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Open Phase Fault Tolerant Control of BLDC Motors

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Abstract: This paper proposes a simple technique for open phase fault detection, and identification of BLDC motor. Also it explains a fault tolerant strategy which can be used to continue the normal operation of a BLDC motor in spite of the fault. As BLDC motors are used in critical control areas like military services, space vehicles a fault tolerant drive is essential to maintain the operation. In this paper the detection and identification of open phase fault is done using simple logical technique. This technique can be easily incorporated in an already existing normal closed loop speed control drive.

Keywords:BLDC motor drive, hysteresis controller, fault detection, fault tolerance.

I. INTRODUCTION

BLDC motors have become more popular now a days. BLDC motors are electronically commutated motors so that it has several advantages over ordinary brushed dc motor. These motors are normally reliable and more efficient. These motors have noiseless operation, good dynamic response, long life and they are less affected by adverse climatic conditions. Also their torque to size ratio is high which makes them applicable where space and weight are critical factors. They are mainly used in industries like automotive industries, aerospace, military & robotic applications and medical & consumer automation equipment's and instruments.

As these motors are mostly used in high risk areas like military services, robotics, aerospace, etc. continuous operation is required every time. So the occurrence of fault should not affect the normal working of motor. The detection and identification of fault and its remedy thus gain attention. In this paper the open phase fault detection and identification method using a simple logical technique is proposed. This method is cost effective and can be used in speed controlled BLDC motor. The remedial strategy includes the working of motor using a four level inverter.Several such detection techniques and the modeling of motor are proposed in [1-7]. Fault tolerant ripple free Model for BLDC motor based on Fourier coefficients are explained in [1]. Based operating characteristics the fault detection explained in [3]. Remedial strategies for BLDC faults are explained in [6]. Four switch inverter drives is explained in [7]. This paper detects the fault and identifies it and a remedial model which is working on two level inverter.

The fault tolerant model is simulated using MATLAB – Simulink software. The entire fault tolerant model is represented as a block diagram in fig.1

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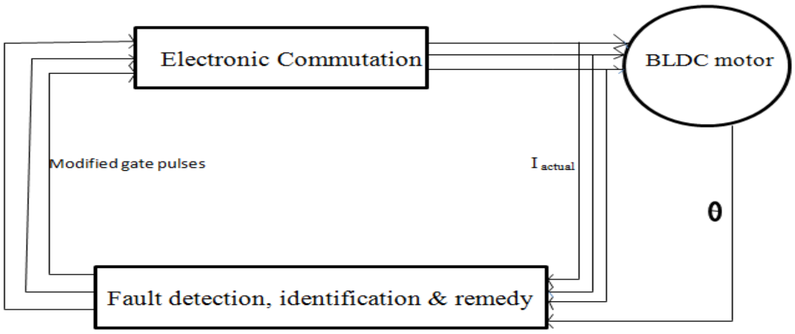

Fig.1 Block diagram of Fault tolerant BLDC motor

II. MODELLING OF SPEED CONTROLLED BLDC MOTOR.

A. *Modelling of BLDC motor*

The three phase star connected BLDC motor drives are governed by the following equations.

$V_a = i_a R_a + L(di_a/dt) + e_a$ (1)

$V_b = i_b R_b + L(di_b/dt) + e_b$ (2)

$V_c = i_c R_c + L(di_c/dt) + e_c$ (3)

Where e_a, e_b, e_c are back emf of motor which is the function of rotor position. Also the torque equations are given by

$T_e = T_a + T_b + T_c$ (4)

$T_e - T_l = J(d^2\theta_m/dt^2) + B(d\theta_m/dt)$ (5)

$\omega_m = (d\theta_m/dt)$ (6)

$\theta_e = (P/2)\theta_m$ (7)

The parameters used in this modeling are

Table 1. Motor parameters

Type of motor	3phase, 310V, star connected BLDC motor
Rated speed, N	4600 rpm
Rated current, I	4.52 A
No. of poles, P	4
Stator resistance, R	4.36 ohms
Stator inductance, L	0.0306 H
Torque constant, K_t	0.49 Nm/A
Back Emf constant, K_e	0.051 V/rad/sec
Polar moment of inertia, J	1.8e-4 Kg-m^2
Frictional Co-efficient, B	0.01 /rad/sec

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B. Modeling of normal speed controlled BLDC motor

From the rotor position the actual speed is compared with a set speed. The error is given to PI controller. The output of the controller is the torque reference. Current is calculated from the torque reference and it is compared with actual currents. By tuning the K_p and K_i values the error in the current is made to zero. Then a hysteresis current controller is used to generate gate pulses to the six step inverter.

$$i_{ref} = T_{ref} / K_t \qquad (8)$$

The Simulink model uses a PI controller and their tuning results in controlled performace.

