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A Novel Speed Control Method Based on Hybrid Controller and Loss Minimisation Scheme for BLDC Motor Drive System

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Abstract – This paper presents the speed control method using a hybrid controller for the BLDC motor. The hybrid controller is the fuzzy PID controller. The fuzzy PID controller controls the speed of the BLDC motor which forms the outer loop in the BLDC motor drive system, whereas, the inner loop is the current control loop which reduces the losses in the BLDC motor. Simulation is carried out in MATLAB/SIMULINK. A comparison is done between existing PID controller and the fuzzy PID controller for the speed control application and loss minimization is incorporated into this method.

Keyrds — Fuzzy PID control, Speed Control, Loss Minimization, Power Factor.

Introduction

The advancement in motor drives with new technologies is increasing day by day and also these electric drives are important for applications such as electric trains, rolling mills, aviation and robotics. There are different kinds of drives available. Generally, a high performance motor drive system with good dynamic response is required to perform the tasks. Conventional DC motors have excellent characteristics such as favorable cost, high reliability and flexibility etc. The disadvantages are regular maintenance, frequent replacement of brushes, high initial cost etc. The alternative to the conventional DC motor is the squirrel cage induction motor. The squirrel cage induction motor offers robustness with low cost however, its disadvantages are poor starting torque and low power factor [1]. Moreover, for high speed applications neither conventional DC motors nor induction motors can be used. To overcome the disadvantages of the conventional DC motors and induction motors brushless DC motors can be used for such applications.The alternativeto the conventional DC motor is the squirrel cage induction motor but it also has certain disadvantages like poor starting torque and low power factor. Moreover, for high speed applications neither conventional DC motors nor induction motors can be used. To overcome the disadvantages of both the conventional DC motors and induction motors brushless DC motors can be used for such applications.BLDC motors are gaining wide popularity because of its simple structure, small size, high reliability and high torque. It finds applications in automobile, automation, consumer electronics, medical, electric vehicle and industrial applications due to their high efficiency, long operating life ratio of torque delivered to the size and fast dynamic response. applications due to their high efficiency, long operating life ratio of torque delivered to the size and fast dynamic response Therefore a more accurate speed control and loss minimisation scheme is needed. The speed of the motor is generally affected due to sudden change in load or speed. Hence to prevent this sudden change in speed controllers have to be designed. In this paper, fuzzy PID controller is used for the speed control of BLDC motor. The loss minimisation scheme is also incorporated in this paper.

II. BRUSHLESS MOTOR SYSTEM CONTROL BLOCK DIAGRAM

In various control strategies applied to brushless DC motor controller, double closed-loop PI technology is the most mature and is widely applied [2]. It has two loops hence it is known as double closed loop control. The outer loop is the speed loop or velocity loop. The function of the speed loop is to maintain steady speed and resist load disturbance [3] and the inner current loop (torque loop), stablilises current and resistance to voltage effect. The design of the speed controller needs to consider work environment, load variations, position detection such that the goal of having optimal speed control over wide range, small static error and dynamic control is achieved. Hence a fuzzy PID controller for speed control is discussed here.

The Block Diagram of the proposed system is shown below:

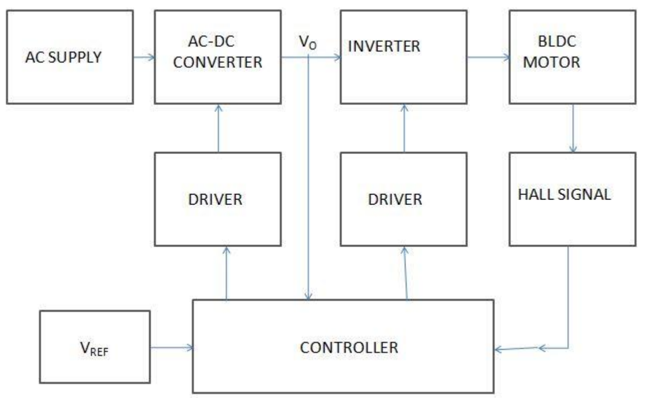

Fig.1 Block Diagram of the system

The block diagram consists of 24 V AC supply given to a AC-DC converter. The output of the converter is given to the inverter which in turn runs the BLDC motor. The control unit provides necessary signals for the converter and the inverter.

