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Fuzzy Logic Based Sensorless Control of Three-Phase Brushless DC Motor Using Virtual Instrumentation

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ABSTRACT

This paper presents a novel sensorless control of permanent magnet brushless DC motor (PMBLDC) using fuzzy controller. It is based on “indirect position sensing” method. The postion detection can be derived from the voltage and current waveforms. Such position information is derived from the line voltage difference measured at the terminals of the motor instead of back-electromagnetive force to eliminate the harmonics. For precise control and to get desired performance the motor is controlled using fuzzy controller. This Controller is virtually implemented in LABVIEW software of virtual Instrumentation. The waveforms also obtained easily from the front panel of LABVIEW. Because of the virtual fuzzy controller, there is no need of any separate processor like microcontroller or FPGA or DSP to implement the fuzzy logic. So this drive system has more advantage than the conventional sensorless control. As a result the proposed drive system is cost effective , more flexible and robust.

Keywords: *PMBLDC, Sensorless control, Line Voltage difference method, Fuzzy Logic, LABVIEW*

1. INTRODUCTION

Permanent magnet brushless DC motor have found wider applications due to their high power density and ease of control. In recent years , research on reduction of motor costs and drive systems has been intensively conducted. In order to perform current control and speed control according to the permanent magnet rotor position, various position sensors such as encoders, resolvers and magnetic hall sensors are necessary. However these position sensors are very expensive, and produce complex problems involving motor assemblers, and wiring between a sensor board and a drive circuit. Hence many researchers took effort to reduce these problems and to realize light weight, compact size.

More methods are used to eliminate sensors and to find the position information, but these are generally classified into two approaches. One approach is to estimate the initial rotor position without position sensors in the stopped state of the rotor. The other approach is that, after BLDC motor rotates, the BLDC motor speed is controlled without position sensors. The latter approach is normally considered.

Novel direct back emf detection for sensorless BLDC motor is given in [1]. Analysis of BLDC motor is given in [2]. Modeling of BLDC motor is given in [3]. Feed forward speed control of Brushless DC motor with input shaping is given in [4]. A PSO-based optimization of PID controller for a Linear BLDC Motor is given in [5]. Speed Control of BLDC based on CMAC & PID controller is given in [6]. A sensorless drive system for BLDC using a Digital Phase-Locked Loop is given in [7]. Classical control methods can be implemented in well- defined systems to achieve good performance of the systems. To control a system, an accurate mathematical model of the complete system is required. Systems with non linear behavior cannot be exactly modeled. The fuzzy Logic control has adaptive characteristics that can achieve robust response to a system with uncertainty, parameter variations and load disturbance. Fuzzy Logic and Fuzzy set theory was presented by Zadeh [8]. Fuzzy a Logic Controllers have been broadly used for ill-defined, non-linear and complex systems [9], [10]. In the area of electrical drives, fuzzy logic controllers have been applied to switched reluctance motors [11], [12], induction motors [13] and PMBLDC motors [14] successfully. This literature does not deal with voltage control method to control the speed using sensorless approach.

This paper demonstrates a sensorless technique to drive a three phase brushless DC motor with virtually created Fuzzy logic control using LABVIEW. PMBLDC motors drives are used in a wide range of commercial and residential applications such as domestic appliances, heating, ventilating and air-conditioning equipment due to their highest possible efficiencies. The speed control ability using Hybrid fuzzy controller is able to provide operation at their high efficiency.

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2. ANALYSIS OF SENSORLESS CONTROL OF THREE-PHASE BLDC MOTOR DRIVE

BLDC motor has characteristics like a DC motor, Where as it is controlled the same as AC motors. Fig. 1 shows trapezoidal back-EMF, current profiles, and Hall-sensor signals of the three-phase BLDC motor. One electrical cycle of the motor is divided to six 60^0 modes that at each mode, only two phases are conducting the current. In ideal case, the current profiles are regulated as quasisquare waveforms.

