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A Novel FUZZY based PFC Half-Bridge Converter for Voltage Controlled Adjustable PMBLDCM for Hybrid Vehicle

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ABSTRACT:

This paper deals with a novel controller viz. fuzzy logic controller to drive a voltage controlled PMBLDCM drive for better performance and efficiency. Here a buck half-bridge DC-DC converter was use as a single-stage power factor correction (PFC) converter for feeding a voltage source inverter (VSI) based permanent magnet brushless DC motor (PMBLDCM) drive. The front end of this PFC converter is a diode bridge rectifier (DBR) fed from single-phase AC mains. The PMBLDCM is used to drive a compressor load of an air conditioner through a three-phase VSI fed from a controlled DC link voltage. The speed of the compressor is controlled to achieve energy conservation using a concept of the voltage control at DC link proportional to the desired speed of the PMBLDCM. The proposed PMBLDCM drive with voltage control along with FUZZY control based PFC converter is designed, modeled and its performance is simulated in Matlab/ Simulink 7.8 version software.

Index Terms:

PFC, PMBLDCM, Air conditioner, Buck Half-bridge converter, Voltage control, VSI. Fuzzy controller

I. INTRODUCTION:

1.1. IMPORTANCE of BLDC Motor:

Brushless DC motors were developed from conventional brushed DC motors with the availability of solid state power semiconductors. So brushless DC motors are similar to AC synchronous motors.

The major difference is that synchronous motors develop a sinusoidal back EMF, as compared to a rectangular, or trapezoidal, back EMF for brushless DC motors. Both have stator created rotating magnetic fields producing torque in a magnetic rotor. The BLDC motors contains electronic commutator rather than brushes, thus they have higher efficiency, strong construction, long operating life and noiseless operation so it is more reliable than the DC motor. In a BLDC motor, rotor magnets generate the rotor's magnetic flux, so BLDC motors achieve higher efficiency. The stator has three phase windings whereas the rotor has pole magnets. Therefore, BLDC motors may be used in high-end white goods (refrigerators, washing machines, dishwashers, etc.), high-end pumps, fans and in other appliances which require high reliability and efficiency

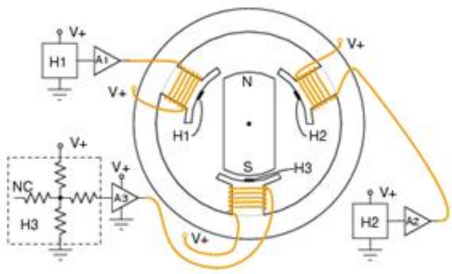

Fig.1.1 3-φ BLDC motor with Hall Effect sensors for commutation

The fig 1.1 shows hall sensors implanted in the motor detects the rotor position. Here the decoder decodes the position of the rotor and produces proper gate pulses to trigger the 6switch in inverter to produce AC voltage that gives the stator windings to

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produce current. Air-conditioners (Air-Cons) constitute a considerable amount of load in AC distribution system . However, most of the existing air-conditioners are not energy efficient and thereby, provide a scope for energy conservation. Air-Cons in domestic sector are usually driven by a single-phase induction motor running at constant rated torque with on-off control. A permanent magnet brushless DC motor (PMBLDCM) is a good drive for Air-Cons due to its high efficiency, silent operation, compact size, high reliability, ease of control and low maintenance requirements. The Air-Con system with PMBLDCM has low running cost, long life, and reduced mechanical and electrical stresses compared to a single-phase induction motor-based Air-Con system operating in "on/off" control mode.

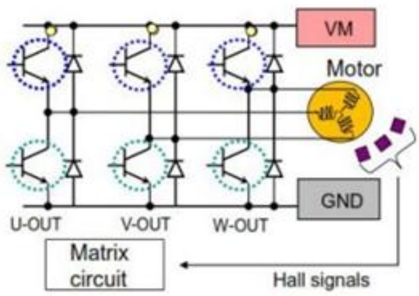

Fig.1.2. electrical circuit of 3-phase BLDC Motor Drive with Hall Sensors

The most commonly used topology for PMBLDCM Drive fed from single-phase AC mains uses a diode bridge rectifier (DBR) followed by a smoothening DC capacitor as shown in Fig. 1.Because of uncontrolled charging of DC link capacitor, the AC mains current waveform is a pulsed waveform featuring a peak value higher than the amplitude of the fundamental input current as shown in fig. 1. The Power Factor (PF) is 0.741 and Crest Factor (CF) of AC mains current is 2.2 with 67% efficiency of the drive. Therefore, many Power Quality (PQ) problems arise at input AC mains including poor power factor, increased Total Harmonic Distortion (THD) and high Crest Factor (CF) of AC mains current etc.