III. SPEED CONTROL

There are different controllers incorporated for speed control applications. Among these controllers the most classic speed controller is the conventional PID controller and most widely used controller is the fuzzy PID controller.

A). Conventional PID Controller:

The transfer function of the conventional PID controller is: K(S)= Kp+Ki/s+KdS – (1);

Where, Kp, Ki and Kd are proportional gain, integral gain and derivative gain respectively. Each part of the controller performs specific function. The proportional part reduces the error responses of the system to disturbances, the integral part eliminates the steady-state error, and finally the derivative part dampens the dynamic response and improves the system stability [4]. These parameters should be chosen such that it is suitable for the plant. There are many methods to determine these parameters. Some of them are: trial and error method, Ziegler- Nichols (ZN) method and genetic algorithm technique. But these methods cannot guarantee to be effective always and also due to sudden variation in speed and load these parameters get altered all the time so to prevent this variation fuzzy PID controllers are to be used. Also the settling time is reduced in fuzzy PID controller.

B). Fuzzy PID Controller:

The term 'fuzzy' means vagueness. This logic was developed by Lotfi Zadeh. Fuzzy systems are rule based systems. The Fuzzy PID used in this paper is realised using two inputs: Error (E) and Change in Error (CE). This is shown below:

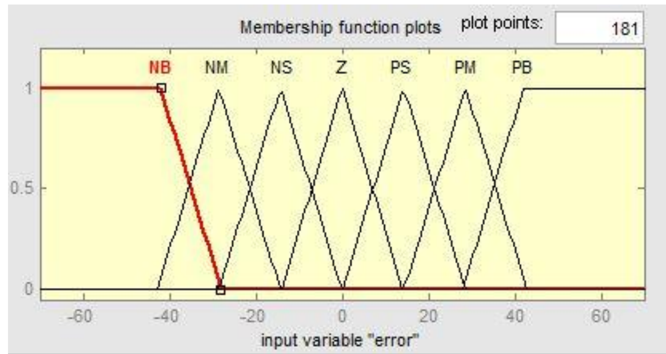

Fig. 2 Input membership functions for error

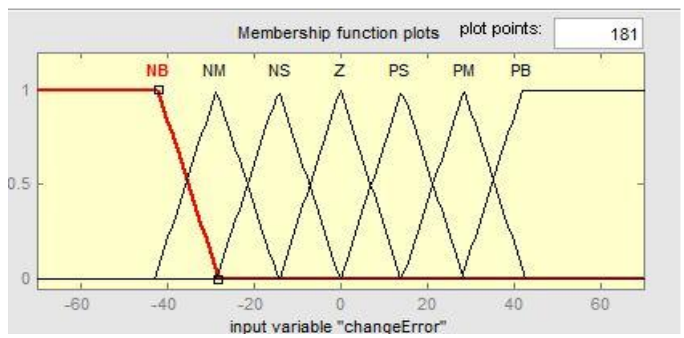

Fig. 3 Input membership function for change in error

The output graph is shown below:

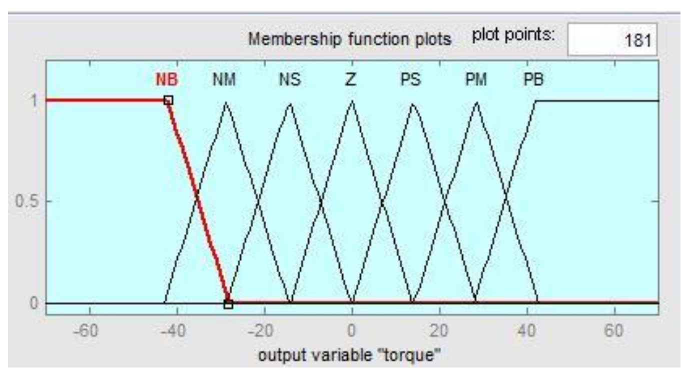

Fig. 4 Output membership functions

The membership functions used are: Positive Big (PB), Zero (Z), Positive Small (PS), Positive Medium (PM), Negative Medium (NM), Negative Small (NS) and Negative Big (NB). The input parameters, error and delta error or change in error are the inputs to the fuzzy system and output can be called as modulation or torque. The fuzzy rules are formulated using the

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AND operation with the two inputs. The advantage of using hybrid controller (Fuzzy PID) controller is settling time of the BLDC speed graph is reduced to a small value and noise is also less.The speed control is obtained by comparing the reference voltage to the actual voltage of the converter output and the error signal is given to the gate of the converter. Since voltage is proportional to speed in BLDC, speed increases when voltage increases. In this paper, speed control is obtained from 217 rpm -317 rpm, with the reference voltage varying from 20 V to 30 V. This low speed of BLDC can be used in aerospace application [5].