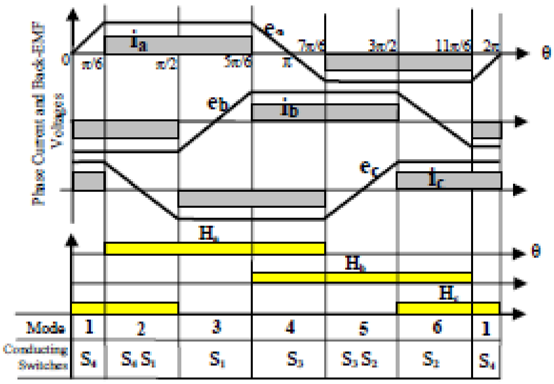

Fig. 1: Current profile , Back EMF , Hall Sensor signals of BLDC motor

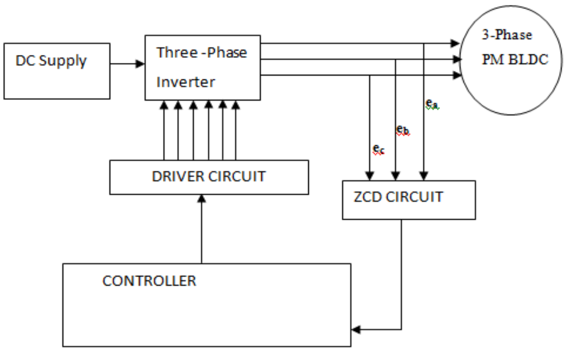

Fig. 2: Conventional position detection of BLDC motor

The typical mathematical model of a three-phase BLDC motor is described by the following equations.

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \times \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L_s\text{-}M & 0 & 0 \\ 0 & L_s\text{-}M & 0 \\ 0 & 0 & L_s\text{-}M \end{bmatrix} \frac{d}{dx} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \qquad (1)$$

where R , s L , M are the resistance, inductance and mutual inductance of the stator and v_x , i_x and e_x are phase voltage, back EMF voltage and phase current of the stator respectively [1]. Electromagnetic torque is expressed as

$$T_e = \frac{Z_p}{2.\omega_s}(e_a + e_b + e_c) \text{ ------} \qquad (2)$$

where ω_s is the electrical speed of the rotor and Z_P is the number of magnetic poles.

The major sensorless methods published in the literature can be classified as follows : back-EMF sensing techniques, flux estimation method, stator inductance variations method, observers and intelligent control methods. The sensorless techniques that utilize the back-EMF voltage include: (1) terminal voltage sensing, (2) third harmonic back-EMF voltage sensing, and (3) freewheeling diode conduction current sensing. Sensorless techniques based on back-EMF and terminal voltages are the most popular due to their simplicity, ease of implementation and lower cost. Back-EMF estimation methods typically rely on the zero crossing detection of the EMF waveform. The technique of estimating back-EMF by sensing the terminal voltages with respect to a virtual neutral point is proposed in [1]. The neutral point will not be stable during PWM switching. Low pass filters have been used to eliminate the higher harmonics and to convert the terminal voltages into triangular waveform signals. Delay is introduced in the sensed signal due to heavy filtering, which also varies with the operating speed shown in Fig.3. Therefore this method is well suited only for a narrow speed range.

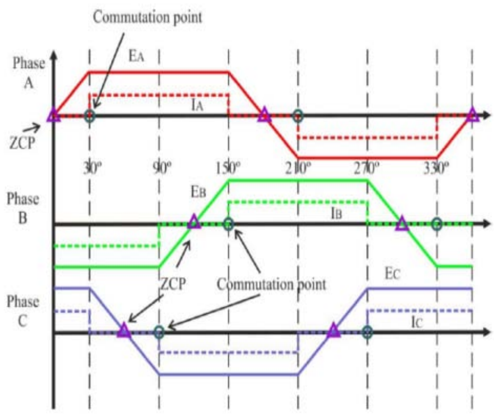

Fig. 3: Position detection of BLDC motor from BEMF

To overcome the difficulties and for wide speed range the position information is detected from the line voltage difference. The difference of line voltages

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provides an amplified version of the back-EMF in appropriate phase near the zero crossing.