These PQ problems as addressed in IEC 61000-3-2 especially in low power appliances become severe for the utility when many such drives are employed simultaneously at nearby locations.

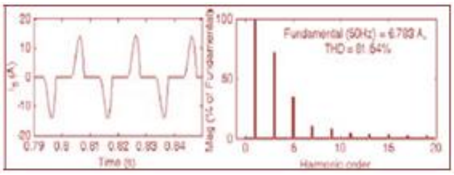

Figure. 1: Current Waveform at AC Mains and Its Harmonic Spectra for the PMBLDCM Drive (PMBLDCMD) Without PFC

Therefore, PMBLDCM drives having inherent Power Factor Correction (PFC) become the preferred choice for the Air-Cons. The PFC converter draws sinusoidal current from AC mains in phase with its voltage. In this PFC converter a DC-DC converter topology is mostly used amongst several available topologies e.g. boost, buck-boost, Cuk, SEPIC, zeta converters with variations of capacitive/inductive energy transfer. It results in an improved performance, such as reduction of AC mains current harmonics, acoustic noise, electromagnetic interference (EMI) and number of components; improved efficiency, wide input voltage range utilization etc. For the proposed voltage controlled drive, a Cuk dc–dc converter is used as a PFC converter because of its continuous input and output currents, small output filter, and wide output voltage range as compared to other single switch converters. Moreover, apart from PQ improvement at ac mains, it controls the voltage at dc link for the desired speed of the Air-Con.

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

The proposed control scheme for improved Power Quality converter i.e. the forward buck converter or PFC converter is shown in Figure 2 which uses average current control with current multiplier approach. The forward buck converter controls the DC link voltage as well as performs PFC action by its duty ratio (D) at a constant switching frequency (fs).

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The proposed PFC control scheme employs a current control loop inside the voltage control loop in the continuous conduction mode (CCM) operation of the PFC converter. A Fuzzy Lozic (Fuzzy) controller forms an integral part of this controller which processes the voltage error resulting from the comparison of set voltage reference and sensed voltage at DC link. The resultant control signal of Fuzzy controller is multiplied with a unit template of input AC voltage and compared with DC current sensed after the DBR. The resultant current error is amplified and compared with a saw-tooth carrier wave of fixed frequency (fs) for generating the PWM pulses for controlling switch of PFC converter. Use of a high switching frequency results in a fast control of DC link voltage and effective PFC action along with additional advantage of reduced size magnetics and filters. The optimum switching frequency is decided by various factors such as the switching device, switching losses and operating power level.

A metal oxide field effect transistor (MOSFET) is used as the switching device for the proposed PFC converter The proposed speed control scheme (as shown in Fig. 1) controls reference voltage at DC link as an equivalent reference speed, thereby replaces the conventional control of the motor speed and a stator current involving various sensors for voltage and current signals. Moreover, the rotor position signals are used to generate the switching sequence for the VSI as an electronic commutator of the PMBLDC motor. Therefore, rotor-position information is 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.

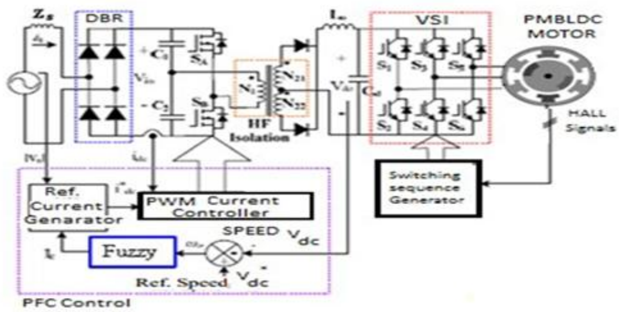

Figure 2. Control schematic of Proposed Bridge-buck PFC converter fed PMBLDCM drive (with Fuzzy Controller)

