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A BLDC Motor Ceiling Fan with Reduced Inverter Switches and an Improved DTC Method

Tijina Treasa Ignatius[1], Unnikrishnan .L[2]

PG Scholar [IDAC], Dept. of EEE, Rajagiri School of Engineering & Technology, Kakkanad, Kerala, India[1]

Assistant Professor, Dept. of EEE, Rajagiri School of Engineering & Technology, Kakkanad, Kerala, India[2]

ABSTRACT: In most of the tropical and subtropical regions on the globe ceiling fan is an inevitable part of the households mainly because of the climatic conditions of these regions. And these ceiling fans mainly uses an induction motor since they are readily available and due to the fact that they have been in usage since the past decades for various purposes such as pumps, elevators, compressors etc. But on a detailed analysis we can clearly see that the induction motor fans are accompanied with various drawbacks and losses. Thus replacing this with a more efficient BLDC motor can tremendously reduce the power consumption thus helping to overcome the present scenario of shortage of electrical power generation. Here the replacement of IM with BLDC motor is accompanied with an improved DTC control and reduced inverter switch configuration.

KEYWORDS: Brushless DC motor, Induction motor, Direct Torque Control, Four switch inverter.

I.INTRODUCTION

In the recent years, the need for electrical energy has in increased tremendously due to various technological and scientific advancements. Thus the gross domestic product or GDP of our country has increased to about 8% per annum. Rather than increasing the power generation the best way to curtail the energy demands is by conservation of energy. And many related works for the same is in progress now a days. On analysing the present scenario it is evident that the electrical energy consumption is highest in the residential sector and it is in this sector where conservation is maximum possible too. Among the various household equipments in the residential sector about 6% of power is consumed by ceiling fans. According to the recent studies it is estimated to increase up to 9% by 2020, which is equivalent to 15 mid-sized power plants working simultaneously. This itself shows the immediate need for conservation of energy consumed by ceiling fans. Various studies related to this crisis is carried out all-around the world also.

Since several years about one third of the world's electrical energy consumption is used for running induction motors, which are used in elevators, pumps, compressors and various machines. Even though induction motor has several merits like simple, robust, rugged in construction, can be used in any environmental condition etc., they have certain major drawbacks such as poor starting torque, high in rush of current, lagging and low power factor and difficulties in speed control. These drawbacks increases their losses and power consumption.

A household celling fan also make use of an induction motor which due to its drawbacks lead to larger power consumption and losses. Thus replacing this induction motor with a BLDC motor can tackle the crisis of larger power consumption and thus saves power. The proposed system is accompanied with a four switch inverter, which makes the system cost effective and an improved Direct Torque Control (DTC), gives a constant output torque and thus constant output power [2], [3]. The dc-dc converter used here is a bridgeless cuk rectifier with a power factor correction.

II.PROPOSED SYSTEM

The proposed system for replacing the ceiling fan consists of a pfc bridgeless cuk rectifier, a B4 inverter or commonly called as a four switch inverter, the BLDC motor which is loaded to the ceiling fan and its improved direct torque control method. The block diagram for the proposed system is as shown below.