C. Simulink Results

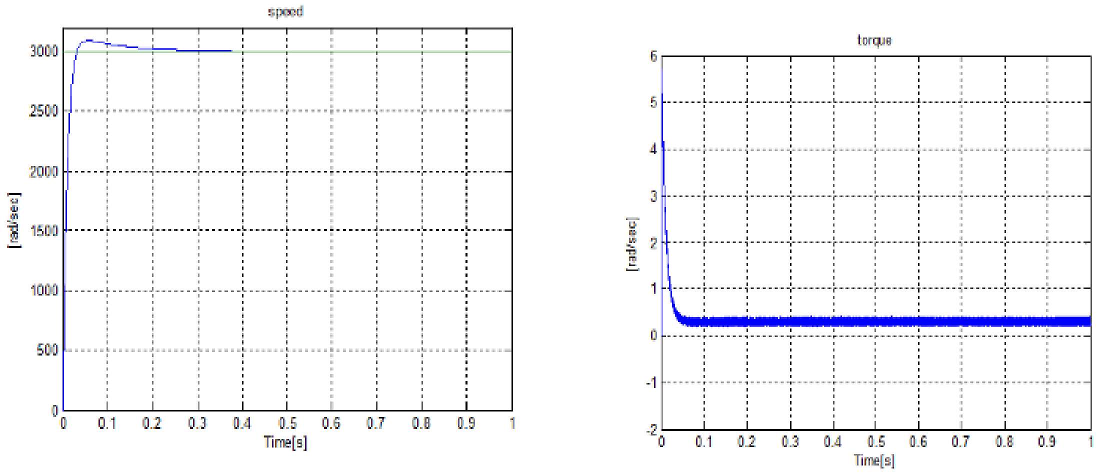

Fig.2 Speed and torque curves

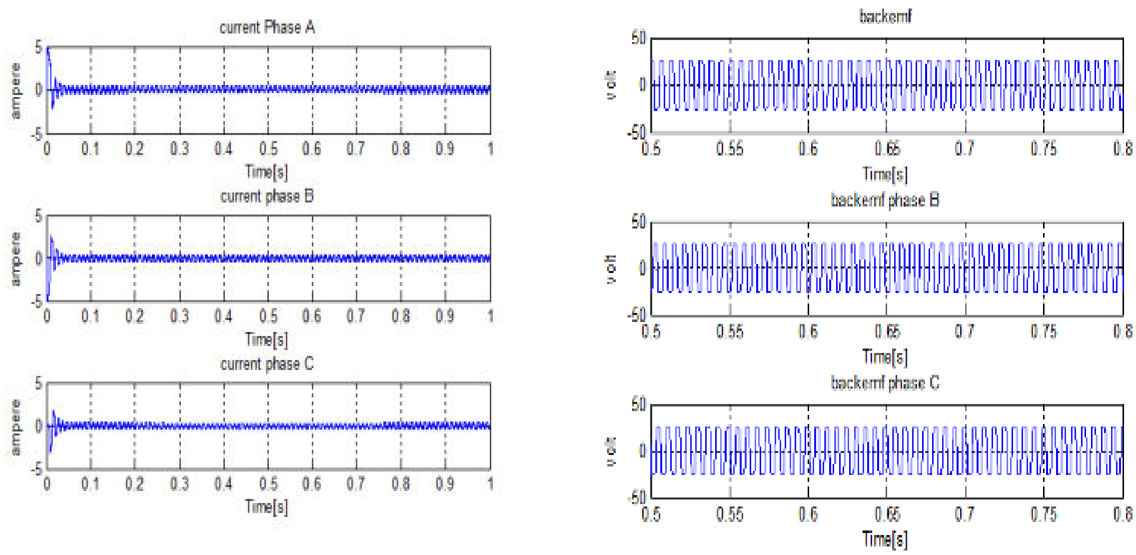

Fig.3 Current and Back Emf curves

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III. FAULT TOLERANT CONTROL OF BLDC MOTOR

A. *Fault Detection and Identification of BLDC motor*

The major faults commonly occurring in a BLDC motor are stator faults like open circuit and short circuit faults, air gap irregularities, dynamic eccentricity, broken end rings etc. In this paper only open phase fault is considered as it is 30-35% of all faults.