TABLE I: Back EMF Signals Based on Hall Effect Sensors

H_a	H_b	H_c	E_a	E_b	E_c
0	0	0	0	0	0
0	0	1	0	-1	+1
0	1	0	-1	+1	0
0	1	1	-1	0	+1
1	0	0	+1	0	-1
1	0	1	+1	-1	0
1	1	0	0	+1	-1
1	1	1	0	0	0

TABLE II: VSI switching sequence based on the hall effect Sensor signals

E_a	E_b	E_c	S_1	S_2	S_3	S_4	S_5	S_6
0	0	0	0	0	0	0	0	0
0	-1	+1	0	0	0	1	1	0
-1	+1	0	0	1	1	0	0	0
-1	0	+1	0	1	0	0	1	0
+1	0	-1	1	0	0	0	0	1
+1	-1	0	1	0	0	1	0	0
0	+1	-1	0	0	1	0	0	1
0	0	0	0	0	0	0	0	0

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 magnetic 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. Metal oxide field effect transistors (MOSFETs) are used as the switching device for high switching frequency in the proposed PFC converter. However, insulated gate bipolar transistors (IGBTs) are used in VSI bridge feeding PMBLDCM, to reduce

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the switching stress, as it operates at lower frequency compared to PFC switches.The PFC control scheme uses a current control loop inside the speed control loop with current multiplier approach which operates in continuous conduction mode (CCM) with average current control. The control loop begins with the comparison of sensed DC link voltage with a voltage equivalent to the reference speed. The resultant voltage error is passed through a Fuzzy Logic (Fuzzy) controller to give the modulating current signal. This signal is multiplied with a unit template of input AC voltage and compared with DC current sensed after the DBR. The resultant current error is amplified and compared with saw-tooth carrier wave of fixed frequency (fs) in unipolar scheme (as shown in Fig.2) to generate the PWM pulses for the half-bridge converter. For the current control of the PMBLDCM during step change of the reference voltage due to the change in the reference speed, a voltage gradient less than 800 V/s is introduced for the change of DC link voltage, which ensures the stator current of the PMBLDCM within the specified limits (i.e. double the rated current).

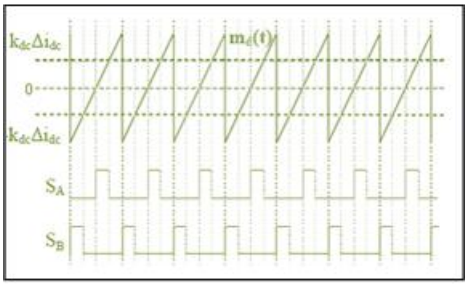

Figure 2. PWM control of the buck half-bridge converter

2.1 Design Of PFC Buck Half-Bridge Converter Based Pmbldcm Drive

The proposed PFC buck half-bridge converter is designed for a PMBLDCM drive with main considerations on PQ constraints at AC mains and allowable ripple in DC link voltage. The DC link voltage of the PFC converter is given as,

Vdc = 2(N2/N1)Vin D and N2=N21=N22 …………(1)

Where **N1, N21, N22** are number of turns in primary, secondary upper and lower windings of the high frequency (HF) isolation transformer, respectively.**Vin** is the average output of the DBR for a given AC input voltage (Vs) related as,

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

A ripple filter is designed to reduce the ripples introduced in the output voltage due to high switching frequency for constant of the buck half-bridge converter. The inductance (Lo) of the ripple filter restricts the inductor peak to peak ripple current (ΔILo) within specified value for the given switching frequency (fs), whereas, the capacitance (Cd) is calculated for a specified ripple in the output voltage (ΔVCd). The output filter inductor and capacitor are given as,

$L_o = (0.5-D)V_{dc}/\{f_s(\Delta I_{Lo})\}$ .... (3)

$C_d = I_o/(2\omega \Delta V_{Cd})$ .... (4)

The PFC converter is designed for a base DC link voltage of Vdc = 400 V at Vin = 198 V from Vs = 220 Vrms. The turn's ratio of the high frequency transformer (N2/N1) is taken as 6:1 to maintain the desired DC link voltage at low input AC voltages typically at 170V. Other design data are fs = 40 kHz, Io = 4 A, ΔVCd= 4 V (1% of Vdc), ΔILo= 0.8 A (20% of Io). The design parameters are calculated as Lo=2.0 mH, Cd=1600 μF.

