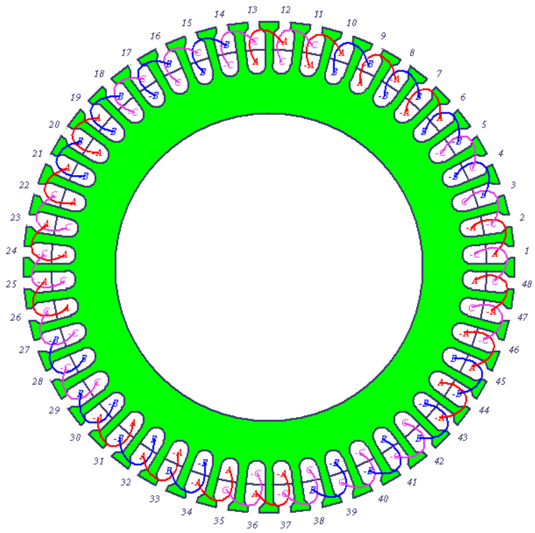

Figure. 6 Stator Winding

3.5 Rotor Data

The general data for the Motor rotor is tabulated below,

Parameter	Value	Unit
Outer Diameter	262	mm
Inner Diameter	242	mm
Stacking Factor	0.95	
Length	50	mm
Steel Type	M100-23P	
Pole Type	1	

Figure. 7 General Rotor Data

Due to the outer rotor geometry of the BLDC Motor only pole type 1 is allowed for analysis.

3.6 Pole Data

The pole data is tabulated below,

Parameter	Value	Unit
Embrace	0.9	
Offset	4	mm
Magnet Type	NdFeB	
Magnet Thickness	4	mm

Figure. 8 Pole Data

3.7 Analysis Setup

The Motor's rated operating state input/output parameters are tabulated below,

Parameter	Value	Unit
Load Type	Constant Power	
Rated Output Power	1500	W
Rated Voltage	48	V
Rated Speed	380	Rpm
Operating Temperature	75	˚C

Figure. 9 Analysis Setup

3.8 Solution Data

The important output parameters and plots are described below. Fig 11 shows the entire solution data of the BLDC Motor designed in ANSYS Software with 1.5kW rating.The Fig 12 Shows the BLDC Motor with outer rotor of 48 Slots, 22 Poles.

Parameter	Value	Unit
Armature Current (RMS)	32.22	A
Total Loss	265	W
Output Power	1500	W
Input Power	1765	W
Efficiency	84.98	%
Rated Speed	378.86	Rpm
Rated Torque	37.81	Nm
Total Net Weight	11.57	Kg
Total Steel Consumption	25.2	Kg
No-Load Speed	434.64	Rpm
Residual Flux Density(Rotor)	1.23	T
Minimum Air-Gap	1	mm
Stator Slot Fill Factor	68.72	%
Stator Winding Factor	0.63	
Single Phase Resistance	0.025	Ω
Time Constant	0.0022	s
Back EMF Constant (K_E)	0.97	V/rad
Rated Torque Constant	1.04	Nm/A
Armature Current Density	3.64	A/mm^2
Locked Rotor Torque	864.32	Nm
Locked Rotor Current	888.61	A
Stator Teeth Flux Density	3.1	T

Figure. 10 Solution Data of 1.5kW BLDC Motor

With this the design of 1.5kW BLDC Motor using ANSYS software is completed. The test and results will be seenunder the result and conclusion heading.

By using of this ANSYS Software results we can design the hardware system. Here we have designed hardware circuit with the PCB, PIC, MOSFET. And we use the results and designed the speed control of the BLDC Motor for E vehicle application.

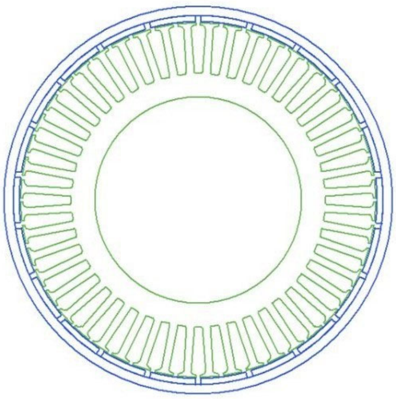

Figure. 11 48 Slots, 22 Poles BLDC Motor

4 BLOCK DIAGRAM

The block diagram consists of

a. Microcontroller.
b. MOSFET Driver Circuit.
c. MOSFET Power Section.