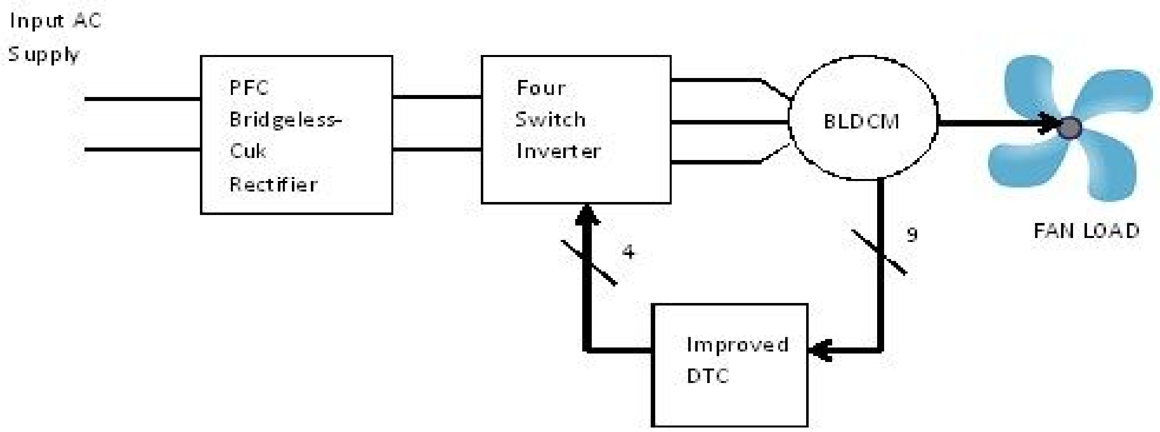

Fig. 1 Block diagram of the proposed system.

The BLDC motor when compared to other motors have several advantages. It provides a much large and constant torque and power for a vast range of speed thus making it a high performance motor when compared to other motors. It has a high operating speed which can be as high as 10,000 rpm under loaded and unloaded conditions, it also has a compact size and gives a quick response. Quick response is due to the low inertia of the inner rotor of the BLDCM which allows to accelerate, decelerate and reverse direction quickly. It has the highest running torque per cubic inch of any DC motor thus making it a machine with high power density. Also due to the absence of brushes it produces less heat, requires low maintenance and has longer life.

The B4 inverter or the four switch inverter is been replaced by the typical B6 inverter or the six switch inverter which thereby reduces number of switches and the number of driver circuits required and the by reducing the cost, the switching losses, the conduction losses, and also the effects of EMI [2].

Unlike other control techniques Direct Torque Control or DTC has various advantages. Among the control strategies which exhibits high torque dynamics one can distinguish it as DTC. It was proposed in the middle of 1980s and due to its high efficiency it is used in many systems [1]. Some of the advantages of DTC are that it has a very fast dynamic response to torque and coordinates reference frame is alpha-beta plane, hence other coordinate transformations not required. Other merits of DTC are that no current control, PWM modulators is required, switching frequency varies widely around average frequency, switching losses are lower, audible noise is lower, complexity or processing requirements is lower and also the typical control time cycle is 10 to 30 microseconds.

The pfc rectifier used here is bridgeless cuk rectifier due to its advantages such as it improves the efficiency of the drive as well as maintains a unity power factor, lesser conduction losses which improves the efficiency and reduction in the cost because of the absence of the bridge rectifier configuration.

III.IMPROVED DTC CONTROL

The direct torque control of four-switch three-phase BLDC motor drive could be a better alternative to the usual six-switch inverter part with respect to lower price and better performance. DTC method in BLDC with four-switch three phase inverter has some unique advantages over its six switch inverter system: reduced cost due to the reduction of switches, reduced switching losses and reduced probability of damaging the switches due to lesser interaction between the switches. A BLDC motor requires quasi square current waveforms to generate constant output torque. Also, at all instant of time only two phases should be conducting and the other phase must be inactive.

But it can be seen that in certain sectors or region of operation, the BLDC motor operates under the three- phase conduction mode, where all the three legs of the inverter conducts. Even though these regions of operation are characterized by the conduction of phase-a and phase-b, there is always a current flowing through the phase-c because it's back EMF and its connection to the dc-bus. Thus, phase-c behaves like a generator which creates a torque opposite

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to the ones of phase-a and phase-b. Hence, their currents become temporarily distorted by undesirable surges. No to prevent arrest the same an improved torque control method is made use of where the reduction of the current distortions can be obtained from an independent control of the torques developed byphase-a and phase-b, respectively, instead of the motor overall torque using two l and four level torque controllers. The block diagram for the improved DTC is as shown below.

