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Fuzzy Based PFC Buck Half-Bridge Converter for Voltage Controlled Adjustable Speed PMBLDC Motor

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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 modification technique. A Buck Half-Bridge DC -DC converter is used as a single-stage power-factor-correction converter for a permanent magnet brushless dc motor (PMBLDCM) fed all the way through diode bridge rectifier from a single-phase ac mains. This reduced the power quality problems and improve the power factor at input ac mains. A three-phase voltage-source inverter is used as an electronic commutator which switches the PMBLDCM drive. The concept of voltage control at the dc link comparative to the desired speed of the PMBLDCM is used to control the speed of the compressor. The stator current of the PMBLDCM during step change of the reference speed is controlled within the specified limits by an addition of a rate limiter in the reference DC link voltage. The proposed power factor converter topology is designed, modeled and its performance is evaluated in Matlab-Simulink environment for an air conditioner driven through a PMBLDC motor. The results illustrate an improved power quality and good power factor in wide speed range of the drive.**

Key Words**:-- Air-conditioner (Air-Cons), CUK converter, power factor (PF) correction (PFC), permanent-magnet (PM) Brushless dc motor (PMBLDCM), voltage-source inverter (VSI), Fuzzy controller.**

I. INTRODUCTION

PERMANENT magnet brushless DC motors (PMBLDCMs) area unit most popular motors for a mechanical device of Associate in Nursing air-conditioning (Air-Con) system because of its options like high potency, wide speed vary and low maintenance needs [1-4]. The operation of the mechanical device with the speed management leads to Associate in Nursing improved potency of the system whereas maintaining the temperature within the cool zone at the set reference systematically. Whereas, the present air conditioners largely have a single-phase induction motor to drive the mechanical device in 'on/off' management mode. This leads to hyperbolic losses because of frequent 'on/off' operation with hyperbolic mechanical and electrical stresses on the motor, thereby poor potency and reduced lifetime of the motor. Moreover, the temperature of the air conditioned zone is regulated during a physical phenomenon band. Therefore, improved potency of the Air-Con system will definitely scale back the price of living and energy demand to cope-up with ever-increasing power crisis.

A PMBLDCM that could be a quite three-phase electric motor with permanent magnets (PMs) on the rotor and quadrangle back electromotive force wave type operates on electronic commutation accomplished by solid state switches. It is

Powered through a three-phase voltage supply electrical converter (VSI) that is fed from single-phase AC provide employing a diode bridge rectifier (DBR) followed by smoothening DC link electrical device. The mechanical device exerts constant force (i.e. rated torque) on the PMBLDCM and is operated in speed management mode to boost the potency of the Air-Con system.

Since, the back-EMF of the PMBLDCM is proportional to the motor speed and therefore the developed force is proportional to its section current [1-4], therefore, a continuing force is maintained by a continuing current within the mechanical device winding of the PMBLDCM wherever because the speed are often controlled by varied the terminal voltage of the motor. supported this logic, a speed management theme is planned during this paper that uses a

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reference voltage at DC link proportional to the required speed of the PMBLDC motor. However, the management of VSI is simply for electronic commutation that relies on the rotor position signals of the PMBLDC motor. The PMBLDCM drive, fed from a single-phase AC mains through a diode bridge rectifier (DBR) followed by a DC link electrical device, suffers from power quality (PQ) disturbances reminiscent of poor power issue (PF), hyperbolic total harmonic distortion (THD) of current at input AC mains and its high crest issue (CF). it's chiefly because of uncontrolled charging of the DC link electrical device which ends up during a periodical current wave form having a peak price above the amplitude of the basic input current at AC mains. Moreover, the PQ standards for low power equipments reminiscent of IEC 61000-3-2 [5], emphasize on low harmonic contents and close to unity power issue current to be drawn from AC mains by these motors. Therefore, use of an influence issue correction (PFC) topology amongst numerous obtainable topologies [6-14] is nearly inevitable for a PMBLDCM drive [7-8]. The DC-DC convertor employed in the second stage is sometimes a fly back or forward convertor for low power applications and a full-bridge convertor for higher power applications. However, these 2 stage per fluorocarbon converters have high value and complexness in implementing 2 separate switch-mode converters, thus one stage convertor combining the per fluorocarbon and voltage regulation at DC link is a lot of in demand. The single-stage per fluorocarbon converters operate with only 1 controller to control the DC link voltage in conjunction with the facility issue correction. The absence of a second controller features a bigger impact on the performance of single-stage per fluorocarbon converters and needs a style to control over a far wider vary of in operation conditions.