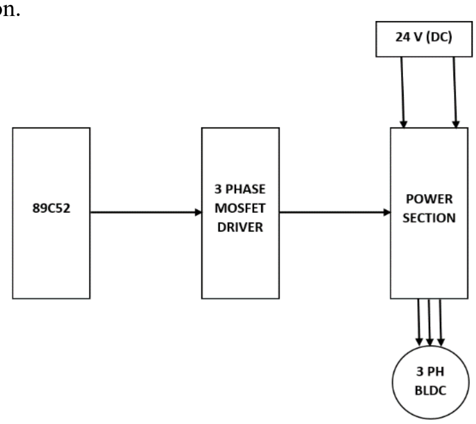

Figure. 12 Basic Block Diagram of BLDC Drive

4.1 Microcontroller

The family of microcontrollers is 8051, and the same family member is 89c51, 89c52, etc. There are several packages,such as dual online packages (DIP), quad-flat packages (QFP), and lead-free chip carriers (LLC). The family of microcontrollers like 89c51, 89c52 consists of 40 pins, consisting of four I / O ports. The supply voltage is applied to pin 40 of the controller and grounded to pin 20. The crystal oscillator is used to generate a frequency that is connected to pins 18 and 19 of the controller.

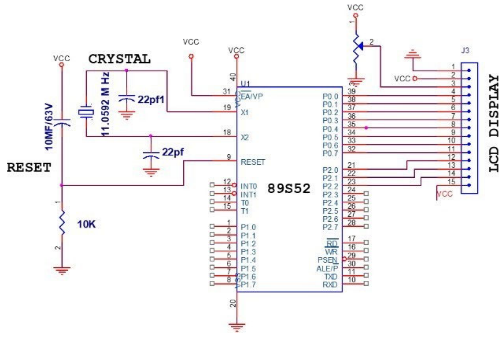

Figure. 13 Circuit diagram of Microcontroller

4.1.1 MOSFET driver section

The MOSFET driver section is consisting of

1. Transistor
2. Optocoupler section
3. Current boosting section
    i. Resistor Current Source
    ii. Active Current Source
    iii. Simple Transistor Current Source

4.1.2 Transistor

BC557 Transistor is a bipolar PNP device. It has DC Current gain up to 300. Continuous collector current is100mA. Emitter Base is 6V. Table 1 shows the Transistor range and parameters.

Table 1. Transistor range and parameters

Parameters	Range
Collector base voltage	-50 V
Collector emitter voltage	-45 V
Emitter base voltage	-5 V
Collector current	-30 A

4.1.3 Opto coupler section

In electronics, an optocoupler is a device that uses a short optical transmission path to transmit a signal between elements of a circuit, usually a transmitter and a receiver, while they are kept electrically isolated, as the signal goes from an electrical signal to an optical signal and then to an electrical signal, the electrical contact along the way is broken.

4N35 is optocoupler ic used in this hardware. It has high direct current transfer ratio, High voltage electrical isolation (1.5kV, 2.5kV or 3.55kV rating). Typical application includes remote SCR, Triac Triggers.

4.1.4 Current Boosting

A current source is an electrical or electronic device that delivers or absorbs electric current. A current source is the dual of a voltage source. The term constant-current sink is sometimes used for sources fed from a negative voltage supply.

Table 2. Parameters of opto coupler and its rating

Parameters	Range
Peak voltage	3.55kV
Collector base voltage	2.5kV
Collector emitter voltage	70 V
Emitter base voltage	7 V
Diode reverse voltage	6 V

4.1.4.1 Resistor Current Source

The simplest current source consists of a voltage source in series with a resistor. The current available from sucha source is given by the ratio of the voltage across the voltage source to the resistance of the resistor. For a nearly ideal current source, the value of this resistor should be very large but this implies that, for a specified current, the voltage sourcemust be very large. Thus, efficiency is low (due to power loss in the resistor) and it is usually impractical to construct a 'good' current source this way.

4.1.4.2 Active Current Sources

Active current sources have many important applications in electronic circuits. Current sources (current-stable resistors) are often used in place of ohmic resistors in analog integrated circuits to generate a current without causing attenuation at a point in the signal path to which the current source is attached. The collector of a bipolar transistor, the drain of a field effect transistor, or the plate of a vacuum tube naturally behave as current sources (or sinks) when properly connected to an external source of energy (such as a power supply) because the output impedance of these devices is naturally high when used in the current source configuration.

