A Novel Fuzzy Control Strategy High-Efficiency Minimum-Torque-Ripple reduction of Three-Phase BLDC Motor Drive

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Abstract **:** Brushless DC motors (BLDCM) are widely used for many industrial applications because of their high efficiency, high torque and low volume. This paper proposed an improved Adaptive Fuzzy controller to control speed of BLDCM. This paper provides an overview of performance conventional PI, Fuzzy controller and Adaptive Fuzzy controller. It is difficult to tune the parameters and get satisfied control characteristics by using normal conventional PI controller. As the Adaptive Fuzzy has the ability to satisfied control characteristics and it is easy for computing. The matlab results verify that a Adaptive Fuzzy controller has better control performance than the both Fuzzy controller and conventional PI controller. The modeling, control and simulation of the BLDC motor have been done using the software package MATLAB/SIMULINK.

Introduction

The Brushless DC Motor (BLDC) has been widely used in application where small volume size, high power density, low maintenance, and high reliability are important design issues. Battery-fed BLDC drives use bank of parallel and series batteries as power source. Their BLDC motor is usually supplied by a hard switching PWM inverter which lowers the inverter efficiency and produce heat which must be dissipated by a heat-sink. Reduce the switching losses not only reduces the heat sink size but also endures power source for longer operation. Most applications where make choose of BLDC motors a suitable and economically competitive with other type of electric motors, are portable devices. Because relatively higher cost of BLDC motor in comparison with other types, depicts use of it in cases with space constraints and need of highest torque per volume ratios. In such cases, (vehicles, portable tools, etc.) DC power supplies (mostly batteries and ultra capacitors) used as main source. Because the nature of batteries and ultra-capacitors are based on series of individual cells, usually mid-point access is available free of cost. Many soft switching inverters are proposed in recent years which are classified in three main categories of resonant pole inverter, resonant ac-link inverter, and resonant dc-link inverter Resonant ac-link inverter is not appropriate for BLDC motors drive application. Resonant dc-link inverter introduces high voltage stress on the switches and high dc-link voltage ripple. To solve these problems quasi-parallel resonant dc-link inverters are proposed with additional main conduction path which increase conduction losses.

PROPOSED SPEED CONTROL SCHEME OF PMBLDC MOTOR FOR AIR CONDITIONER

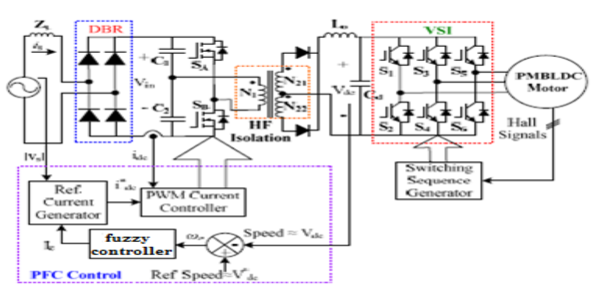


Figure1. Control schematic of Proposed Bridge-buck PFC converter fed BLDCM drive

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.

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 prime component of this control scheme, is a proportional-integral (PI) controller which closely tracks the reference speed as an equivalent reference voltage. If at kth instant of time, V*dc(k) is reference DC link voltage, Vdc(k) is sensed DC link voltage then the voltage error Ve(k) is calculated as,

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

The PI controller gives desired control signal after processing this voltage error. The output of the controller Ic(k) at k^{th} instant is given as,

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

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 idc* and given as,

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

Where uVs is the unit template of the voltage at input AC mains, calculated as,

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

Where Vsm is the amplitude of the voltage and ω is frequency in rad/sec at AC mains.

3) PWM Controller: The reference input current of the buck half-bridge converter (idc*) is compared with its sensed current (idc) to generate the current error Δidc=(idc* - idc). This current error is amplified by gain kdc and compared with fixed frequency (fs) saw-tooth carrier waveform md(t) (as shown in Fig.2) in unipolar switching mode to get the switching signals for the MOSFETs of the PFC buck half-bridge converter as,

If

$$k_{dc}\,\Delta i_{dc} > m_d(t) \quad \text{then } S_A = 1 \text{ else } S_A = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

If

$$-k_{dc}\,\Delta i_{dc} > m_d(t) \quad \text{then } S_B = 1 \text{ else } S_B = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Where SA, SB are upper and lower switches of the half-bridge converter as shown in Fig. 1 and their values ‘1’ and ‘0’ represent ‘on’ and ‘off’ position of the respective MOSFET of the PFC converter.