IV. THE COMPLETE CIRCUIT DIAGRAM

The complete circuit diagram of the entire system is shown below:

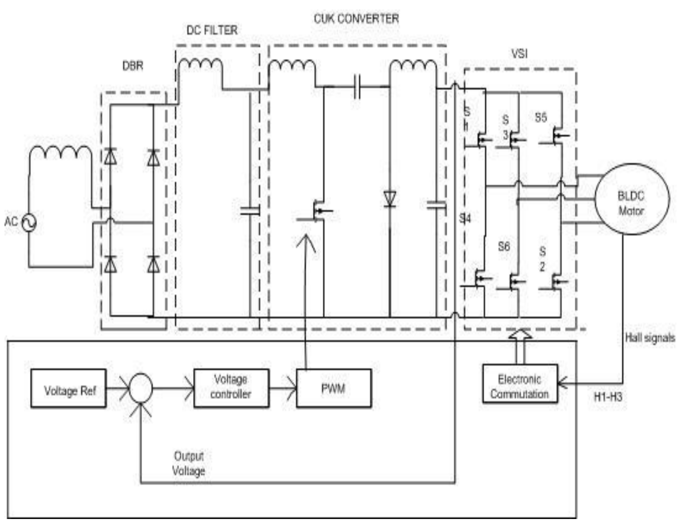

Fig.5 Complete Circuit Diagram of the system

It consists of Diode Bridge Rectifier (DBR), DC Filter, a power factor correction unit, which is Cuk converter and a Voltage Source Inverter (VSI). The inverter switches are triggered by constant PWM technique and a varying PWM is applied to the converter section. The system is designed for a 24V input supply and 32 V output and a switching frequency of 20 kHz. The design equations are discussed in the following sections.

V). LOSS MINIMISATION SCHEME

The loss minimization discussed in [6] deals with harmonic losses employing fuzzy logic. In this paper, the loss minimization is done by improving the power factor of the proposed system. The power factor is improved by incorporating a power factor correction circuit. Such circuits are generally DC- DC converters. The converter used in this paper is the Cuk' converter. By incorporating this converter the power factor of the system is made to improve, thereby reducing the power losses and the harmonic losses. The speed control of the BLDC is also obtained along with losses reduction.Conventional schemes of PFC converters fed BLDC motor drive utilize an approach of constant DC link voltage of the VSI and controlling the speed by controlling the duty ratio of high frequency pulse width modulation (PWM) signals [18-21]. But switching losses are high in this case as switching losses varies as square of switching frequency. To reduce this loss, the VSI is gated for constant PWM signal and only the converter switch is made to operate under varying PWM. The converter circuit used is discussed below.

The Cuk' converter circuit is shown below:

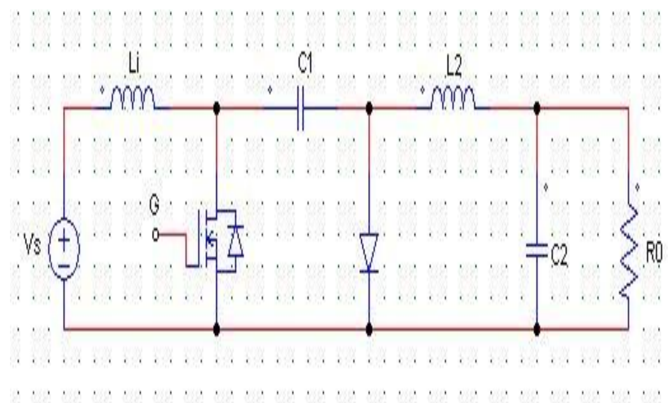

Fig.6 Cuk Converter circuit

The Cuk Converter has two modes of operation:- Mode I and Mode II.