4.1.4.3 Simple Transistor Current Source

Table 3. Parameters of transistor as current source

Parameters	Range
Collector base voltage	80 V
Collector emitter voltage	80 V
Emitter base voltage	5 V
Collector current	0.5A

4.2 MOSFET Power Section

An inverter is an electrical device that converts direct current (DC) into alternating current (AC). The converted alternating current can be at any required voltage and frequency using suitable transformers, switching circuits, and control.

Static inverters have no moving parts and are used in a variety of applications, from small computer switched power supplies to high-voltage DC applications from large power companies that carry mass flow. Inverters are commonlyused to supply AC power from DC sources, such as solar panels or batteries. The electric inverter is a high-performance electronic oscillator.

5 PWM TECHNIQUE

PWM is an effective method for adjusting the amount of power delivered to the load. PWM technique allows smooth speed variation without reducing the starting torque and eliminates harmonics. In PWM method, operating power to the motors is turned on and off to modulate the current to the motor. The ratio of on to off time iscalled as duty cycle. The duty cycle determines the speed of the motor. The desired speed can be obtained by changing the duty cycle. The Pulse Width Modulation (PWM) in microcontroller is used to control duty cycle of DCmotor drive.

PWM is an entirely different approach to controlling the speed of a DC motor. Power is supplied to the motor in square wave of constant voltage but varying pulse-width or duty cycle. Duty cycle refers to the percentage of one cycle during which duty cycle of a continuous train of pulses. Since the frequency is held constant while the on-off time is varied, the duty cycle of PWM is determined by the pulse width. Thus, the power increases duty cycle in PWM.

6 POWER SECTION

Starting from an AC voltage, a constant DC voltage is obtained by rectifying the AC voltage, then filtering it to a DC voltage level, and finally regulating it to obtain a desired fixed DC voltage. Dimming is usually obtained from a voltage regulating unit IC that receives a DC voltage and supplies a somewhat lower DC voltage that remainsthe same even if the DC input voltage changes or the output load connected to the DC voltage changes.

Figure 16 shows a block diagram with the parts of a typical power supply and the voltage at different pointson the device. The AC voltage, typically 120 V rms, is connected to a transformer that reduces this AC voltage to thelevel of the desired DC output. A diode rectifier then supplies a full-wave rectified voltage, which is initially filteredthrough a simple capacitor filter to produce a DC voltage. This resulting DC voltage typically has some fluctuationor fluctuation of AC voltage. A regulator circuit can use this DC input to provide a DC voltage that not only has a much lower ripple voltage, but also remains the same when the DC input voltage changes slightly or the load connected to the output voltage of CC changes. This voltage regulation is generally obtained using one of several common voltage regulator IC units.

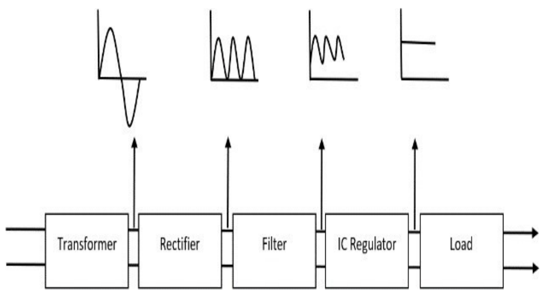

Figure. 16 Typical Power Supply

Table 4. Parameters of power source

Parameters	Range
Drain to source voltage	55 V
Drain to source leakagecurrent	25 μa
Gate threshold voltage	2 V

6.1 IC Voltage Regulators

Voltage regulators include a class of widely used integrated circuits. The IC controller units contain the circuit forthe reference source, the comparator amplifier, the control unit and the overload protection in a single IC. Although the IC's internal structure differs somewhat from that described for discrete voltage regulator circuits, the external operation is largelythe same. IC units regulate a fixed positive voltage, a fixed negative voltage, or an adjustable voltage.

A power supply can be built using a transformer connected to the AC power line to bring the AC voltage to the desired amplitude, then rectify that AC voltage, filter with a capacitor and RC filter if desired, and finally DC voltage usingan IC regulator to regulate. Regulators can be selected to operate with load currents from hundreds of milliamps to dozens of amps, corresponding to ratings from milliwatts to ten watts.