III.CLOSED LOOP SPEED CONTROL USING FUZZY CONTROLLER

3.1.Fuzzy logic

Fuzzy logic provides a medium to represent imprecision and vague values in terms of linguistic constructs. Fig. 3 shows a fuzzy logic diagram with two error inputs and one output. The crisp error values given to the fuzzy inference system follows three steps. First, the crisp values are fuzzified to give relatively graded membership values. Secondly, rule set contained in the fuzzy rule based system takes decision to produce an output.

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Thirdly, this output value is defuzzified to deliver crisp outputs. Defuzzification types like max- min membership, weighted average, centroid method, etc. can be used. Membership functions like triangular, trapezoidal, Gaussian can be incorporated.

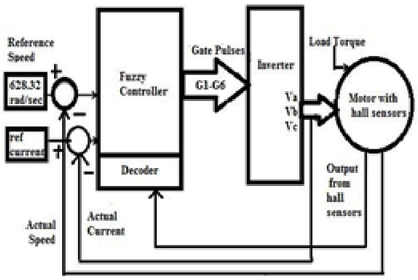

Figure 4 Closed loop Fuzzy speed controller

3.2. Fuzzy logic structure:

In the proposed fuzzy speed controller for BLDC, two inputs are defined: current error (three Gaussian membership functions i.e. S,Z and L) as shown in Fig. 5 and speed error(seven Gaussian membership functions i.e. NB,NM,NS,Z,PS,PM and PB) as shown in Fig. 6. The current error range varies from 0 to 1.45 A, whereas, the speed error range varies from -630 to 630 rad/sec.

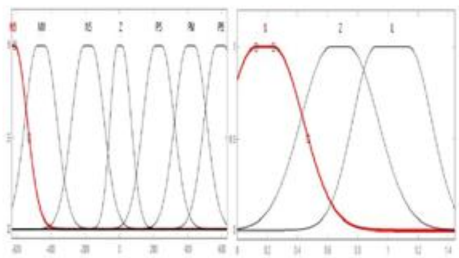

Figure 5 Input 1 Speed error membership functions

The output of the Mamdani inference model is a Gaussian membership function varying from 0.59 to1 with nine membership functions i.e. NVB, NB, NM, NS, Z, PS, PM, PB and PVB) as shown in Fig7.The output is a duty cycle that is compared with a triangular pulse to generate pulse width modulated signal, which is further anded with the gate pulses to modulate the inverter voltage and maintain a constant speed.
The rule set followed is shown in Table 2.

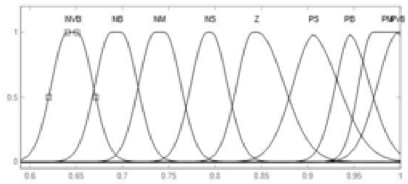

Fig. 7 Output membership functions

TABLE II Fuzzy rule table

CE/SE	NB	NM	NS	Z	PS	PM	PB
S	NVB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
L	NM	NS	Z	PS	PM	PB	PVB

3.3 Speed Control:

Commutation ensures proper rotor rotation of the BLDC motor, while the motor speed depends only on the amplitude of the applied voltage. The amplitude of the applied voltage is adjusted by using the PWM technique. The required speed is controlled by a speed controller. The speed controller is implemented as a Fuzzy controller. The difference between the actual and required speed is input to the Fuzzy controller and, based on this difference, the Fuzzy controller controls the duty cycle of PWM pulses, which corresponds to the voltage amplitude required to keep the required speed.

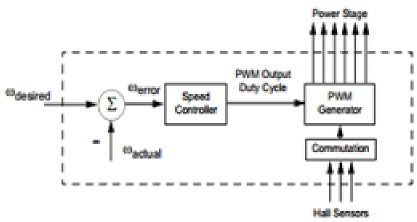

Fig 8. Speed control Strategy

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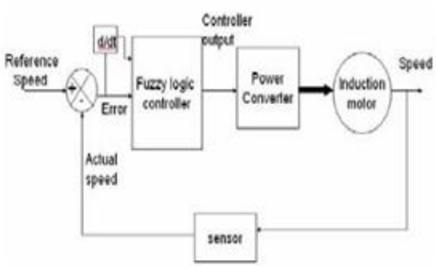