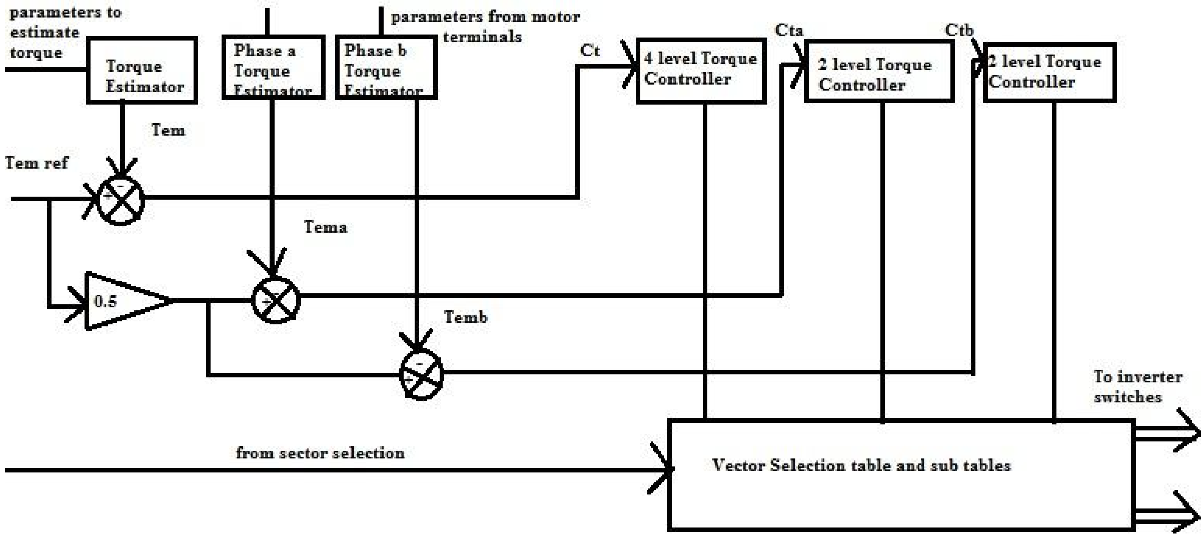

Fig. 2 Block diagram of the improved DTC

It can noticed that this implementation strategy does not include a flux loop, and that the identification of the sectors is acquired considering suitable combinations of the Hall-effect signals. It has been seen that a reduction of the current distortion in Sectors II and V can be achieved through an independent control of the torques Tema and Temb developed by phase-a and phase-b, respectively, instead of the motor overall torque Tem. To do so, Ozturk et al. proposed [2]method where the control combinations adopted in Sectors II and V are gained by the vector selection table below, where Cta and Ctb are the outputs of the two-level hysteresis controllers of Tema and Temb, respectively.

C_{ta}	-1		+1	
C_{tb}	-1	+1	-1	+1
SECTOR V	V3 (0110)	V4(0101)	V2(1010)	V1(1001)
SECTOR II	V1(1001)	V2(1010)	V4(0101)	V3(0110)

Table. 1 Vector selection sub table in order to reduce phase current distortion in sector II and V.

The proposed system familiarises the use of a four level torque controller along with two 2 level torque controllers and the estimation of phase torques separately leading to the reduction in torque ripples and thus obtaining a constant torque.

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C_t	-2
SECTOR II to SECTOR I	V1(1001)
SECTOR I to SECTOR VI	V4(0101)
SECTOR V to SECTOR IV	V3(0110)
SECTOR IV to SECTOR III	V2(1010)

C_t	+2
SECTOR VI to SECTOR I	V2(1010)
SECTOR II to SECTOR III	V3(0110)
SECTOR III to SECTOR IV	V4(0101)
SECTOR V to SECTOR VI	V1(1001)

Table. 2 Vector selection sub table in case of clockwise and anticlockwise rotation respectively.