6.2 Three-Terminal Voltage Regulators

The fixed voltage regulator has an unregulated DC input voltage Vi applied to one input terminal, a regulated DCoutput voltage Vo from a second terminal, the third terminal is grounded. For a selected regulator, the IC device specifications list a voltage range over which the input voltage can vary to maintain a regulated output voltage over a rangeof the load current. The amount of change in output voltage resulting from a change in load current (load control) or input voltage (line control) is also listed in the specifications.

7 HARDWARE

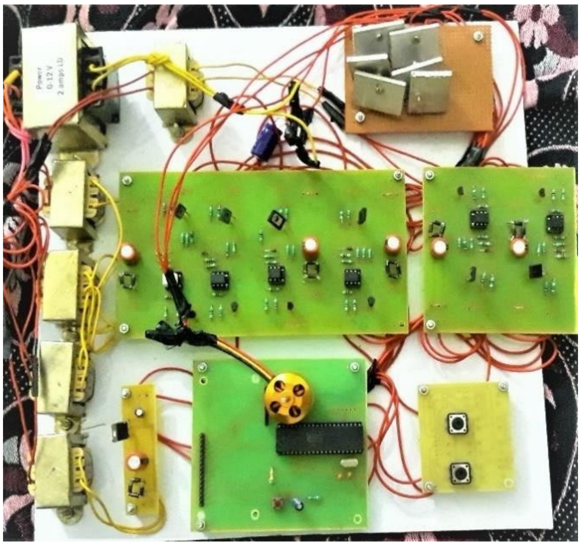

Fig. 17 Hardware Setup

Table 5. Hardware specifications

Equipment	Range
BLDC Motor	48 V{test motor)
Hardware Items	Low Range (for testing)

8 RESULTS

The ANSYS Software shows the entire details of the BLDC Motor design.

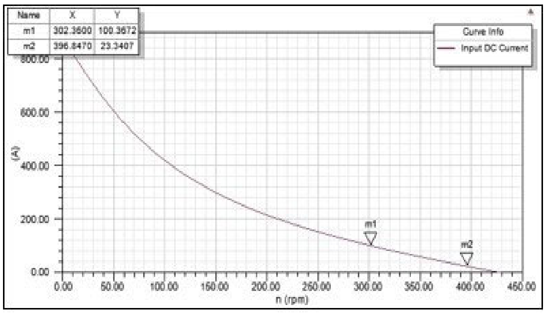

Fig. 18 Input Current vs Speed

From fig. 18 the graph shows that at starting input current was high and by changing the speed input current reduces slowly. M2 is the point where the input current is low compared to m1 point.

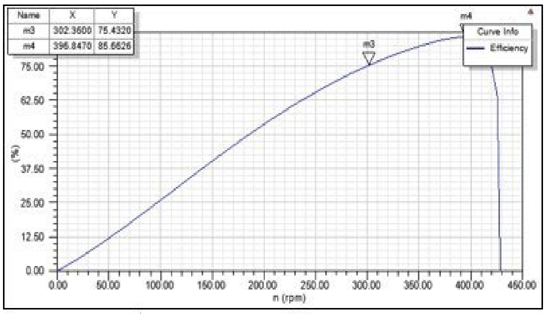

Fig. 19 Efficiency vs Speed

From fig. 19 the graph shows that efficiency of the motor increases with speed. M4 is the point where the efficiency of the motor is high.

From fig. 20 the graph shows that output power of the motor is keep on increasing with speed. From this result images, we come to know that the motor is working properly and the output of the motor is reaching the expected level.

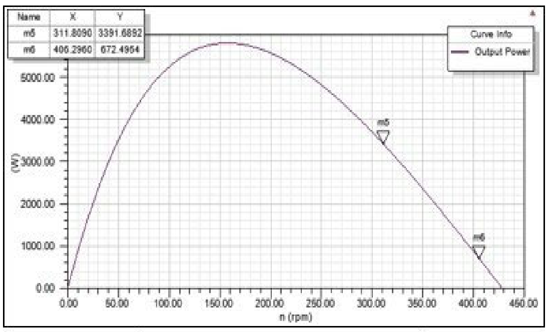

Fig. 20 Output Power vs Speed

9 CONCLUSIONS

In this paper, with help of ANSYS Software 48 Slots, 22 Poles,1.5 kW BLDC Motor designed and the results are obtained. Speed control of three phase BLDCM was done by hardware. The speed of the BLDC Motor increases when the duty cycle increases and speed decreases when the duty cycle decreases. BLDCM has many advantages like weight less, easy maintained. The proposed drive system has shown satisfactory result in all aspects. This drive recommended solution for low power BLDC motor drives. The future work is to implement the hardware circuit in high power rating. By this methodology, we can avoid the vibration of motor during starting. And we can achieve high speed operation without any lag. From fig. 20 the graph shows that output power of the motor is keep on increasing with speed. From this result images, we come to know that the motor is working properly and the output of the motor is reaching the expected level.