Fig. 9.Block Diagram of Closed Loop Using Fuzzy Logic Controller

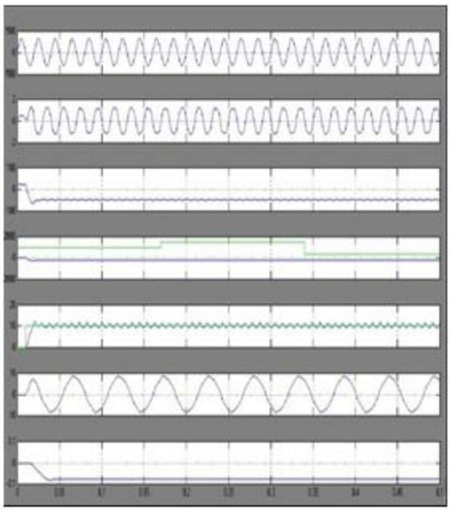

Fig. 10: Starting performance of the PMBLDCM drive at 900 rpm with Fuzzy controller

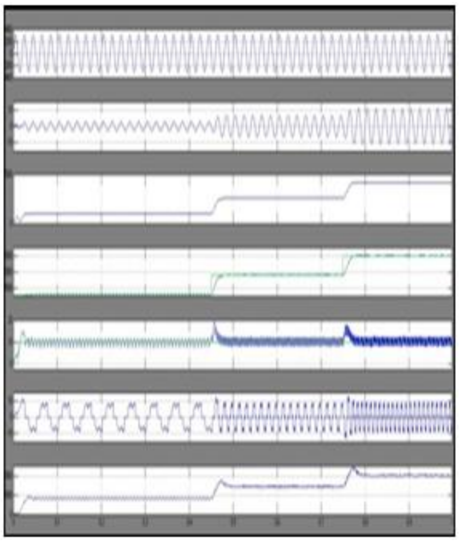

Fig. 11: Starting performance of the PMBLDCM drive at 900 rpm with PI controller

IV.MAT LAB SIMULATION CIRCUIT AND RESULTS

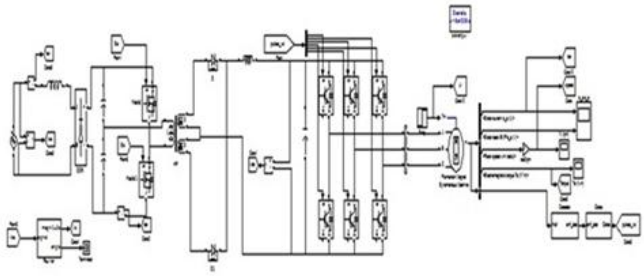

Fig. 12 Mat Lab Based Designed Proposed PMBLDC Motor with Fuzzy Control Circuit

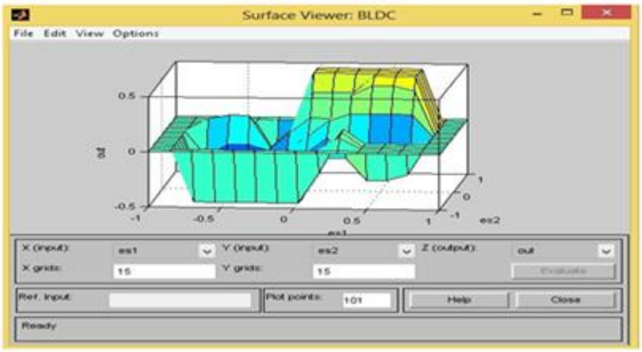

Fig. 13 FUZZY outputs in Surface Viewer Diagram

V.CONCLUSION:

A new speed control strategy of a PMBLDCM drive is validated for a compressor load of an air conditioner which uses the reference speed as an equivalent reference voltage at DC link. The speed control is directly proportional to the voltage control at DC link. The rate limiter introduced in the reference voltage at DC link effectively limits the motor current within the desired value during the transient condition (starting and speed control). The additional PFC feature to the proposed drive ensures nearly unity PF in wide range of speed and input AC voltage. Moreover, power quality parameters of the proposed PMBLDCM drive are in conformity to an International standard IEC 61000-3-2. The proposed drive has demonstrated good speed control with energy efficient operation of the drive system in the wide range of speed and input AC voltage.

The proposed drive has been found as a promising candidate for a PMBLDCM driving Air-Con load in 1-2 kW power range.

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