For the planned voltage controlled drive, a half-bridge buck DC-DC convertor is chosen as a result of its high power handling capability as compared to the only switch converters. Moreover, it's switch losses admire the only switch converters as only 1 switch is operative at any instant of your time. It are often operated as a single-stage power issue corrected (PFC) convertor once connected between the VSI and therefore the DBR fed from single-phase AC mains, besides dominant the voltage at DC link for the required speed of the Air-Con mechanical device. an in depth modeling, style Associate in Nursingd performance analysis of the planned drive area unit conferred for an cooling mechanical device driven by a PMBLDC motor of one.5 kW, 1500 rpm rating.

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

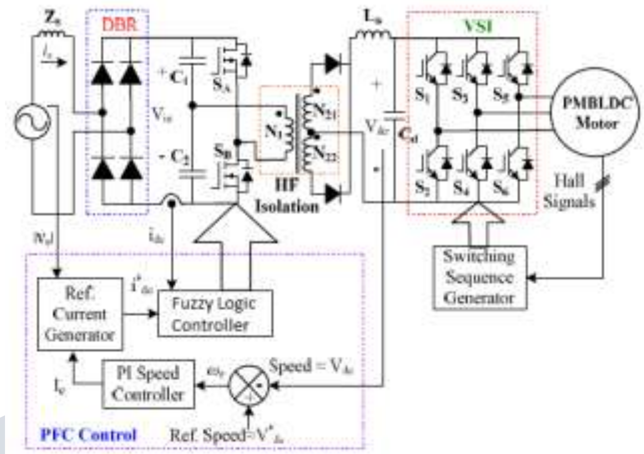

Fig 1. Control schematic of Proposed Bridge-buck PFC converter fed PMBLDCM drive

The proposed control scheme is shown in Fig. 1 with the commutation control in VSI and speed control (i.e., voltage control) with PFC through a DC-DC converter. The Buck Half-Bridge converter controls the DC link voltage as well as performs PFC action by its duty ratio (D) at a constant switching frequency (fs). 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 Logic (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 errors 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 magnetic and filters. The optimum switching frequency is decided by various factors such as the switching device, switching losses and operating power level. 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

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PMBLDCM, to reduce the switching stress, as it operates at lower frequency compared to PFC switches.

III. 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,

$V_{dc} = 2\,(N2/N1)\,V_{in}\,D$ 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.

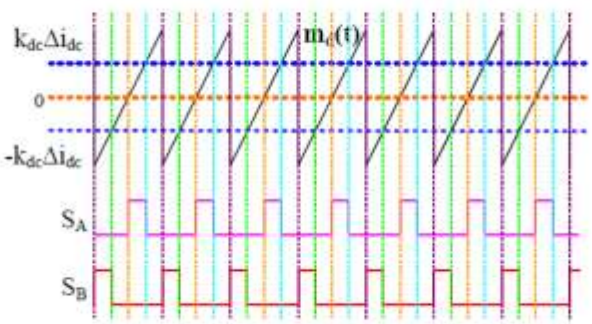

Fig. 2. PWM control of the buck half-bridge converter

V_{in} is the average output of the DBR for a given AC input voltage (V_s) 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 (ΔI_{Lo}) within specified value for the given switching frequency (fs), whereas, the capacitance (C_d) is calculated for a specified ripple in the output voltage (ΔV_{Cd}) [7-8]. The output filter inductor and capacitor are given as,

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

$C_d = Io/(2\omega \Delta VC_d)$ (4)

The PFC converter is designed for a base DC link voltage of V_{dc} = 400 V at V_{in} = 198 V from Vs =220 V_{rms}. The turns 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% ofV_{dc}), ΔI_{Lo}= 0.8 A (20% of Io). The design parameters are calculated as Lo=2.0 mH, C_d=1600 µF.