B. PMBLDCM DRIVE

The PMBLDCM drive consists of electronic commutators, a VSI and a PMBLDC motor.

1) Electronic Commutator*:* The electronic commutators uses signals from Hall effect position sensors to generate the switching sequence for the voltage source inverter based on the logic given in Table I.

2) Voltage Source Inverter*:* Fig. 3 shows an equivalent circuit of a VSI fed PMBLDCM. The output of VSI to be fed to phase ‘a’ of the PMBLDC motor is given as,

$$v_{ao} = (V_{dc}/2) \qquad \text{for } S_1 = 1 \quad \ldots\ldots\ldots\ldots (11)$$

$$v_{ao} = (-V_{dc}/2) \qquad \text{for } S_2 = 1$$ ……………….. (12)

$$v_{ao} = 0 \qquad \text{for } S_1 = 0, \text{ and } S_2 = 0$$ ………… (13)

$$v_{an} = v_{ao} - v_{no}$$ ………………… (14)

Where vao, vbo, vco, and vno are voltages of the three-phases and neutral point (n) with respect to virtual mid-point of the DC link voltage shown as 'o' in Fig. 3. The voltages van, vbn, vcn are voltages of three-phases with respect to neutral point (n) and Vdc is the DC link voltage. S= 1 and 0 represent 'on' and 'off' position of respective IGBTs of the VSI and considered in a similar way for other IGBTs of the VSI i.e. S3- S6.

Using similar logic vbo, vco, vbn, vcn are generated for other two phases of the VSI feeding PMBLDC motor.

3) PMBLDC Motor*:* The PMBLDCM is represented in the form of a set of differential equations given as,

$$v_{an} = Ri_a + p\lambda_a + e_{an}$$ …………….. (15)

$$v_{bn} = Ri_b + p\lambda_b + e_{bn}$$ ………………… (16)

$$v_{cn} = Ri_c + p\lambda_c + e_{cn}$$ …………………… (17)

Where p is a differential operator (d/dt), ia, ib, ic are three-phase currents, λa, λb, λc are flux linkages and ean, ebn, ecn are phase to neutral back emf of PMBLDCM, in respective phases, R is resistance of motor windings/phase.

The flux linkages are represented as,

$$\lambda_a = Li_a - M(i_b + i_c)$$ ……………. (18)

$$\lambda_b = Li_b - M(i_a + i_c)$$ …………… (19)

$$\lambda_c = Li_c - M(i_b + i_a)$$ ………… (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)

From Eqs. (14-21) the voltage between neutral terminal (n) and mid-point of the DC link (o) is given as,

$$v_{no} = \{v_{ao} + v_{bo} + v_{co} - (e_{an} + e_{bn} + e_{cn})\}/3$$ ……………. (22)

From Eqs. (18-21), the flux linkages are given as,

$$\lambda_a = (L+M)\, i_a, \quad \lambda_b = (L+M)\, i_b, \quad \lambda_c = (L+M)\, i_c,$$ …………. (23)

From Eqs. (15-17 and 23), the current derivatives in generalized state space form is given as,

$$pi_x = (v_{xn} - i_x R - e_{xn})/(L+M)$$ ………………. (24)

Where x represents phase a, b or c.