The fault is detected using a simple logical approach. The open phase fault is easily calculated by comparing the currents in each phase. For normal working the absolute values of three phase currents is around three times each phase value. But in single phase fault it reduces to double times or less than three times phase value. For fault detection a threshold value and a residual value of currents are calculated.The threshold value is a function of reference value and the residual value is the sum of absolute values of each phase current.

$$I_{threshold} = 2\times g_f \times i_{ref} \quad (9)$$

Under faulty condition the reference value is not strictly double times the reference value. So a constant g_f is introduced.

where g_f is a constant whose value can be varied between 0 and 0.5. Above that the system becomes more unstable.

$$I_{residual} = |i_a| + |i_b| + |i_c| \quad (10)$$

Using the above two equations a comparison is made to detect fault in system.

$$I_{residual} > I_{threshold} \text{--------- no fault} \quad (11)$$

$$I_{residual} < I_{threshold} \text{---------- fault} \quad (12)$$

This logic is implemented using MATLAB embedded function.

The current and voltage across the inverter switch is measured and displayed continuously. When fault is detected the current across open faulty switch become zero and voltage become dc link voltage. The faulty phase is thus identified and then connected to the midpoint of capacitor. Thus the faulty switch is identified and the remedy circuit gets activated.

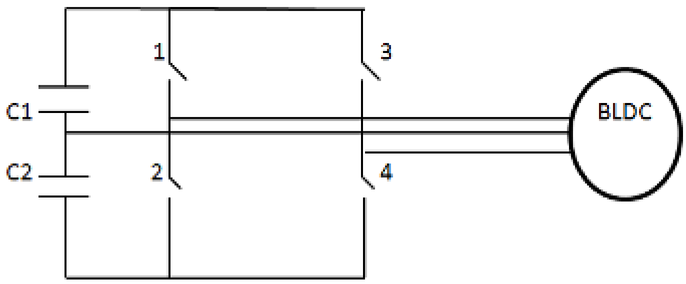

Fig.4 Four switch BLDC drive

B. *Fault tolerant model*

After the identification of faulty phase, modified gate pulses are given to other two phases for the normal working of drive.

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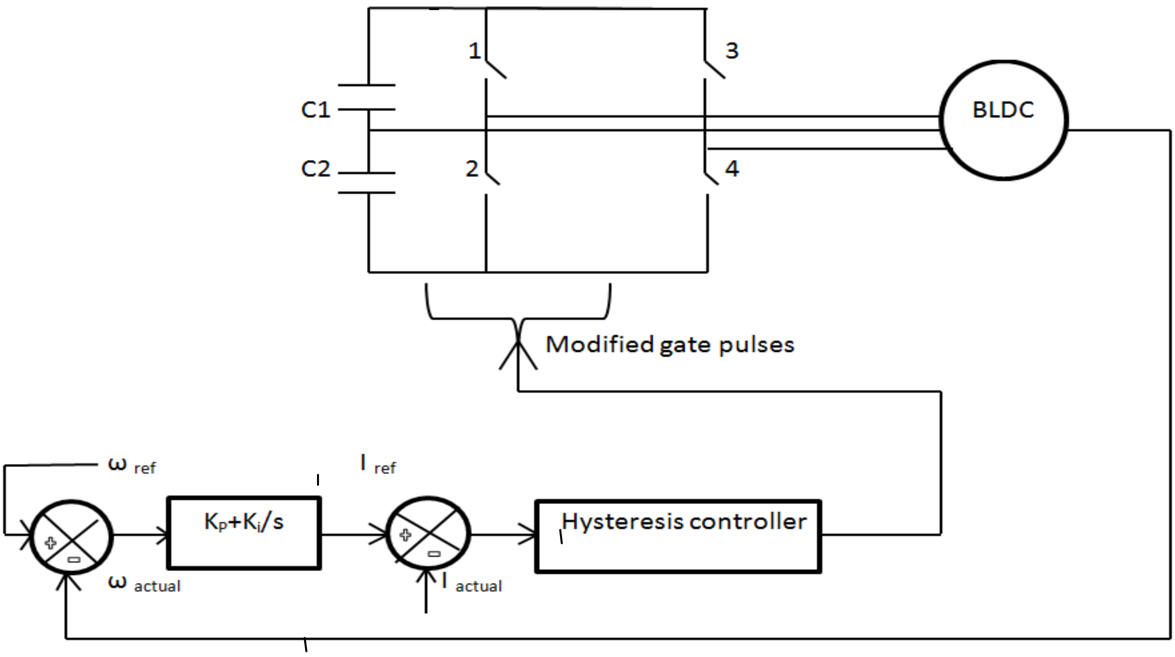