Mode I: When the switch is closed:

The current flows from L1 through the switch in one loop and in the other it flows from in the other loop. The figure of this mode is shown below:

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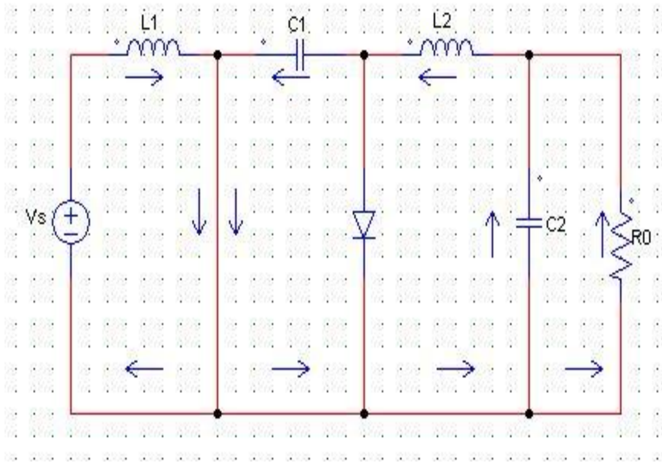

Fig. 7 Mode I: Switch is ON

Mode II: When the switch is opened:

The diode becomes forward biased and current flows from

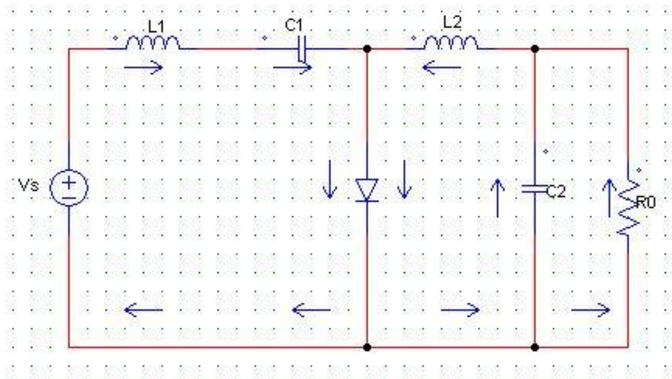

Fig. 8 Mode II: Switch is OFF

These two modes explain the working of the cuk converter.

V A) DESIGN OF CUK' CONVERTER:

For the design purpose we take the input voltage, Vs= 24V, output voltage, Vo= 36V, switching frequency of 50kHz for a motor of rated power of 60Watts.

The values of the components are designed using design equations, as follows:

The duty ratio can be calculated by:

$$\frac{Vo}{Vs} = \frac{D}{1-D} \text{ - (1)}$$

Therefore, D=0.6. The inductors, L1 and L2 can be calculated as follow:

$$L_1 \geq \frac{V_S D}{f \Delta i_{L1}} = 1.15\text{mH - (2)}$$

The output inductor, L2 is calculated as:

$$L_2 \geq \frac{V_S D}{f \Delta i_{L2}} = 1.73\text{mH - (3)}$$

The value of capacitor C_1 is given by:

$$C_1 = \frac{V_o D}{Rf \Delta V_{c1}} = 150\text{uF - (4)}$$

And the output capacitor, C2 is calculated as:

$$C_2 = \frac{1-D}{\frac{\Delta V_O}{V_O}} \times \frac{1}{8 L_2 f^2} = 12000\text{uF - (5)}$$

VI. SIMULATION RESULTS

The simulation of the entire system is carried out in MATLAB, 2009 version.

Case 1: Simulation when no PFC is incorporated:

The Fig. 4 shows the simulation of BLDC motor without pfc .