The developed electromagnetic torque Te in the PMBLDCM is given as,

$$T_e = (e_{an}\, i_a + e_{bn}\, i_b + e_{cn}\, i_c)/\ \omega$$ …………………… (25)

Where ω is motor speed in rad/sec,

The back emf may be expressed as a function of rotor position (θ) as,

$$e_{xn} = K_b f_x(\theta)\ \omega$$ ……………….. (26)

Where x can be phase a, b or c and accordingly *fx*(θ) represents function of rotor position with a maximum value ±1, identical to trapezoidal induced emf given as,

$$f_a(\theta) = 1 \qquad \text{for } 0 < \theta < 2\pi/3$$ ………….. (27)

$$f_a(\theta) = \{(6/\pi)(\pi - \theta)\} - 1 \qquad \text{for } 2\pi/3 < \theta < \pi$$ ……………. (28)

$$f_a(\theta) = -1 \qquad \text{for } \pi < \theta < 5\pi/3$$ ………… (29)

$$f_a(\theta) = \{(6/\pi)(\theta - 2\pi)\} + 1 \qquad \text{for } 5\pi/3 < \theta < 2\pi$$ ……………. (30)

The functions *fb*(θ) and *fc*(θ) are similar to *fa*(θ) with a phase difference of 120º and 240º respectively.

$$T_e = K_b\{f_a(\theta)\, i_a + f_b(\theta)\, i_b + f_c(\theta)\, i_c\}$$ ……………. (31)

The mechanical equation of motion in speed derivative form is given as,

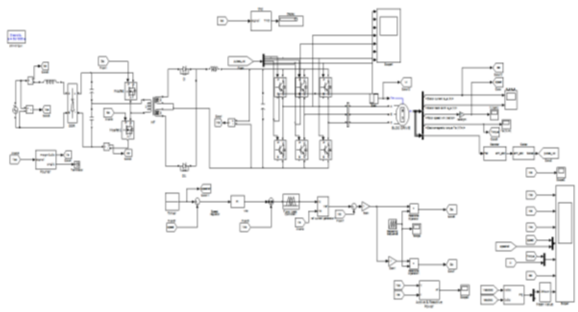
$$p\omega = (P/2)\,(T_e - T_L - B\omega)/(J)$$ ………….. (32)

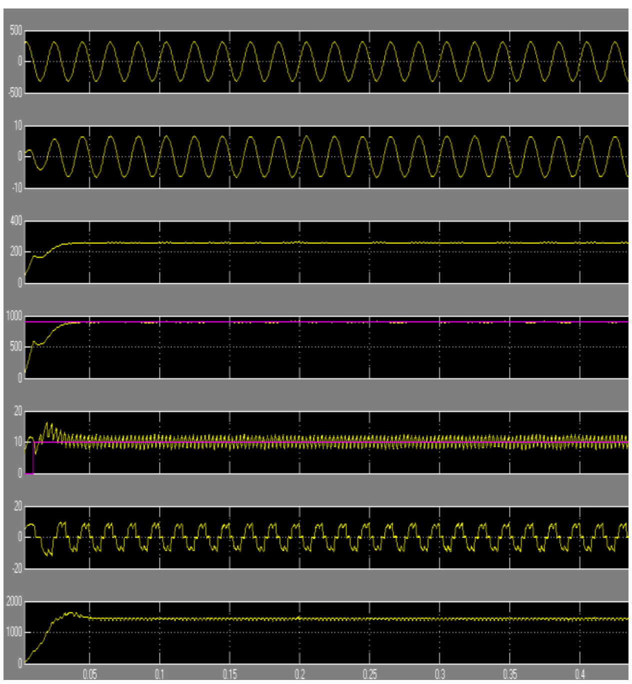
The derivative of the rotor position angle is given as,

$$p\theta = \omega$$ ………. (33)

Where P is no. poles, TL is load torque in Nm, J is moment of inertia in kg-m2 and B is friction coefficient in Nms/Rad.
These equations (15-33) represent the dynamic model of the PMBLDC motor.

MAT LAB DESIGN OF CASE STUDY AND RESULTS





Starting performance of the PMBLDCM drive at 900 rpm

CONCLUSION

This paper presents simulation results of conventional PI controller, Fuzzy controller and Adaptive Fuzzy controller of three phase BLDC Motor. In conventional control it is not necessary to change the control parameters as the reference speed changes. With results obtained from simulation, it is clear that for the same operation condition the BLDC speed control using Adaptive Fuzzy controller technique had better performance than the conventional PI controller and Fuzzy controller, mainly when the motor was working at lower and higher speeds. In addition, the motor speed to be constant when the load varies.

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