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AVoltage Controlled PFCCUK Converter Based PMBLDC Drive With Fuzzy Controller For Air Conditioners

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Abstract:

This paper deals with the method used to improve the speed quality and the efficiency of BLDC motor drive by implementing fuzzy based controller with power factor correction technique. A Cuk dc–dc converter as a single-stage power-factor-correction converter for a permanent magnet (PM) brushless dc motor (PMBLDCM) fed through a diode bridge rectifier from a single-phase ac mains. A three-phase voltage source inverter is used as an electronic commutator to operate the PMBLDCM driving an air-conditioner compressor. The speed of the compressor is controlled to achieve optimum air-conditioning using a concept of the voltage control at dc link proportional to the desired speed of the PMBLDCM. The stator currents of the PMBLDCM during step change in the reference speed are controlled within the specified limits by an addition of a rate limiter in the reference dc link voltage. The proposed PMBLDCM drive (PMBLDCMD) is designed and modeled, and its performance is evaluated in Matlab–Sim`ulink environment. Simulated results are presented to demonstrate an improved power quality at ac mains of thePMBLDCMD system in a wide range of speed and input ac voltage. Test results of a developed controller are also presented to validate the design and model of the drive.

INTRODUCTION:

The use of a permanent-magnet (PM) brushless dc motor (PMBLDCM) in low-power appliances is increasing because of its features of high efficiency, wide speed range, and low maintenance [1]–[4]. It is a rugged three-phase synchronous motor due to the use of PMs on the rotor. The commutation in a PMBLDCM is accomplished by solid state switches of a three-phase voltage-source inverter (VSI). Its application to the compressor of an air-conditioning (Air-Con) system results in an improved efficiency of the system if operated under speed control while maintaining the temperature in the airconditioned zone at the set reference consistently.

The Air-Con exerts constant torque (i.e., rated torque) on the PMBLDCM while operated in speed control mode. The Air-Con system with PMBLDCM has low running cost, long life, and reduced mechanical and electrical stresses compared to a single-phase

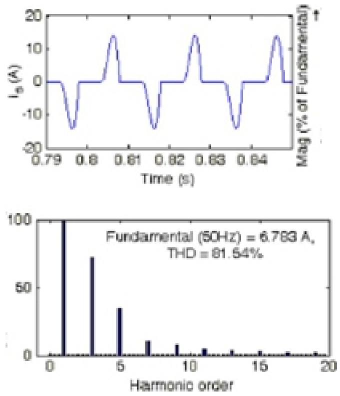

Fig.Current waveform at ac mains and its harmonic spectra for the PMBLDCM drive (PMBLDCMD) without PFC.

induction motor-based Air-Con system operating in “on/off” control mode. A PMBLDCM has the developed torque proportional to its phase current and its back electromotive force (EMF), which is proportional to the speed . Therefore, a constant current in its stator windings with variable voltage across its terminals maintains constant torque in a PMBLDCM under variable speed operation. A speed control scheme is proposed which uses a reference voltage at dc link proportional to the desired speed of the permanent-magnet brushless direct current (PMBLDC) motor.

However, the control of VSI is only used for electronic commutation based on the rotor position signals of the PMBLDC motor. The PMBLDCMD is fed from a single-phase ac supply through a diode bridge rectifier (DBR) followed by a capacitor at dc link. It draws a pulsed current as shown in Fig. 1, with a peak higher than the amplitude of the fundamental input

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current at ac mains due to an uncontrolled charging of the dc link capacitor. This results in poor power quality (PQ) at ac mains in terms of poor power factor (PF) of the order of 0.728, high total harmonic distortion (THD) of ac mains current at the value of 81.54%, and high crest factor (CF) of the order of 2.28. Therefore, a PF correction (PFC) converter among various available converter topologies is almost inevitable for a PMBLDCMD. Moreover, the PQ standards for low power equipments, such as emphasize on low harmonic contents and near unity PF current to be drawn from ac mains by these drives.

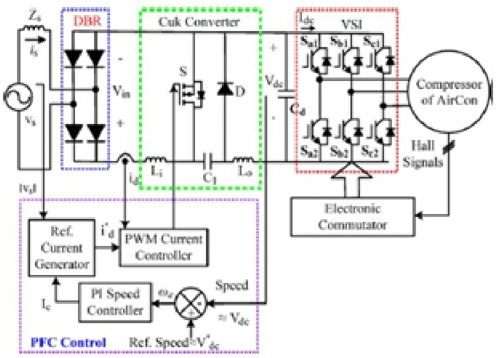

Fig.Control scheme of the proposed Cuk PFC converter-fed VSI-based PMBLDCMD.