10 REFERENCES

[1] Vijay T, Naveen Gowda BR ‘ Design of brushless dc motor for electric vehicle’ JETIR October 2020, Volume 7, Issue 10 www.jetir.org (ISSN-2349-5162)

[2] C. P. Priyanka & G. Jagadanand Conference paper First Online ‘Design and Analysis of BLDC Motor for Electric Vehicle Application’ 05 March 2021

[3] J. Sriram and K. Sureshkumar, "Speed control of BLDC motor using fuzzy logic controller based on sensorless technique," 2014 International Conference on Green Computing Communication and ElectricalEngineering (ICGCCEE), 2014.

[4]] C.L. Xia, “Permanent Magnet Brushless DC Motor Drives Controls”, Wiley Press, Beijing, 2012

[5] I. A. Khan, "Power electronics in automotive electrical systems," Power Electronics in Transportation, Dearborn, MI, USA, 1996, pp. 29-38

[6] O. Rahmani, M. Iltarabian and S. A. Sadrossadat, "Modeling and simulation of speed and efficiency of BLDC motor as a starter motor," 2018 IEEE Transportation Electrification Conference and Expo, Asia-Pacific (ITEC Asia-Pacific), Bangkok, 2018, pp. 1-5.

[7] X huang, A. Goodman, C. Gerada, Y.Fang and Q. Lu “A Single Sided Matrix Converter Drive For A Brushless DC Motor in Aerospace Applications”, IEEE Trans. Ind. Electron, Vol. 59, No.9, pp. 3542: 3552 Sept. 2012.

[8] Dr. Ashok Kusagur, Jagdish pujar, SF Kodad, T.C. Manjunath, “Fuzzy Logic Based Flexible Multi-Bus Voltage Control of Power Systems”, Proc. of the 31st National Systems Conference, NSC-2007, MITMAHE Campus, Manipal576104, Karnataka, India, 14-15, Nov. 2007

[9] M. Kumar, B. Singh and B. P. Singh, "Fuzzy pre-compensated PI controller for PMBLDC motor drive," 2006 International Conference on Power Electronic, Drives and Energy Systems, New Delhi, 2006, pp. 1-5.

[10] J. P. Johnson, M. Ehsani and Y. Guzelgunler, "Review of sensorless methods for brushless DC," Conference Record of the 1999 IEEE Industry Applications Conference. Thirty-Forth IAS Annual Meeting (Cat. No.99CH36370), Phoenix, AZ, USA, 1999, pp. 143-150 vol.1.

[11] P. K. Khanke and S. D. Jain, "Comparative analysis of speed control of BLDC motor using PI, simple FLC and Fuzzy - PI controller," 2015 International Conference on Energy Systems and Applications, Pune, 2015, pp. 296-301.

[12] R. Krishnan, Electric Motor Drives: Modeling Analysis and Control, Prentice Hall, 2001.

[13] T.J.E. Miller, Brushless Permanent-Magnet and Reluctant Motor Drives, Oxford, 1989.

[14] P. Damodharan and K. Vasudevan, "Sensorless brushless DC motor drive based on the zero-crossing detection of back electromotive force from the line voltage difference," in IEEE Transactions on Energy Conversion, vol. 25, no. 3, pp. 661-668, Sept. 2010.

[15] J.F. Gieras and M. Wing, “Permanent magnet motor technology design and application”, Mareel Dekker Inc., New York, 2002.

[16] Bimal K. Bose, Modern Power Electronics and AC Drives, Prentice Hall, 2002.

[17] Jianwen Shao, D. Nolan and T. Hopkins, "A novel direct back EMF detection for sensorless brushless DC (BLDC) motor drives," APEC, Seventeenth Annual IEEE Applied Power Electronics Conference and Exposition (Cat. No.02CH37335), Dallas, TX, USA, 2002, pp. 33-37 vol.1.