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PI tuning control of Four Switch Three Phase Brushless DC Motor

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Abstract: Brushless DC (BLDC) motor are one of the electrical drives that are rapidly gaining popularity, due to their high efficiency, good dynamic response and low maintenance. The paper presents the comprehensive study on the controllability and generated torque ripple of phase commutation in Four Switch Three Phase Inverter(FSTPI) Brushless DC (BLDC) motor drive which is suitable for low cost application. The conventional techniques for controlling the phase current in a FSTPI brushless DC drive are practically effective in low speed and cannot reduce the commutation torque ripple in high speed range. A single neuron PI controller is used to control the speed, by adjusting the weight .Then a novel current control technique is developed to minimize the commutation torque ripple for a wide speed range. According to simulation and experimental results, the proposed strategy shows good self adapted track ability, also the structure of the drive is simplified.

Keywords: Four switch inverter, single neuron PI, current slopes.

1. Introduction

The BLDC motor is a rotating electric motor consisting of three- phase armature windings on the stator and permanent magnets on the rotor. The mechanical structure of BLDC motor is the conventional permanent magnet brushed DC motor (PMDCM) inside out, the rotor contains permanent magnets and the motor windings are mounted on the stator. The BLDC motor does not have any brushes, those required in the commutation of PMDCM. Therefore the maintenance free motor drive system is possible with BLDC motor. The permanent magnets on the rotor of the BLDC motor provide a constant rotor magnetic field, and makes possible a highly efficient, high torque-per volume, and low moment of inertia [1]. The BLDC motor is an electronically commutating permanent magnet DC motor. Because of this motor's inherent variable speed drive nature, its applications are growing, in automobile and machine building industries.

Conventionally, BLDC motors are excited by a six switch inverter. However, cost effective design is becoming one of the most important concerns for the modern motor control research. Some papers [2]-[3] are based on power inverter with reduced costs and losses. Among these developments, the three phase voltage source inverter with only four switches is a solution. In comparison with the usual three phase inverter with six switch, the features are, the reduction of switches and freewheeling diodes, reduction of conduction losses and the cost. It results in the possibility of the four switch topology instead of six switches. In four switch converter, the generation conducting current profiles is inherently difficult due to its 120° limited voltage vectors. This is known as asymmetric voltage PWM. That is conventional PWM schemes for the four switch induction motor drive cannot be directly used for the BLDC motor drive. Still lot of equations for the transformation of voltage and current vectors, α-β and a-b-c axis. Due to this the current control become more complicated. Another problem is, in four switch BLDC the uncontrollable phase current causes unsymmetrical voltage vectors, and its waveform is much of distortion from rectangular. The direct current control based on hysteresis avoids this problem, and it senses currents of phase a and b

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individually by two current sensors and then switches them separately. Some work has also been done in sensorless Four switch BLDC motor drive [4]-[5] the position information of the rotor can be acquire based on the zero crossing points of the stator terminal voltages, and there is no need to build a 30° phase shift, which prevalent in most of the sensorless algorithms. In this paper explains the modelling of four switch three phase BLDC motor with speed control by single neuron PI controller.

1.1. Four switch three phase BLDC motor

The modelling of the four switch three phase BLDC motor drive system is based on some assumptions

- All the stator phase windings have equal resistance per phase and constant self and mutual inductances.
- Power semiconductor devices are ideal.
- Iron losses are negligible and the motor is unsaturated.

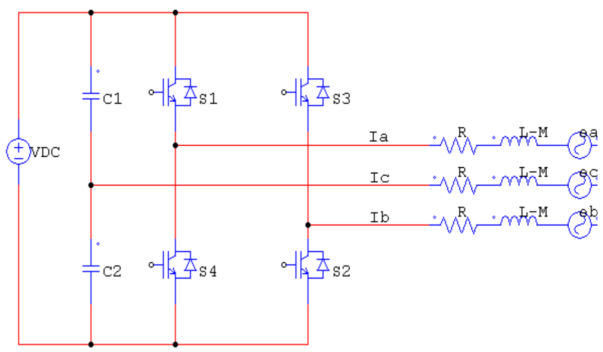

Fig.1: Equivalent circuit for four switch BLDC motor.