Modeling, design, and performance evaluation of the proposed drive are presented for an air-conditioner driven by a 0.816-kW 1500-r/min PMBLDC motor Permanent magnet brushless DC motors (PMBLDCMs) are considered as better option in various low power (less than 5 kW) applications due to their energy efficiency and ease of control [1-3]. The PMBLDCM is a three-phase synchronous motor with permanent magnets (PMs) on the rotor. The commutation in a PMBLDCM is accomplished by solid state switches of a three-phase voltage source inverter (VSI). The combination of VSI and PMBLDCM is referred as PMBLDCM drive [4-10]. The efforts of researchers towards improvement in the performance of traditionally used motors such as induction motors, DC motors and synchronous motors has opened up new application areas of the PMBLDCMD. Moreover, the advancements in power electronics and digital signal processors (DSPs) have added many features to the PMBLDCM drives to make them preferred choice for various industrial installations. The most commonly used topology for PMBLDCMD fed from single-phase AC mains uses a diode bridge rectifier (DBR) followed by a smoothening DC capacitor . It draws an uncontrolled charging current for the DC capacitor resulting in a pulsed current from the AC mains as resulting in various power quality (PQ) disturbances at AC mains such as poor power factor (PF), increased total harmonic distortion (THD) of AC mains current and its high crest factor (CF). The power quality (PQ) disturbances at AC mains of a PMBLDCMD are represented in terms of various power quality indices such as PF, CF, total harmonic distortion (THDi) of AC mains current, displacementpower factor (DPF) and ripples in DC link voltage(@Vdc). Current waveform at AC mains and its harmonic spectra for the PMBLDCMD topology shown in Fig. 1 These PQ disturbances result in transformer and neutral conductor heating, heating of motors and cables, EMI, power supply failure (brownout or blackout) and component failure. Reduction of harmonic currents and voltage distortion at AC mains with near unity PF are referred as power factor correction (PFC) and mitigation of PQ disturbances. Various DC –DC converters are operated as PFC converters for variety of applications. The performance of a PFC converter is evaluated on the basis of these PQ indices.

For the monitoring and mitigation of these PQ problems in the low power applications, there are international standards such as. These standards emphasize on low harmonic contents and near unity power factor current to be drawn from AC mains by various loads. As reported in the literature , the PFC converter topologies in various commercial applications possess two-stages of DC-DC converters. A boost DC-DC converter is used as a power factor pre-regulator (PFP) at the front-end followed by second stage DC-DC converter for voltage regulation. The second converter is usually a flyback or a forward converter for low power application (less than 1 kW) and a full-bridge converter for higher power applications (1-5kW).

There are many DC-DC converter topologies e.g. buck, boost, buck-boost, Ćuk, SEPIC, zeta, push-pull, half bridge and full bridge, reported in the literature for general purpose loads, which can be modeled and designed for PMBLDCM drives. However, the high cost and complexity in operation of two DC-DC converters are the constraints of the two stage PFC converters resulting in the use of a single stage PFC converter in many applications. Moreover, the additional cost and complexity of two-stage PFC is not justified for low power applications, therefore, the converter topologies with features of PFC as well as voltage regulation in single stage are preferred in the PMBLDCM drives.

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There are various control strategies reported in the literature for PFC. This paper primarily focuses on the two control strategies which are based on current multiplier control and voltage follower control due to their inherent advantages of PFC with other added features. The current multiplier control is further investigated in terms of peak current control and average current control for PFC at AC mains. The current multiplier control uses continuous conduction mode (CCM) operation of the PFC converters as shown in , whereas, the voltage follower control uses discontinuous conduction mode (DCM) operation of PFC converters

MATLAB
2.1 Introduction to Matlab:

Matlab is a high-performance language for technical computing. The name mat lab stands for matrix laboratory. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Typical uses include Math and computation Algorithm development Data acquisition Modeling, simulation, and prototyping Data analysis, exploration, and visualization Scientific and engineering graphics Application development, including graphical user interface building.Matlab is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a scalar no interactive language such as C or FORTRAN.