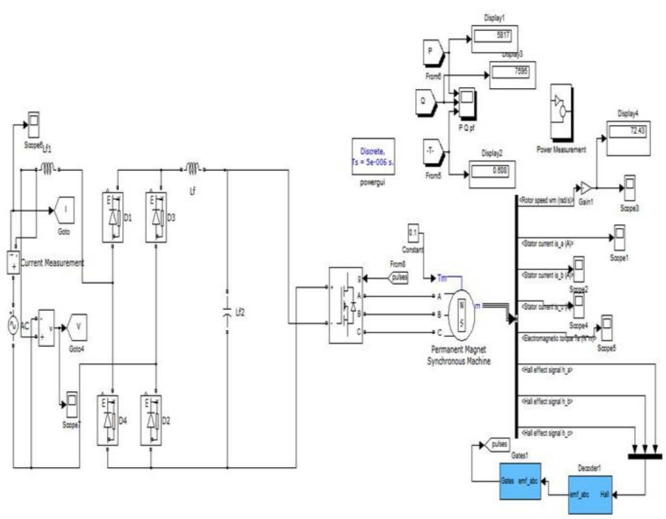

Fig. 9 Simulation of BLDC motor with no PFC circuit

The power factor for this case is 0.608, which is very low. This low power factor will draw more power from the circuit and increase the losses in the circuit. The various graphs are shown below. The fig. 10 shows the stator current graph.

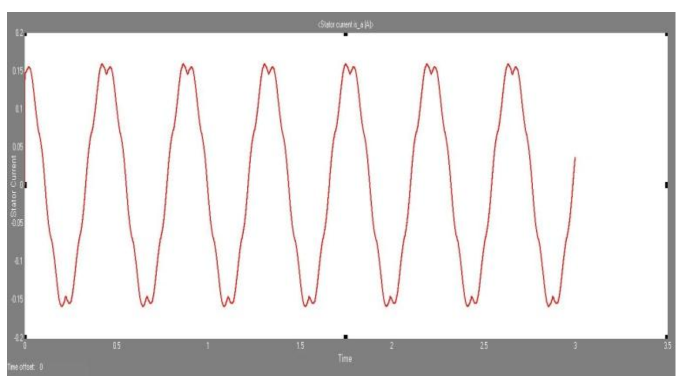

Fig. 10 Stator current graph when no PFC is incorporated

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It can be seen that the stator current has ripples. Hence THD is also high when no PFC is incorporated. The fig. 11 shows the speed of the BLDC motor and the fig. 12 shows the THD which was observed when PFC is not added into the circuit.

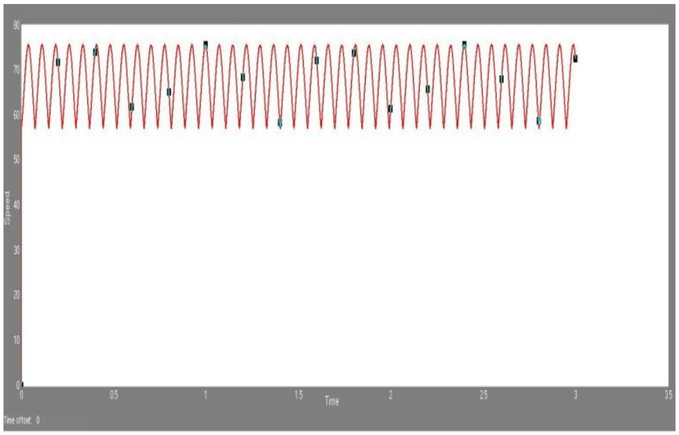

Fig. 11 Speed response of BLDC motor

The speed graph shows that it has large amount of ripples. The THD is observed as shown below.

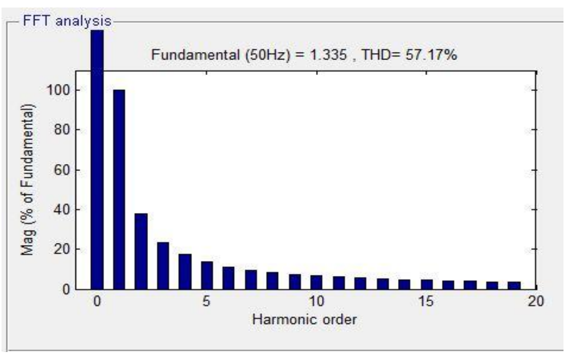

Fig. 12 THD of the system

It can be seen that there is a high value of THD obtained when no PFC is present in the circuit, also this high THD is obtained as the power factor is low. Therefore it is inferred that on improving the power factor of the system, the THD will reduce and also speed of the BLDC will improve and ripple free operation can be obtained.

Case 2: Simulation when PFC is incorporated:

The figure shows the simulation when the power factor correction circuit, Cuk' converter, is incorporated in the system.