The phase A terminal voltage with respect to the star point of the stator

$$V_{an} = R_a i_a + L_a\,(di_a/dt) + e_{an} \qquad (3)$$

Similar equations for the other two phases are,

$$V_{bn} = R_b i_b + L_b\,(di_b/dt) + e_{bn} \qquad (4)$$

$$V_{cn} = R_c i_c + L_c\,(di_c/dt) + e_{cn} \qquad (5)$$

From equation (3),(4),(5) the line voltage V_{ab} and V_{bc} are determined by

$$V_{ab} = V_{an} - V_{bn}$$

$$= R\,(i_{a-} i_b) + L\,(d\,(i_{a-} i_b)\,/dt) + e_{an} - e_{bn} \qquad (6)$$

$$V_{bc} = V_{bn} - V_{cn}$$

$$= R\,(i_{b-} i_{c)} + L\,(d\,(i_{b-} ic)\,/dt) + e_{bn} - e_{cn} \qquad (7)$$

A similar expression can be written for V_{ca} also. These line voltages can however be estimated without the need for STAR point by taking the difference of terminal voltages measured with respect to the negative DC bus.

Subtracting (7) from (6) gives

$$V_{abbc} = R(i_a - 2i_b + i_c) + L\,d(i_a - 2i_b + i_c)/dt + e_{an} - 2e_{bn} + e_{cn} \quad (8)$$

In the interval when phases A and C are conducting and phase B is open, phase A winding is connected to the positive of the DC supply, phase C to the negative of the DC supply and phase B is open.

Therefore $i_a = -i_c$ and $i_b = 0$.

Therefore in this interval the equation is simplified as,

$$V_{abbc} = V_{ab} - V_{bc} = -2\,e_{bn} \qquad (9)$$

The line voltage difference waveform is thus an inverted representation of the back-EMF waveform. The error between the line voltage difference and back EMF ,also shown in Fig. 3 is negligible at the zero crossing instant. Therefore the operation V_{ab}-V_{bc} (V_{abbc}) enables detection of the zero crossing of the phase B EMF. Similarly the line voltage difference V_{bcca} enables the detection of zero crossing of phase C back-EMF. The line voltage difference V_{caab} waveform gives the zero crossing of phase A back-EMF. Therefore the zero crossing instants of the back-EMF waveforms may be estimated indirectly from the line voltage differences.

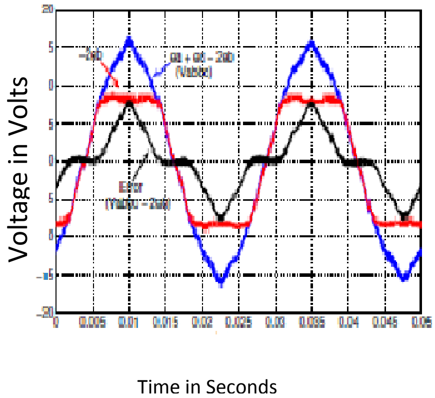

Fig. 4: Relation between Line Voltage Difference and Back EMF

This method is simple, reliable and does not involve any integration. Further, since line voltages are used, the requirement of neutral potential has been eliminated. This also eliminates the common mode noise. Device drops and their variations would also not play a part since line voltages are used. This scheme is easy to implement and no derivative operations are involved.

3. LABVIEW IN VIRTUAL INSTRUMENTATION

Virtual instrumentation software is based on user requirements. It defines general purpose measurement and control hardware functionality. Virtual instrumentation combines main stream commercial technologies, such as pc, with flexible software and a wide variety of measurement and control hardware, So engineers and scientists can create user-defined systems that needs their exact application needs with virtual instrumentation, Engineers and scientists can reduce development time, design higher quality products, lower their design costs. Only with virtual instrumentation can engineers and scientists create the user-defined instruments required to keep up with the world's demands. Another virtual instrumentation component is modular I/O, designed to be rapidly combined in any order or quantity to ensure that virtual instrumentation can both monitor and control any development aspect. LABVIEW (Laboratory Virtual Instrumentation Engineering Workbench) is a graphical programming language that uses icons instead of lines of text to create applications. LABVIEW program facilitates Virtual Instrumentation (VI), which imitates the appearance and operation of physical instruments. VI is defined as a process of combining hardware and software with industry standard computer technology to create a user-defined instrumentation solution. Several other add-on toolsets can be incorporated for developing the specialized applications.