2.2 History of Matlab:
2.3 Strengths of Matlab:

» MATLAB is relatively easy to learn.
» MATLAB code is optimized to be relatively quick when performing matrix operations.
» MATLAB may behave like a calculator or as a programming language.
» MATLAB is interpreted, errors are easier to fix.
» Although primarily procedural, MATLAB does have some object-oriented elements.

2.4 Other features:

» 2-D and 3-D graphics functions for visualizing data
» Tools for building custom graphical user interfaces
» Functions for integrating MATLAB based algorithms with external applications and languages, such as C, C++, FORTRAN, Java, COM, and Microsoft Excel.

2.5 Components of Matlab:

» Workspace
» Current Directory
» Command History
» Command Window

2.6 MATLAB and engineering:

MATLAB was first adopted by researchers and practitioners in control engineering, Little's specialty, but quickly spread to many other domains. It is now also used in education, in particular the teaching of linear algebra and numerical analysis, and is popular amongst scientists involved in image processing. However, many researchers mostly from Computer Science background feel that MATLAB should be used only for mathematical analysis necessary in image processing and not for implementation of image processing software. Moreover, MATLAB should not be used to simulate computer architectures, systems software and computer networks unless while solving some numeric problem.

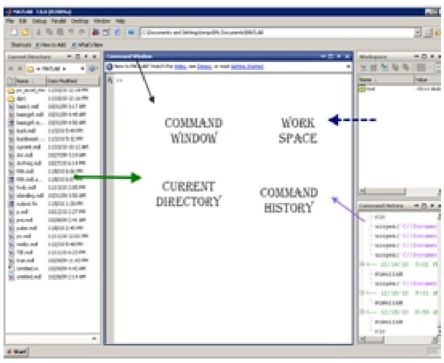

Fig.2.1 Block diagram of Mat lab components

2.7 Toolboxes in Matlab:

•Simulink
•Fuzzy
•Genetic algorithm
•Neural network
•Wavelet

2.8 Simulink:

» Introduction:

Simulink is a software add-on to mat lab which is a mathematical tool developed by The Math works,(http://www.mathworks.com) a company based in Natick. Mat lab is powered by extensive numerical analysis capability. Simulink is a tool used to visually program a dynamic system (those governed by Differential equations) and look at results. Any logic circuit, or control system for a dynamic system can be built by using standard building blocks available in Simulink Libraries. Various toolboxes for different techniques, such as Fuzzy Logic, Neural Networks, DSP, Statistics etc. are available with Simulink, which enhance the processing power of the tool. The main advantage is the availability of templates / building blocks, which avoid the necessity of typing code for small mathematical processes.

» Concept of signal and logic flow:

In Simulink, data/information from various blocks are sent to another block by lines connecting the relevant blocks. Signals can be generated and fed into blocks dynamic / static).Data can be fed into functions. Data can then be dumped into sinks, which could be scopes, displays or could be saved to a file. Data can be connected from one block to another, can be branched, multiplexed etc. In simulation, data is processed and transferred only at discrete times, since all computers are discrete systems. Thus, a simulation time step (otherwise called an integration time step) is essential, and the selection of that step is determined by the fastest dynamics in the simulated system.

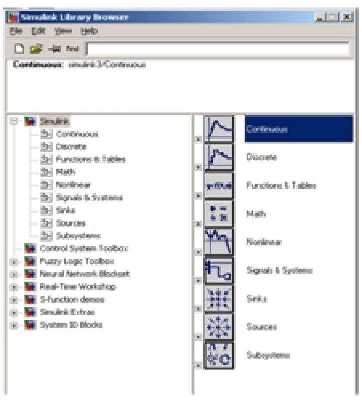

Fig 2.2 Simulink library browser

• Connecting blocks:

To connect blocks, left-click and drag the mouse from the output of one block to the input of another block.

Sources and sinks:

The sources library contains the sources of data/signals that one would use in a dynamic system simulation. One may want to use a constant input, a sinusoidal wave, a step, a repeating sequence such as a pulse train, a ramp etc. One may want to test disturbance effects, and can use the random signal generator to simulate noise. The clock may be used to create a time index for plotting purposes. The ground could be used to connect to any unused port, to avoid warning messages indicating unconnected ports.