TABLE I. VSI Switching Sequence Based On the Hall Effect Sensor Signals

Ha	Hb	Hc	Ea	Eb	Ec	S1	S2	S3	S4	S5	S6
0	0	0	0	0	0	0	0	0	0	0	0
0	0	1	1	-1	0	1	0	0	1	0	0
0	1	0	1	0	-1	1	0	0	0	0	1
0	1	1	0	1	-1	0	0	1	0	0	1
1	0	0	-1	1	0	0	1	1	0	0	0
1	0	1	-1	0	1	0	1	0	0	1	0
1	1	0	0	-1	1	0	0	0	1	1	0
1	1	1	0	0	0	0	0	0	0	0	0

IV. MODELING OF THE PROPOSED PMBLDCM DRIVE

The main components of the proposed PMBLDCM drive are the PFC converter and PMBLDCM drive, which are modeled by mathematical equations and the complete drive is represented as a combination of these models 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 below

1) Speed Controller*:* The speed controller, the main component of this control scheme, is a proportional-integral (PI) controller which closely tracks the situation speed as an equivalent reference voltage. If at k_{th} instant of time, $V^*_{dc}(k)$ is

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reference DC link voltage, $V_{dc}(k)$ is sensed DC link voltage then the voltage error $V_e(k)$ is calculated as,

$$V_e(k) = V^*_{dc}(k) - V_{dc}(k) \quad (5)$$

The PI controller gives desired control signal after Processing this voltage error. The output of the controller Ic(k) at kth instant is given as,

$$I_c(k) = I_c(k-1) + K_p\{V_e(k) - V_e(k-1)\} + KiV_e(k) \quad (6)$$

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

2) Reference Current Generator:

The reference input current of the PFC converter is denoted by i_{dc}^* and given as,

$$i^*_{dc} = I_c(k)\, u_{Vs} \quad (7)$$

where u_{Vs} is the unit template of the voltage at input AC mains, calculated as,

$$u_{Vs} = v_d/V_{sm};\ vd = |v_s|;\ v_s = V_{sm} \sin \omega t \quad (8)$$

Where V_{sm} is the amplitude of the voltage and ω is frequency in rad/sec at AC mains.

3) Fuzzy Logic 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 **c**ould be either positive or negative is added with the existing duty-cycle to determine the new duty-cycle (DC_{new}) Fig. 3shows the basic structure of fuzzy logic controller. The fuzzy controller is collected of the following four elements: Fuzzification, fuzzy rule-base, fuzzy inference engine and defuzzification [18].

A. Fuzzification: Fuzzy logic uses linguistic variables instead of numerical variables. The process of converting a numerical variable in to a linguistic variable is called Fuzzification [18].

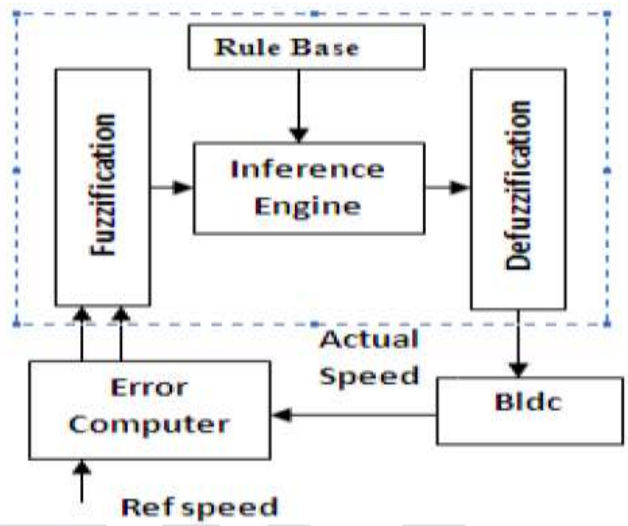

Fig. 3 Fuzzy logic controller

B. The fuzzifier includes two parts: choice of membership function and choice of scaling factor. The fuzzy variables error, change in error and change in duty-cycle are quantized using the linguistic terms NB,NS, ZE,PS, and PB (negative big, , negative small, zero, positive small, and positive big respectively). The motor maximum range of speed is 0-3000rpm.The possible range of error is -3000 to +3000 rpm. The universe of discourse for error is -3000 rpm to +3000 rpm and for the change in duty cycle, defined as - 100 % and +100 %. In order to achieve faster control action and simplification, the inputs and output are normalized to +/-100 rpm, +/-100 rpm and +/-100 respectively. The membership functions used for inputs and output are given in figure 4.