Table. 2 Vector selection sub table in case of clockwise and anticlockwise rotation respectively.

The torque estimation is done making use of the basic equation of torques along with the phase currents and the phase voltages. The torque error is the difference between the actual and the estimated torque and the vector selection tables giving the switching are also given accordingly.

IV.SIMULINK MODEL

The Simulink model that was simulated in the MATLAB 13 software is as shown below.

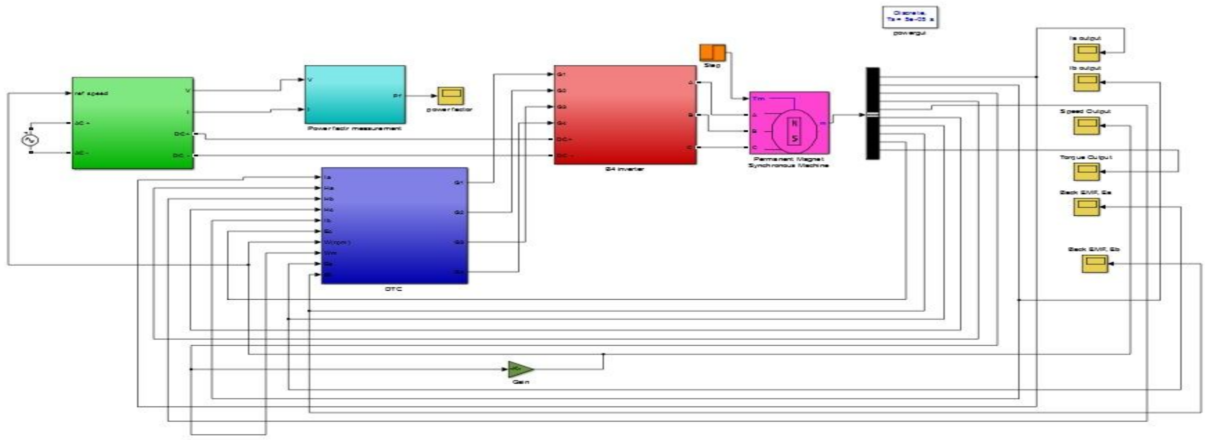

Fig. 3 Simulink model of the proposed system

It consists of the blocks for power factor correction i.e. the bridgeless cuk rectifier, the four switch inverter, the DTC control and the BLDC motor module.

V. SIMULATION RESULTS

The simulation results obtained are as shown below.

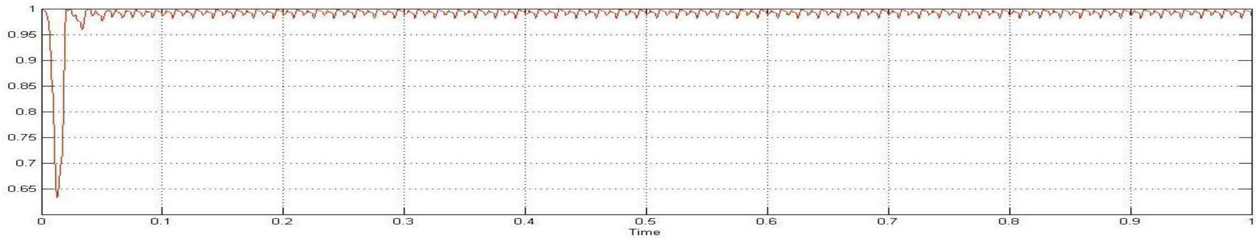

Fig. 4 Power factor waveform.

Power factor of the system was obtained very close to unity.