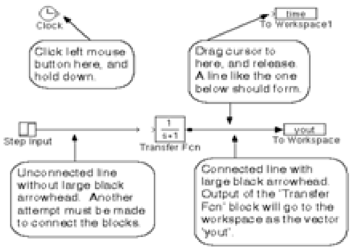

Fig. 2.3 Connectung blocks

The sinks are blocks where signals are terminated or ultimately used. In most cases, we would want to store the resulting data in a file, or a matrix of variables. The data could be displayed or even stored to a file. The stop block could be used to stop the simulation if the input to that block (the signal being sunk) is non-zero.

» Continuous and discrete systems:

All dynamic systems can be analyzed as continuous or discrete time systems. Simulink allows you to represent these systems using transfer functions, integration blocks, delay blocks etc.

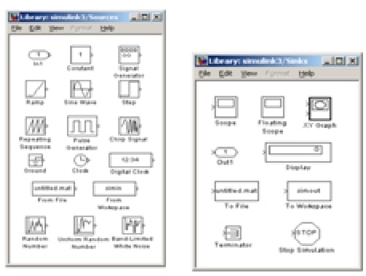

Fig 2.4 Sources and sinks

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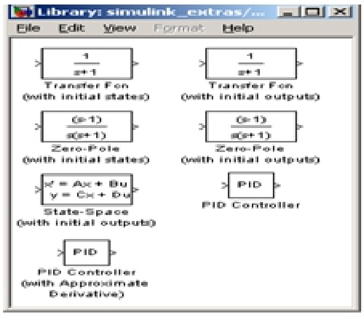

Fig 2.5 continous and descrete systems

Non-linear operators:

A main advantage of using tools such as Simulink is the ability to simulate non-linear systems and arrive at results without having to solve analytically. It is very difficult to arrive at an analytical solution for a system having non-linearities such as saturation, signup function, limited slew rates etc. In Simulation, since systems are analyzed using iterations, non-linearities are not a hindrance. One such could be a saturation block, to indicate a physical limitation on a parameter, such as a voltage signal to a motor etc. Manual switches are useful when trying simulations with different cases. Switches are the logical equivalent of if-then statements in programming.

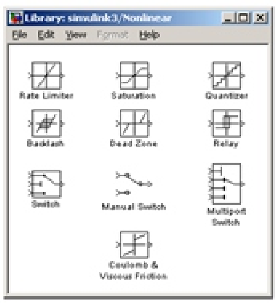

Fig 2.6 simulink blocks

» Mathematical operations:

Mathematical operators such as products, sum, logical operations such as and, or, etc. can be programmed along with the signal flow. Matrix multiplication becomes easy with the matrix gain block. Trigonometric functions such as sin or tan inverse (at an) are also available. Relational operators such as 'equal to', 'greater than' etc. can also be used in logic circuits.

PROPOSED SPEED CONTROL SCHEME OF PMBLDC MOTOR FOR AIR-CONDITIONER:

The proposed speed control scheme which is based on the control of the dc link voltage reference as an equivalent to the reference speed. However, the rotor position signals acquired by Hall-effect sensors are used by an electronic commutator to generate switching sequence for the VSI feeding the PMBLDC motor, and therefore, rotor position is required only at the commutation points . The Cuk dc–dc converter controls the dc link voltage using capacitive energy transfer which results in nonpulsating input and output currents . A detailed modeling, design and performance evaluation of the proposed drive are presented for an air conditioner compressor driven by a PMBLDC motor of 1.5 kW, 1500 rpm rating. required only at the commutation points, e.g., every 60°electrical in the three-phase . The rotor position of PMBLDCM is sensed using Hall effect position sensors and used to generate switching sequence for the VSI as shown in Table-I. The DC link voltage is controlled by a half-bridge buck DC-DC converter based on the duty ratio (D) of the converter. For a fast and effective control with reduced size of magnetics and filters, a high switching frequency is used; however, the switching frequency (fs) is limited by the switching device used, operating power level and switching losses of the device.