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The line voltage difference is measured and given to the zero crossing detection circuit. The zero crossing instants are send to the LABVIEW through Serial communication using RS232. Serial VISA in stacked sequence of LABVIEW program is set with 9600bps and speed in the form of 8 bit data with start and stop bit is given as input. First and fifth stacked sequence structure is shown in Fig. 5 and Fig. 6

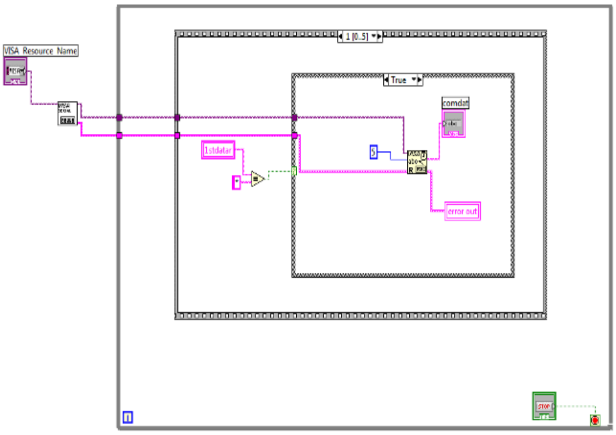

Fig. 5: Stacked sequence-1in LABVIEW Programme

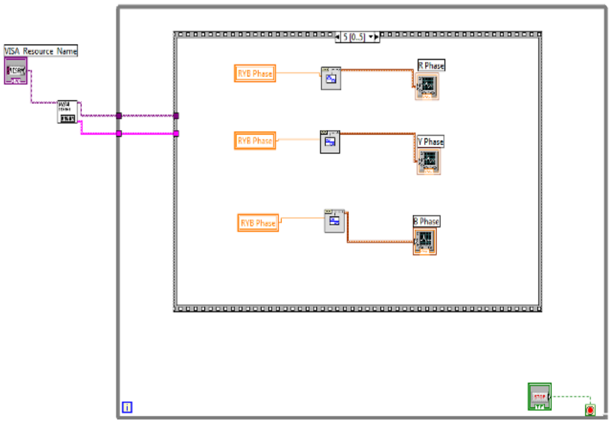

Fig. 6: Stacked sequence-5 in LABVIEW Programme

4. FUZZY CONTROLLER IN LABVIEW

VI is defined as a process of combining hardware and software with industry standard computer technology to create a user-defined instrumentation solution. Several other add-on toolsets can be incorporated for developing the specialized applications, the fuzzy logic, and PID toolkits are used in the present application. In the VI program the fifth stacked sequence gives the frequency at which the pwm pulses is to be produced and the actual speed information.

The Speed obtained using the equation

$$s = (f * 60)/N \text{ rpm} \quad (10)$$

Where s is the speed and N is the number of pulses from Stacked sequence. From the above computations, the measured speed (process variable) is obtained. A controller compares the process variable (pv) with the set point (sp), determines the error and produces the control signal to minimize the error in stacked sequence 6 of a LABVIEW program as shown in Fig.7.

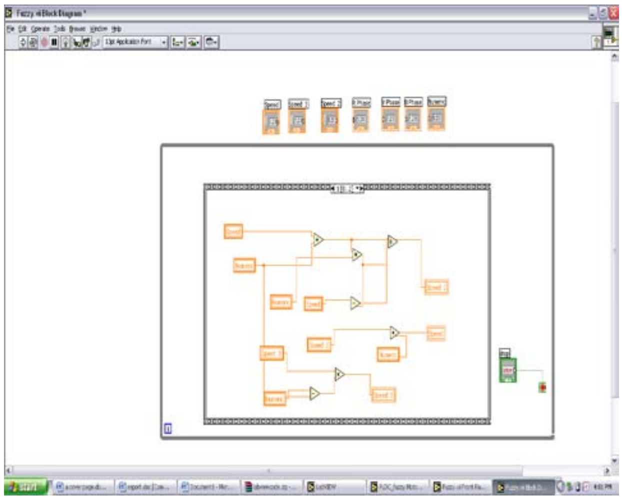

Fig. 7: Stacked sequence-6 Fuzzy control implementation in LABVIEW Programme

The equations for e (k), ce (k), and cce (k) are:

$$e(k) = sp - pv \ (1) \quad (11)$$

$$ce(k) = e(k) - e(k\text{-}1) \quad (12)$$

The e(k), ce(k) are the conditions given as input to the FLC. Depending on these conditions, a particular rule in the rule-base is fired then FLC gives out the control signal u(k). The control signal produces the corresponding pwm pulses which amplified using the driver IC IR 2110. Three driver ICs are used to amplify the gate pulses. The results are also displayed in LABVIEW Front panel diagram easily.
IF e(k) is PL and ce(k) is NL, THEN cu(k) is ZE.