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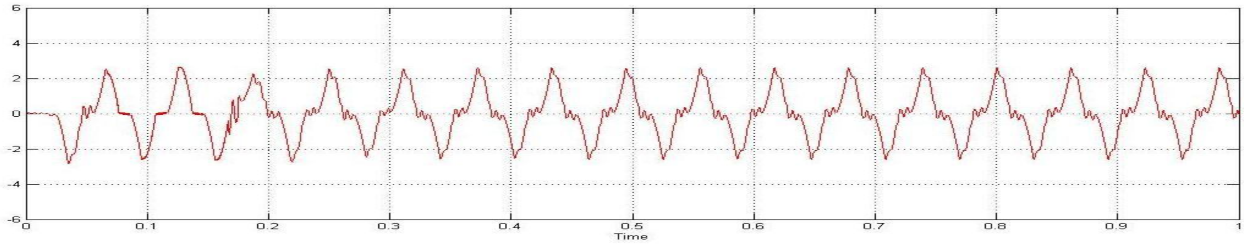

Fig. 5 Stator phase current waveform.

Stator phase current waveforms were obtained as shown above. And the back EMF waveforms were also found to be more or less trapezoidal with slight variations.

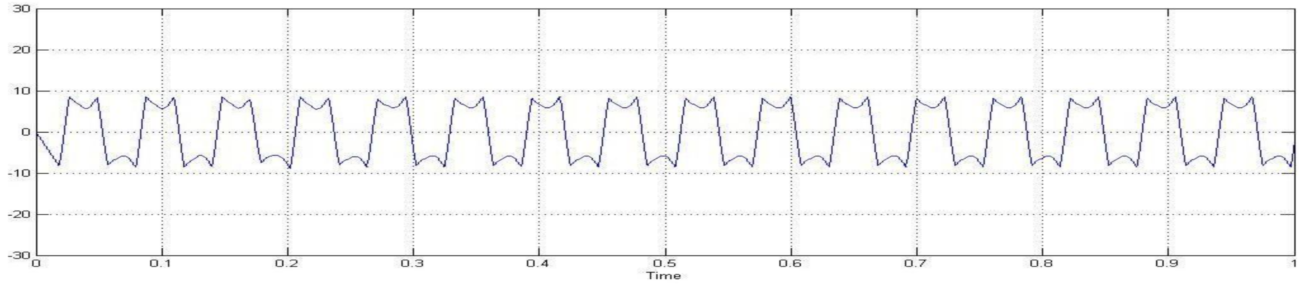

Fig. 6 Back EMF waveform.

The torque waveform of the proposed system is depicted below. And it shows the system has obtained a constant torque on an average, which makes the system more reliable.

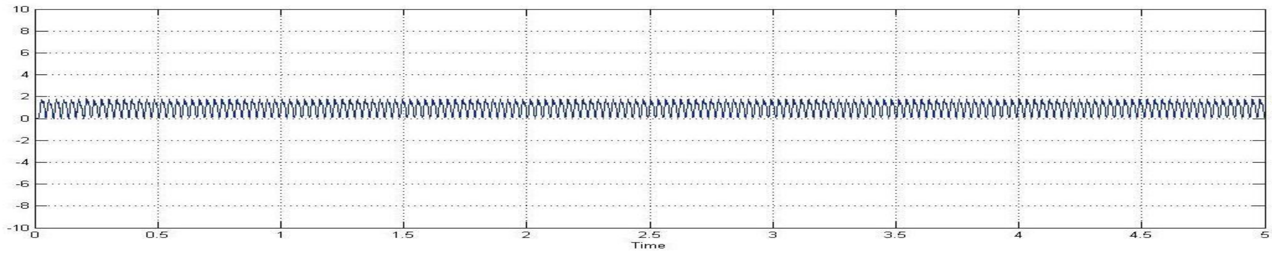

Fig. 7 Torque waveform.

Since for a conventional ceiling fan the speed ranges from about 90 to 300rpm the result below is optimized to 300rpm showing that it can be conveniently for ceiling fan purpose. Whereas it can has a maximum speed that ranges up to 1500rpm.