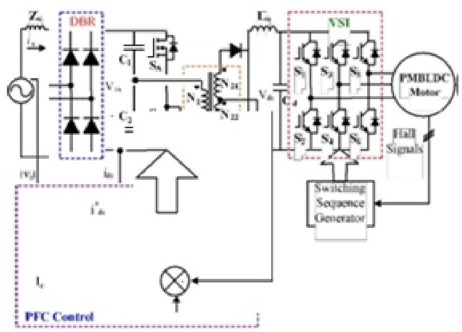

Fig. Control schematic of Proposed Bridge-buck PFC converter fed PMBLDCM drive

[Variable Speed BLDC Compressor Air Conditioner]PMBLDCM Drive:

Permanent Magnet Brushless Direct Current (PMBLDC) are becoming prominent as the demand for efficiency, precise speed and torque control, reliability and ruggedness increases.

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BLDC provide high efficiency and exemplary precision of control when compared to conventional motors. It has the best torque vs. weight or efficiency characteristics. They are used in military, grinding, aircraft, automotive applications, communications equipment etc [1]. The theory of brushless dc motors was proposed in 1962 by T.G. Wilson and P. H. Trickey. But the limitations in magnet and power switching have prevented them to bring into real life. In 1980, Powertec. Industrial Corporation started manufacturing them [2&3]. Brushless, as the name implies there are no brushes and commutators. In conventional motors, the switching of current in the armature coils is done using the combination of brushes and commutators whereas in the brushless, the commutation is performed with the help of electronic circuit, which reduces the mechanic losses and improves the efficiency. There are many other merits of brushless motors over the conventional motors.

• The brushless machines require less maintenance.
• Speed/torque characteristics are flat which enables operation at all speeds with rated load. Whereas brushed dc motors have moderately flat characteristics.
• The electric noise generation is low for brushless.
• Brushless motors have low rotor inertia which improves dynamic response.
• They have higher speed range and output power to frame size ratio.

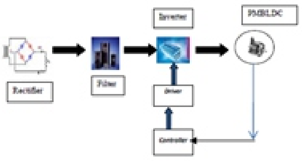

Fig.Basic Block diagram of PMBLDC Motor

DESIGN OF PFC CUK CONVERTER-BASED PMBLDCMD:

The proposed PFC Cuk converter is designed for a PMBLDCMD with main considerations on the speed control of the Air- Con and PQ improvement at ac mains. The dc link voltage of the PFC converter is given as

The proposed PFC Cuk converter is designed for a PMBLDCMD with main considerations on the speed control of the Air- Con and PQ improvement at ac mains. The dc link voltage of the PFC converter is given as

$$V_{dc} = V_{in} D/(1 - D) \quad (1)$$

Where Vin is the average output of the DBR for a given ac input voltage (Vs) related as

$$V_{in} = 2\sqrt{2}V_s/\pi. \quad (2)$$

The Cuk converter uses a boost inductor (Li) and a capacitor ($C1$) for energy transfer. Their values are given as

$$L_i = DV_{in}/\{f_s(\Delta I_{Li})\} \quad (3)$$
$$C_1 = DI_{dc}/\{f_s \Delta V_{C1}\} \quad (4)$$

Where ΔILi is a specified inductor current ripple, ΔVC1 is a specified voltage ripple in the intermediate capacitor ($C1$), and Idc is the current drawn by the PMBLDCM from the dc link. A ripple filter is designed for ripple-free voltage at the dc link of the Cuk converter. The inductance (Lo) of the ripple filter restricts the inductor peak-to-peak ripple current (ΔILo) within a specified value for the given switching frequency (fs), whereas the capacitance (Cd) is calculated for the allowed ripple in the dc link voltage (ΔVCd) . The values of the ripple filter inductor and capacitor are given as

$$L_o = (1 - D)V_{dc}/\{f_s(\Delta I_{Lo})\} \quad (5)$$
$$C_d = I_{dc}/(2\omega \Delta V_{Cd}). \quad (6)$$

The PFC converter is designed for a base dc link voltage of Vdc = 298 V at Vs = 220 V for fs= 40 kHz, Is = 4.5 A, ΔILi = 0.45 A (10% of Idc), Idc = 3.5 A, ΔILo = 3.5 A (≈Idc), ΔVCd = 4 V (1% of Vo), and ΔVC1 = 220 V (≈ Vs). The design values are obtained as Li = 6.61 mH, $C1$ = 0.3 μF, Lo = 0.82 mH, and Cd = 1590 μF.

PMBLDCM is used to drive the air conditioner compressor, speed of which is controlled effectively by controlling the DC link voltage . Permanent Magnet Brushless Direct Current (PMBLDC) motors are one of the motor types rapidly gaining popularity. Permanent Magnet Brushless Direct Current (PMBLDC) is Air conditioning systems are typically the largest consumers of electrical energy in homes and office buildings.