Based on the above assumptions, the three phase input voltages [6] are expressed as follows

$$\left.\begin{aligned} V_a &= RI_a + (L-M)\frac{dI_a}{dt} + e_a + V_m; \\ V_b &= RI_b + (L-M)\frac{dI_b}{dt} + e_b + V_m; \\ V_c &= RI_c + (L-M)\frac{dI_c}{dt} + e_c + V_m; \end{aligned}\right\}$$

The electromagnetic torque can be expressed by

$$T_e = (e_a i_a + e_b i_b + e_c i_c)$$

It can also be expressed in terms of load torque and speed by

$$T_e = T_l + J\frac{d\omega_r}{dt} + B\omega_r$$

The current that passing through the capacitor C_1 and C_2 be i_{c1} and i_{c2} respectively then

$$i_{c1} = C\frac{d(V-u_c)}{dt}$$

$$i_{c2} = C\frac{du_c}{dt} \qquad i_c = -2C\frac{du_c}{dt}$$

In these equations V_a, V_b, V_c indicates the stator phase winding voltage of phase a, b, and c respectively, e_a, e_b, e_c indicates the back emf of each phase, i_a, i_b, i_c be the current in each phase, V_m be the neutral voltage, R, L and M indicates the resistance, inductance and mutual inductance of the phase winding, T_l is the load torque, J be the moment of inertia, ω be the angular speed, B is viscous damping coefficient.

1.2. Working of four switch BLDC motor

It contains two capacitors instead of two switches and the phase c is out of control because it is connected to the midpoint of the series capacitor. The phase c voltage cannot hold at zero, it makes distortion in other phases. The same problem is inherited by the four–switch mode and it causes the produced voltage vectors to be limited and asymmetric, which were well known as asymmetric voltage vectors. The operation of four switch BLDC motor contains six modes of operation.

Table 1: Modes of operation

Modes	Hall values	Active phase	Silent phase	Switching device
Mode1	101	Phase C&B	Phase A	S_4
Mode2	100	Phase A&B	Phase C	S_1 & S_4
Mode3	110	Phase A&C	Phase B	S_1
Mode4	010	Phase B&C	Phase A	S_3
Mode5	011	Phase B&A	Phase C	S_2 & S_3
Mode6	001	Phase C&A	Phase B	S_2

1.3. Speed control of four switch BLDC motor

The required speed is controlled by a speed controller, conventionally the speed controller be a PI controller the required speed and the actual speed, the speed that take from the motor shaft, are the inputs of the controller, based on the difference of this the duty cycle of the PWM signal is changed, which corresponds to the voltage amplitude of required speed. This paper propose a new speed control by single neuron adaptive PI controller. Due to its merits such as simple structure, high efficiency, and easy implementation, the PI controller is widely use in most servo application such as actuation,robotics, machine tools and so on. However, the conventional PI controller is based on a linear model and suffer from parameter sensitivity and nonlinearity of the BLDC motor.

A single neuron model is proposed based on the fact that the output of the neuron is the weight sum of all the signals coming to it. The advantage of the single neuron model is its adaptation ability acquired by adjusting the weight coefficients. Based on the adaptation ability and self study of the single neuron adaptive PI controller has the advantages of simple structure, fast response and good adaptability. The block diagram of speed control of four switch BLDC motor is shown below.