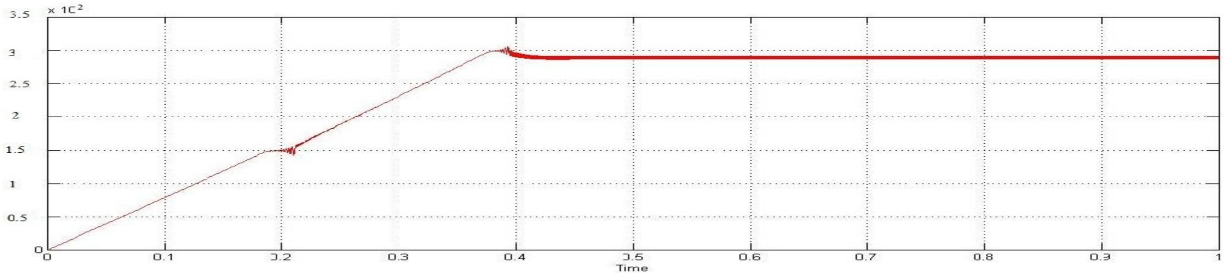

Fig. 8 Speed waveform.

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Thus on a conclusion note, from the above waveforms we can say that a power factor close to unity, a constant speed of 300 rpm which is required for ceiling fans, a constant torque of about 1N/m and also the respective phase current and back EMF waveforms were obtained which makes the system reliable.

VI.HARDWARE SETUP

The hardware of the BLDC motor fan (ceiling fan) was setup and it is depicted below.

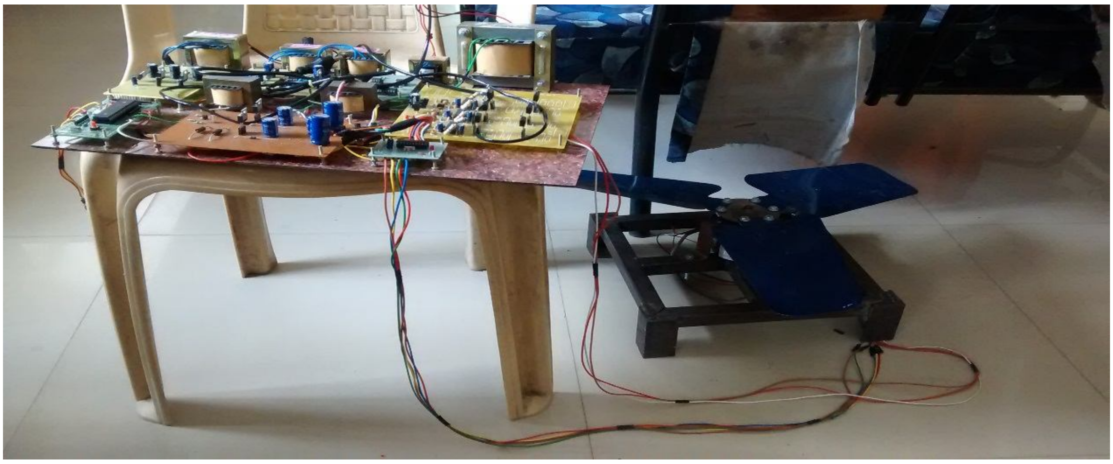

Fig. 9 Hardware setup

This model of a BLDC motor ceiling fan was found to have a power factor of 0.999 , power consumption less than 35W, which eventually reduces the electricity bill and also a maximum speed of 1200rpm. Thus making it more efficient and better than a usual single phase induction motor based ceiling fan.

VII. CONCLUSION

BLDC motor achieves high efficiency than conventional dc motor and induction motor. It has surface mounted permanent magnet on rotor which rotates at synchronous speed. High dynamic response, long operating life, noiseless operation, higher speed range, high output power, low maintenance make it more reliable than other motors. A bldc motor ceiling fan was proposed for better efficiency and reduction in power consumption. The simulation for the proposed system of BLDC motor ceiling fan was developed in SIMULINK/MALAB-13, the waveforms were studied and then the hardware was setup accordingly.

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