The rule-base for two-input FLC is shown in Fig. 8

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ce/e	NL	NM	NS	ZE	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	ZE
NM	NL	NL	NM	NM	NS	ZE	PS
NS	NL	NM	NS	NS	ZE	PS	PM
ZE	NL	NM	NS	ZE	PS	PM	PL
PS	NM	NS	ZE	PS	PS	PM	PL
PM	NS	ZE	PS	PM	PM	PL	PL
PL	ZE	PS	PM	PL	PL	PL	PL

Fig. 8: Rule-base editor for fuzzy logic controller.

5. EXPERIMENTAL SETUP AND RESULTS

Three phase bridge inverter fabricated using n – channel MOSFET is operated in 120 degree mode to provide square wave current excitation to the stator windings. The block diagram for the speed control of brushless dc motor using FLC is shown in Fig. 9.

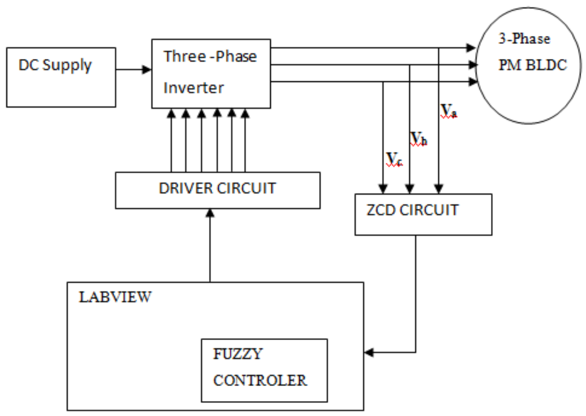

Fig.9: Block diagram of speed control of brushless dc motor using Fuzzy Logic Control in VI.

The brushless dc motor used in the present application has rare earth magnets (SmCo) in its rotor. This motor offers high acceleration and torque capabilities. This motor has two poles with nominal voltage of 48 V, no load speed of 11,500 rpm and no load current of 0.8 A. the entire specification of BLCD motor is given in Table.1. Using the block diagram the hardware is fabricated and tested. The top view of the hardware setup is shown in Fig .10. The hardware consists of power circuit, control circuit and PMBLDC motor. The regulators 7812, 7912 and 7805 in the control circuit give the DC supply required by the driver and operational amplifier respectively. The driver chip amplifies 5V pulse to 10V level. The output of driver circuit is ideally suited for driving power MOSFET's of low ratings. For isolation 4N35 optocoupler are used. DC output from the rectifier is ripple free due to the filter. The crossings of the two controlled voltages which are filtered by low pass filters (LPF), are detected by a comparator.

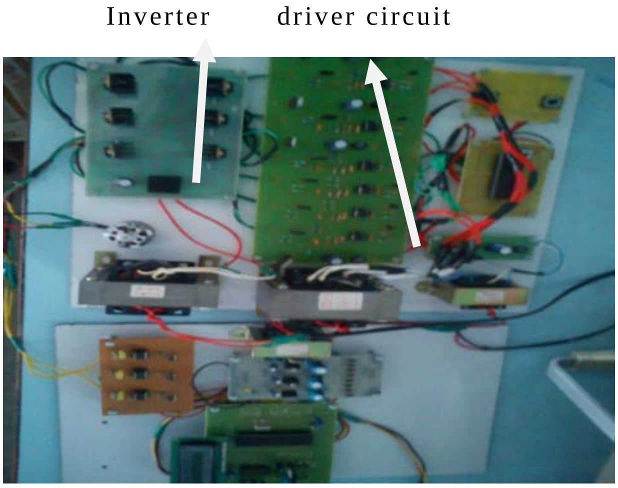

Fig.10: Top view of Hardware setup.

TABLE I

SPECIFICATIONS OF THE BLDC MOTOR

Parameters	Specifications
Number of Poles	4 poles
Line to line Resistance	0.2 0hms
Line to line Inductance	0.45mH
Nominal Voltage	48V
No load Speed	11500 R.P.M
No load current	0.8A
Rated Torque	0.05N-m
Rated Speed	10000 R.P.M
Back EMF	2V/KPRM

The line voltage difference waveform of Three Phase PMBLDC is depicted in Fig. 11. The speed waveform and the pulses a are also displayed in LABVIEW Front panel diagram easily. Fig. 12 shows the results for the speed control of brushless dc motor using LABVIEW. The set speed and the actual speed of the motor is also displayed in front panel of LABVIEW.