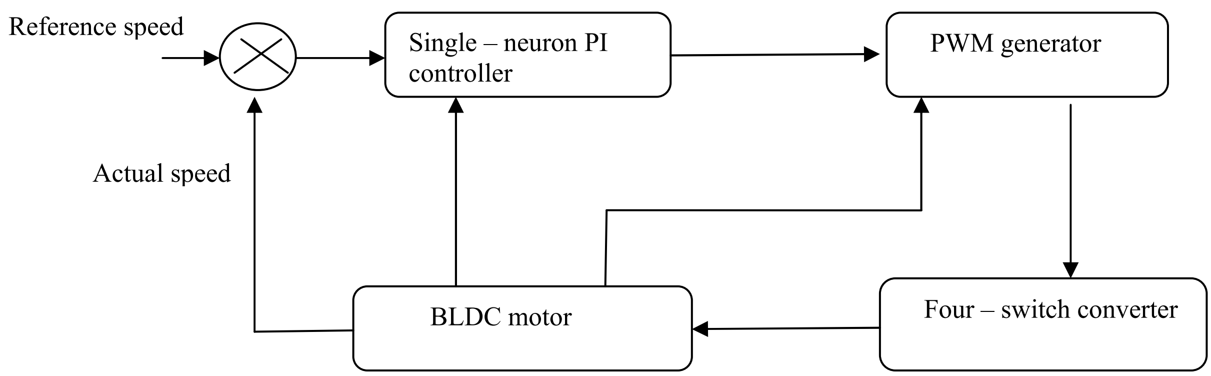

Fig. 2: Block diagram for entire speed control system

The steps of PI controller contains the speed error, updating the weights with K is the learning rate of a neuron. The weight coefficients are tuned by the weight function, thus by tuning the PI controller the speed of the four switch BLDC motor is controlled.

The error controller be

$e(t) = r^*(t)-r(t)$; $r(t)$ be actual speed at time t, and $r^*(t)$ be the reference speed at time t. Then the inputs of the neuron are

$x_1(t) = e(t)$

$x_2(t) = e(t)-e(t-1)$

The output of single-neuron PI controller is

$u(t) = u(t-1)+K\Sigma(x_i(t)w_i(t))/\Sigma|w_i(t)|$; i=1 to 2;

The weight co-efficies of a single neuron are tune by

$W_1(t) = w_1(t-1)+\eta_i e(t)u(t)x_1(t)$

$W_2(t) = w_2(t-1)+\eta_p e(t)u(t)x_2(t)$

Where η_p and η_i are the learning rates of proportion and integration controller respectively.

1.4. Simulation and results

The proposed strategy for the four switch three phase BLDC motor, a complete simulation system was built. The motor parameters be L=0.006H, R=12.5Ω, J=0.2156Kg.m^2, K_b=0.6V/rpm, P=16.

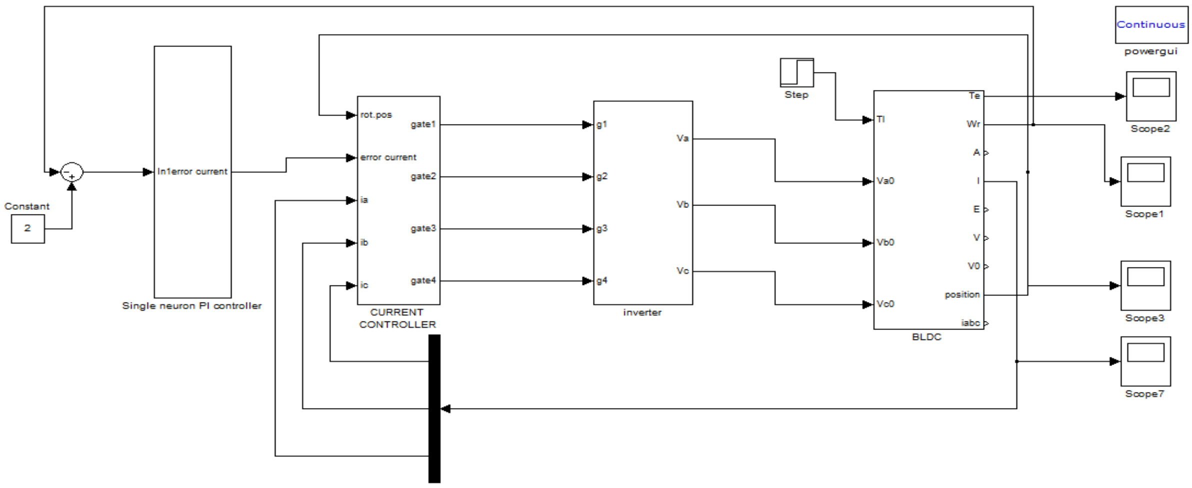

Fig. 3: Simulation diagram of entire system.