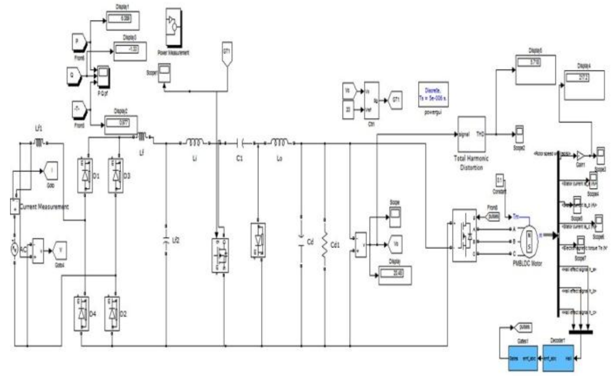

Fig. 13 Simulation of BLDC motor with PFC circuit

The Cuk converter is designed as per the design equations mentioned above. The speed response of the system is shown below for reference voltage range varying from 15 V to 30 V.

a)Speed response when reference voltage is 20 Volts:

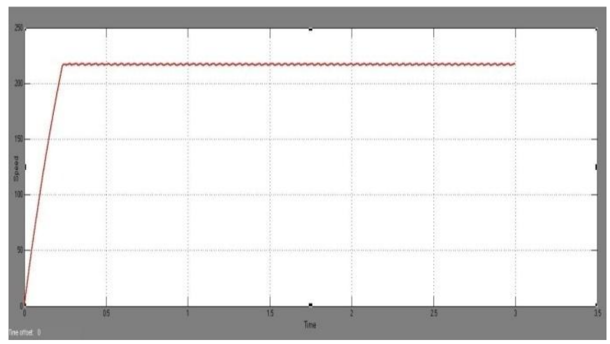

Fig.14 Speed response for reference voltage of 20 V

The stator current graph is shown below, when PFC is incorporated:

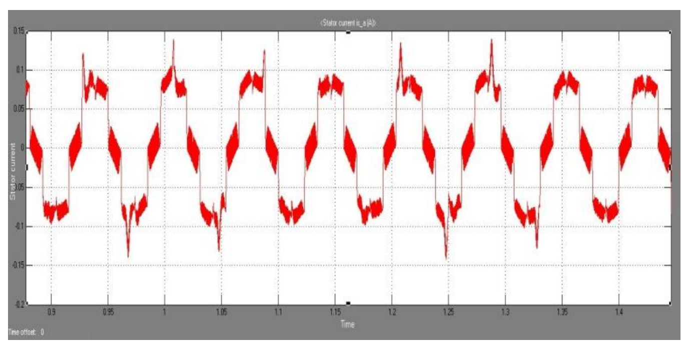

Fig.15 Stator Current when PFC is incorporated

The THD at the corresponding speeds is 7.45 for a reference voltage of 20 Volts and power factor is 0.977 which is shown in the simulation. The THD graph is shown below:

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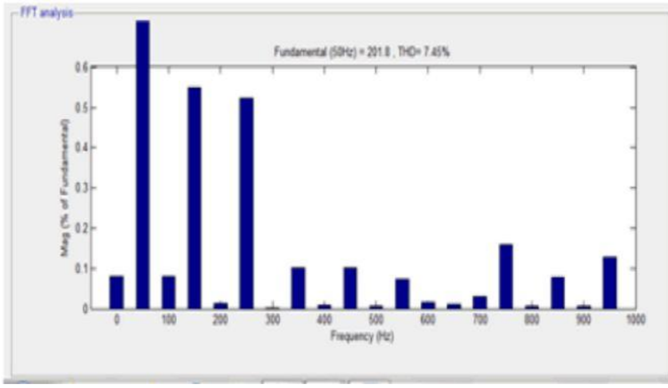

Fig. 16 THD when PFC is incorporated

The table below shows a comparison between the conventional diode bridge without PFC and with PFC. The parameters compared are power factor and THD.

Table1: Parameter comparison between circuit without using PFC and other circuit with PFC circuit.

Parameters	Without PFC	With PFC
Power Factor	0.608	0.977
THD	57.1%	7.45

VII. CONCLUSION

A power factor improvement circuit is incorporated which improves the power factor of the conventional system and reduces the THD. Thus, reducing the harmonic losses of the system. This is obtained in the Simulink model of the BLDC motor system as shown. A hybrid controller is used for the speed control purpose.

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