The most common type of air conditioning that we see is technically referred to as direct expansion, mechanical, vapor-compression refrigeration system. BLDC motors are used in industries such as Appliances, Automotive, Aerospace, Consumer, Medical, Industrial Automation Equipment and Instrumentation.

The compressor load is considered as a constant torque load equal to rated torque with the speed control required by air conditioning system. A 1.5 kW rating A few of these are: Better speed versus torque characteristics, High dynamic response, High efficiency, Long operating life, Noiseless operation, Higher speed ranges.

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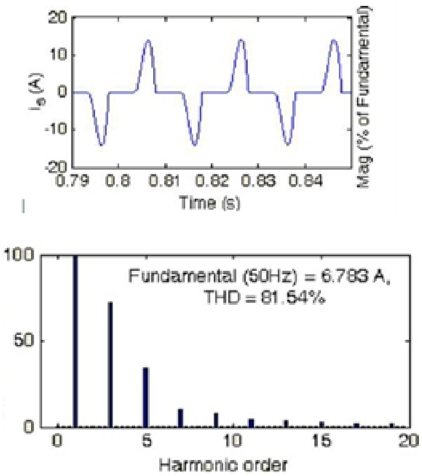

Fig.Current waveform at AC mains and its harmonic spectra for the PMBLDCMD without PFC.

As the PMBLDC machine has nonlinear model, the linear PI may no longer be suitable. This has resulted in the increased demand for modern nonlinear control structures like self-tuning controllers, state-feedback controllers, model reference adaptive systems and use of multivariable control structure. A major economic advantage of PFC converter is that the consumer cuts down on energy costs. In addition, power factor correction reduces the amount of current flowing in the transmission and distribution networks. Reduced current levels mean lower power losses in the distribution network, savings in electrical energy and hence reduced CO2 emissions. PFC converter are used in Stabilized voltage levels, increased capacity of your existing system and equipment, improved profit ability, Lowered expenses. Air conditioning systems are typically the largest consumers of electrical energy in homes and office buildings. In a fixed speed air conditioning system the compressor is cycled on and off to keep the temperature within a set band. For heavy load conditions the compressor operates at a high duty cycle and system efficiency is at its highest. However when the load is lighter, the compressor operates with a lower duty cycle and a much lower system efficiency. The PMBLDCMD is fed from a single-phase ac supply through a diode bridge rectifier (DBR) followed by a capacitor at dc link. It draws a pulsed current.A peak higher than the amplitude of the fundamental.

DESIGN OF FUZZY CONTROLLER:

Error (E) and change in error (CE) are the inputs for the fuzzy controller whereas the output of the controller is change in duty cycle (ΔDC).

The error is defined as the difference between the ref speed and actual speed , the change in error is defined as the difference between the present error and previous error and the output, Change in duty cycle ΔDC is which could be either positive or negative is added with the existing duty-cycle to determine the new duty-cycle (DCnew) Fig. 3shows the basic structure of fuzzy logic controller. The fuzzy controller is composed of the following four elements: fuzzification, fuzzy rule-base, fuzzy inference engine and defuzzification.

MODELING OF PFC CONVERTER-BASED PMBLDCMD:

The PFC converter and PMBLDCMD are the main components of the proposed drive, which are modeled by mathematical equations, and a combination of these models represents the complete model of the drive.

A. PFC Converter:

The modeling of the PFC converter consists of the modeling of a speed controller, a reference current generator, and a PWM controller as given hereinafter.

1)Speed Controller:

The speed controller is a PI controller which tracks the reference speed as an equivalent reference voltage. If, at the kth instant of time, V dc(k) is the reference

TABLE I
ELECTRONIC COMMUTATOR OUTPUT BASED ON THE HALL-EFFECT SENSOR SIGNALS [6], [11]

Hall Signals			Switching Signals					
H_a	H_b	H_c	S_{a1}	S_{a2}	S_{b1}	S_{b2}	S_{c1}	S_{c2}
0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	1	1	0
0	1	0	0	1	1	0	0	0
0	1	1	0	1	0	0	1	0
1	0	0	1	0	0	0	0	1
1	0	1	1	0	0	1	0	0
1	1	0	0	0	1	0	0	1
1	1	1	0	0	0	0	0	0

$$V_e(k) = V_{dc}^*(k) - V_{dc}(k). \qquad (7)$$

The PI controller output $Ic(k)$ at the kth instant after processing the voltage error $Ve(k)$ is given as

$$I_c(k) = I_c(k-1) + K_p\{V_e(k) - V_e(k-1)\} + K_i V_e(k) \qquad (8)$$

Where Kp and Ki are the proportional and integral gains of the PI controller.