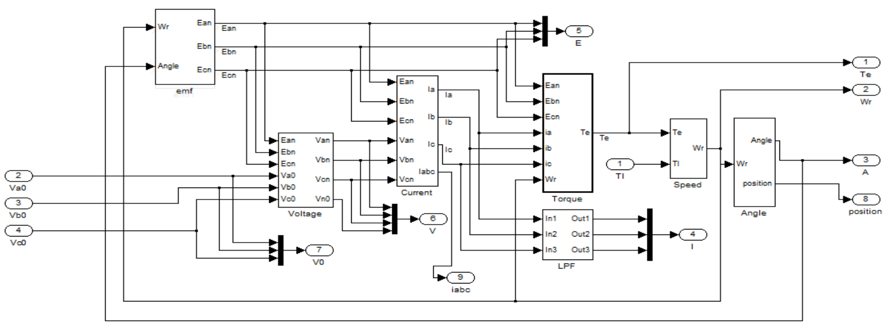

Fig 4: Matlab model of BLDC motor

In this work the drive model with PI controller is developed and simulated in order to validate the four switch three phase inverter control of BLDC motor model. The reference speed is 2 rps and the closed loop response of rotor position, speed, current and torque are shown below.

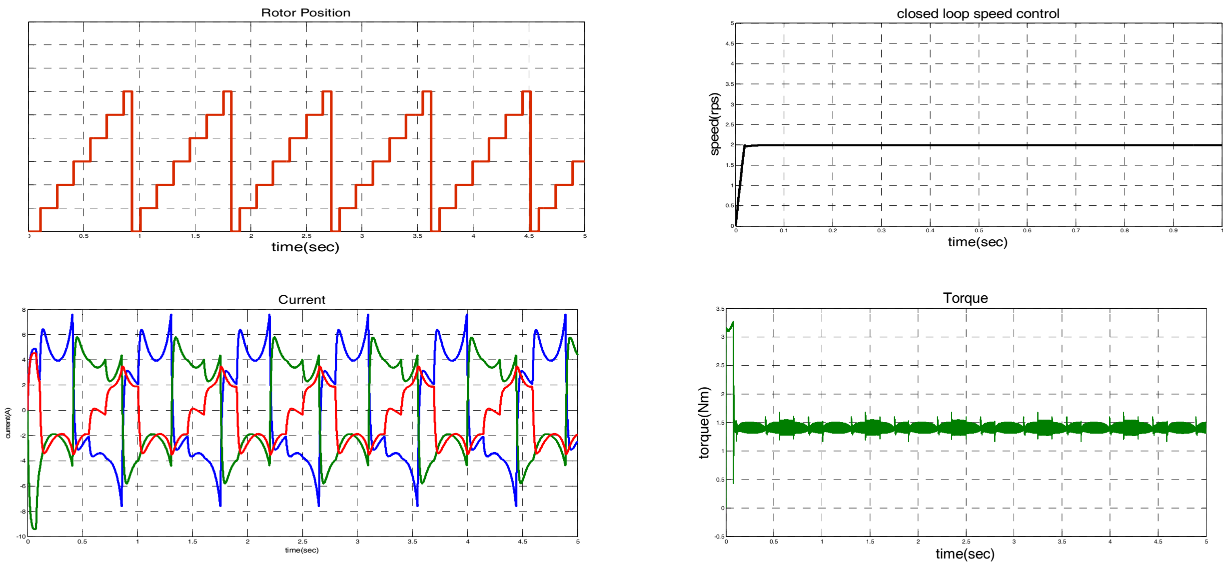

Fig 5: Output response of rotor position, speed, current and torque

1.5. Conclusion

The simulation model of the BLDC motor drive system with single neuron PI controller based speed control and four switch three phase inverter on MATLAB/Simulink platform is presented. The algorithm is easy to implement on the microcontroller, and the cost of whole system is lowered because of reduced number of switches and current sensors. The performance of the developed speed control of the permanent magnet brushless DC motor drive system work satisfactorily. Due to this, the paper put forward a possibility of low cost and high performance three phase BLDC motor drive system.

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