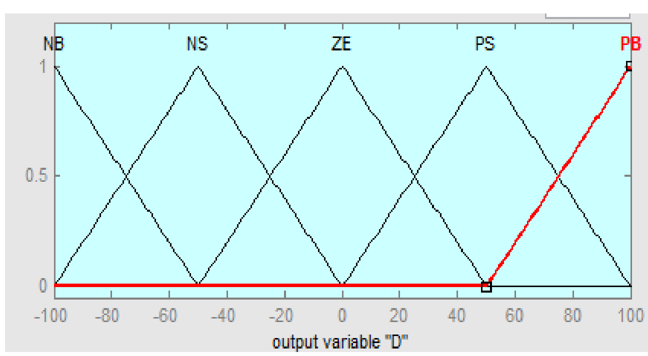

Fig.4 Membership functions for Error Change in Error and Change in Duty-Cycle

C. Rule Base And Inference engine: A rule base (a set of If- Then rules), which contains a fuzzy logic quantification of the expert's linguistic description of how to achieve control action. Once the rules have been established, a fuzzy logic system can be viewed as a mapping from inputs to outputs. Rules may be provided by experts or can be extracted from numerical data. The performance of the controller may be improved by adjusting the membership perform and rules. Different types of inferential procedures to assist US perceive things or to form selections, there square measure many various symbolic logic inferential procedures. The fuzzy inference operation is implemented by using the 25 rules.

Table II. Rule Base

E \ CE	NB	NS	ZE	PS	PB
NB	ZE	ZE	PB	PB	PB
NS	ZE	ZE	PS	PS	PS
ZE	PS	ZE	ZE	ZE	NS
PS	NS	NS	NS	ZE	ZE
PB	NB	NB	NB	ZE	ZE

4. Defuzzification: Finally the fuzzy output is converted into real value output by the process called defuzzification. Centroid method of defuzzification is used because it can be easily implemented and requires less computation time. The defuzzified output is obtained by the following equation

$$Z = \frac{\sum_{x=1}^{n} \mu(x)x}{\sum_{x=1}^{n} \mu(x)} \qquad (9)$$

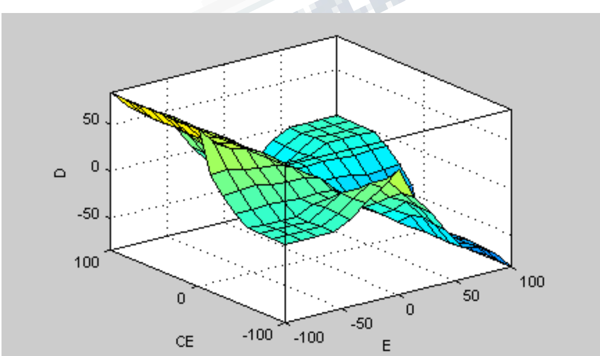

Fig. 5. Surface graph of FLC

B.PMBLDC Motor:

The PMBLDCM is represented in the form of a set of differential equations [3] given as,

$v_{an} = R_{ia} + p_{\lambda a} + e_{an}$ (10)

$v_{bn} = R_{ib} + p_{\lambda b} + e_{bn}$ (11)

$v_{cn} = R_{ic} + p_{\lambda c} + e_{cn}$ (12)

where p is a differential operator (d/dt), i_a, i_b, i_c are three-phase currents, λ_a, λ_b, λ_c are flux linkages and e_{an}, e_{bn}, e_{cn} are phase to neutral back emfs of PMBLDCM, in respective phases, R is resistance of motor windings/phase.