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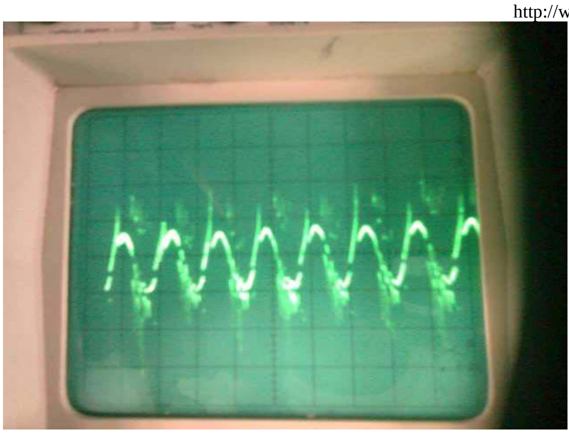

Fig.11: Line voltage difference waveform.

Fig.12: Speed output of three-phase PMBLDC motor in Front panel of LABVIEW.

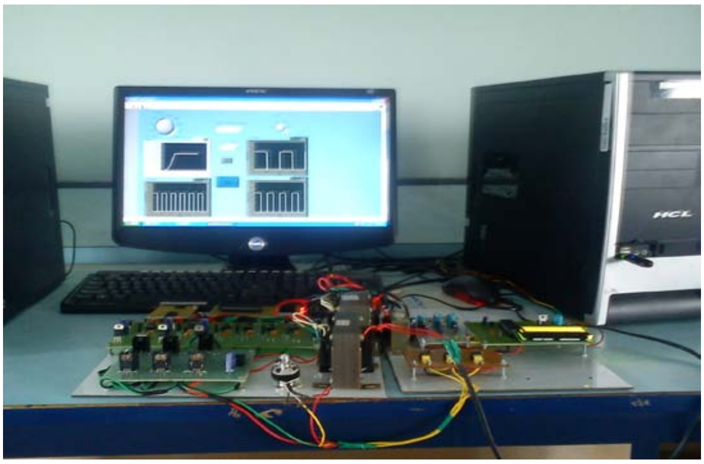

Fig.13: Shows the experimental setup using LABVIEW.

PMBLDC motors drives are used in a wide range of commercial and residential applications due to their highest possible efficiencies. The speed control ability of compressors and blowers is able to provide operation at their high efficiency. The physical integration of controller in the motor body itself is able to make them most suitable for low power (0.5hp) blowers and low power (50W) tube axial fans for cooling the electronic equipment.

6. CONCLUSION

This paper has presented a novel Cost effective FUZZY based sensorless control scheme for Three-phase brushless dc motor drives using Virtual Instrumentation. The position information is estimated from the zero crossings of voltage waveforms in floating phases, and a low cost Fuzzy controller is virtually created in LABVIEW and utilized to implement the algorithm. Speed control of PMBLDC motor is achieved using virtual instrumentation. This proposed method controls the speed for various ranges. When Compared with the conventional back EMF zero crossing sensorless control, the proposed new sensorless control methods for brushless DC technique is more robust, easier to implement. The speed control is achieved for different speed using this method is tabulated in table1 for the motor having specifications given in Table–2.

TABLE 2

SPEED CONTROL OF PM BLDC MOTOR

Set Speed RPM	Actual Speed RPM
1500	1500
2000	2005
4000	4006
7000	7000
8500	8500
10000	10000

The PMBLDCM drive system is successfully fabricated and tested. The hardware system used in the present work has obvious advantage of using single phase supply and we can monitor the actual speed output in front panel of LABVIEW. This drive system uses the fuzzy controller in the LABVIEW, hence it does not need any specific hardware controller. Costly controller is not needed because of elimination of the speed

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estimation algorithm and the complex phase shift circuits.

Also this algorithm completely eliminating the hall sensors and real time processors, this method is cost effective and particularly suitable for cost sensitive applications such as home appliances and related computer. Because of wide range of speed control this drive can be used for variable speed applications like Electrical vehicles, Robotics etc.,

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