Fig.5 Detailed block diagram of Fault tolerant BLDC drive

C. *Simulink results*

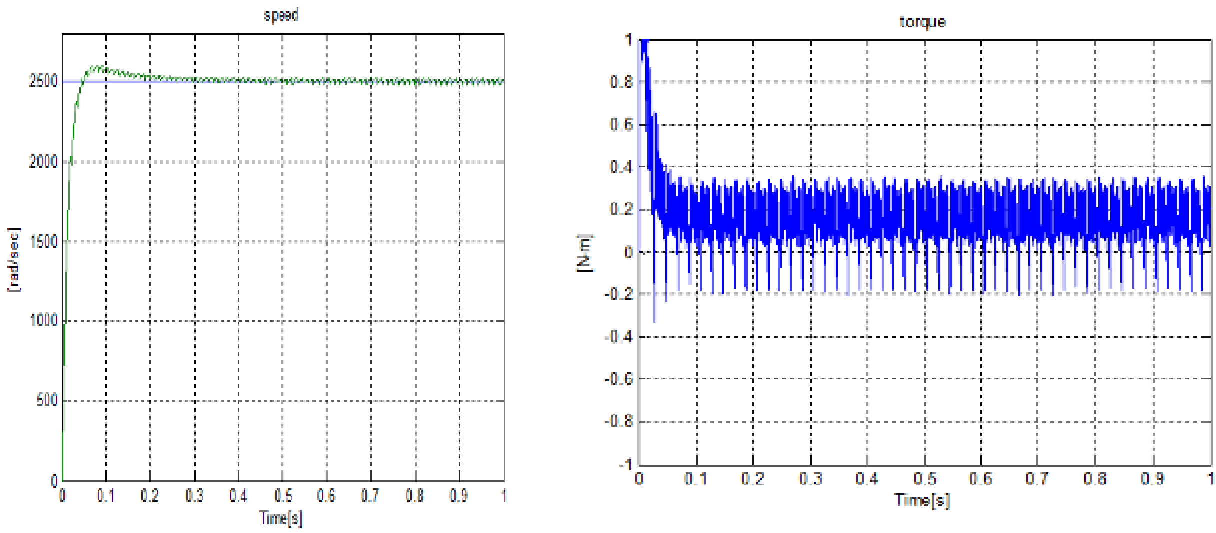

Fig.6 Fault tolerant Speed and Torque curves

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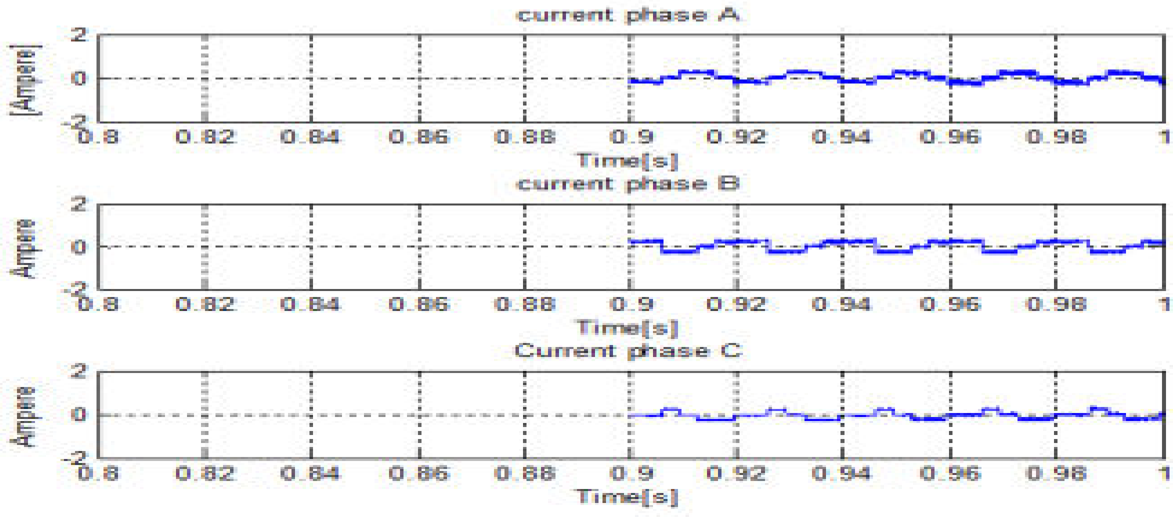

Fig.7 Fault tolerant Current curve

From the above simulation results although there is a ripple in the speed waveform it tracks the set value after 0.25sec.

The torque ripple also attain a steady value after 0.09 sec. Due the open phase the current waveform is disturbed slightlybut

it can effectively run the motor to continue the operation.

IV. CONCLUSION

A simple technique for fault detection and identification ofBLDC motors is proposed.The fault tolerant control model has simulated with effectively reduced torque ripple level. By adjusting the PI controller the peak overshoot of the system is reduced effectively.

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