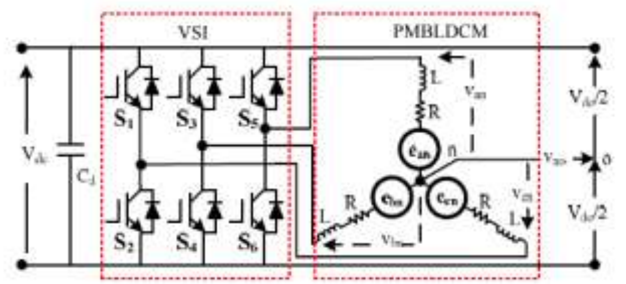

Fig.6. Equivalent Circuit of a VSI fed PMBLDCM Drive
The flux linkages are represented as

$\lambda a = L_{ia} - M\,(i_b + i_c)$ (18)

$\lambda b = L_{ib} - M\,(i_a + i_c)$ (19)

$\lambda c = L_{ic} - M\,(i_b + i_a)$ (20)

Where L is self-inductance/phase, M is mutual inductance of motor winding/phase. Since the PMBLDCM has no neutral connection, therefore,

$i_a + i_b + i_c = 0$ (21)

V. MATLAB/SIMULINK MODELLING AND SIMULATION RESULTS.

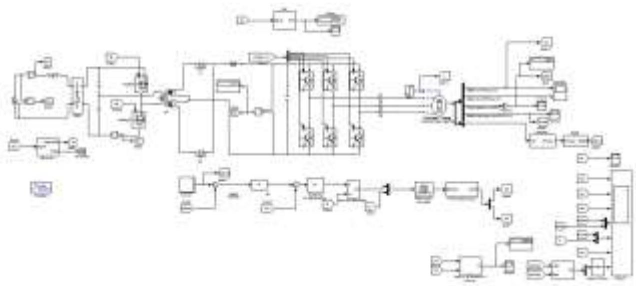

Fig. 7. MATLAB/SIMULATION model of the PFC Buck Half- bridge converter based PMBLDC

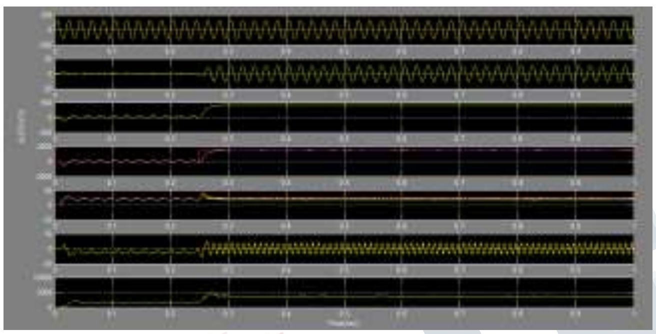

Fig.8. Performance of the PMBLDCM drive at rated speed (1500 rpm).

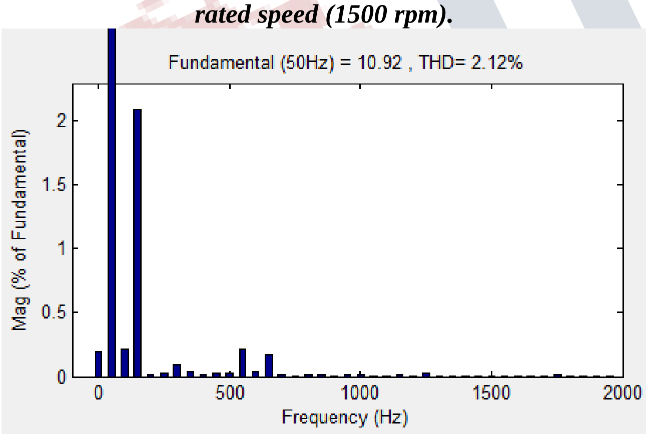

Fig.8. THD of the PMBLDCM drive under steady state condition at rated torque and 220 VAC

VI. 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 Buck Half-Bridge PFC converter and simulation valid at ion 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 within the desired value during the transient conditions (starting and speed control); we get better response as well as better THD values. The PFC Buck Half-Bridge converter has ensured near unity PF in a wide range of the speed and the input ac voltage. These PMBLDC motor drive based fans have similar PQ problems as they use a simple single-phase diode rectifier and no speed control. Moreover, using the intelligence controllers we get better response and error should be nullified as well as THD values also.

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