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2) Reference Current Generator: The reference current at the input of the Cuk converter ($i*d$) is

$$i_d^* = I_c(k) u_{Vs} \quad (9)$$

Where uVs is the unit template of the ac mains voltage, calculated as

$$u_{Vs} = v_d / V_{sm}; \quad v_d = |v_s|; \quad v_s = V_{sm} \sin \omega t$$

where Vsm and ω are the amplitude (in volts) and frequency (in radians per second) of the ac mains voltage.

2)PWM Controller: The reference input current of the Cuk converter ($i*d$) is compared with its current (id) sensed after DBR to generate the current errorΔid= (i*d− id). This current error is amplified by gain $kd$and compared with fixed frequency (fs) sawtooth carrier waveform $md(t)$ [6] to get the switching signal for the MOSFET of the PFC Cuk converter as

$$\text{if} \quad k_d \Delta i_d > m_d(t) \quad \text{then } S = 1 \text{ else } S = 0 \quad (11)$$

where$S$ denotes the switching of the MOSFET of the Cuk converter as shown in Fig. 2 and its values "1" and "0" represent "on" and "off" conditions, respectively.

B. PMBLDCMD:

The PMBLDCMD consists of an electronic commutator, a VSI, and a PMBLDCM.Electronic Commutator:The electronic commutator uses signals from Hall-effect position sensors to generate the switching sequence for the VSI

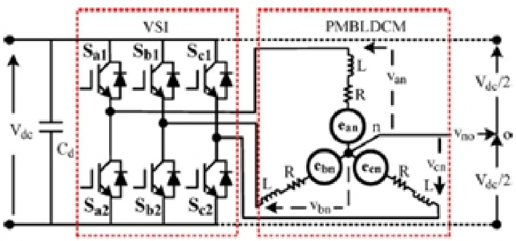

Fig. 3.Equivalent circuit of a VSI-fed PMBLDCMD.

VSI: The output of VSI to be fed to phase "a" of the PMBLDC motor is calculated from the equivalent circuit of a VSI-fed PMBLDCM

$$v_{ao} = (V_{dc}/2) \quad \text{for } S_{a1} = 1 \quad (12)$$
$$v_{ao} = (-V_{dc}/2) \quad \text{for } S_{a2} = 1 \quad (13)$$
$$v_{ao} = 0 \quad \text{for } S_{a1} = 0, \text{ and } S_{a2} = 0 \quad (14)$$
$$v_{an} = v_{ao} - v_{no} \quad (15)$$

where vao, vbo, vco, and vno are the voltages the three phases (a, b, and c) and neutral point (n) with respect to the virtual midpoint of the dc link voltage shown as "o" in Fig. 3.

The voltages van, vbn, and vcn are the voltages of the three phases with respect to the neutral terminal of the motor (n), and Vdc is the dc link voltage. The values 1 and 0 for Sa1 or Sa2 represent the "on" and "off" conditions of respective IGBTs of the VSI. The voltages for the other two phases of the VSI feeding the PMBLDC motor, i.e., vbo, vco, vbn, and vcn, and the switching pattern of the other IGBTs of the VSI (i.e., Sb1, Sb2, Sc1, and Sc2) are generated in a similar way.

CONCLUSION:

A new speed control strategy for a PMBLDCMD using the reference speed as an equivalent voltage at dc link has been simulated for an air-conditioner employing a Cuk PFC converter and simulation validation on a fuzzy based intelligence controller. The speed of PMBLDCM has been found to be proportional to the dc link voltage; thereby, a smooth speed control is observed while controlling the dc link voltage. The introduction of a rate limiter of the fuzzy controller in the reference dc link voltage effectively limits the motor current with in the desired value during the transient conditions (starting and speed control); we get better response as well as better THD values. The PFC Cuk converter has ensured near unity PF in a wide range of the speed and the input ac voltage.

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