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New Direct Torque Control Scheme for BLDC Motor Drives Suitable for Electric Vehicle Applications

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Abstract: This paper proposes a effective scheme for Direct Torque Control (DTC) of Brushless DC Motor. Unlike the traditional DTC where both the torque and flux must be employed in order to deliver the switching table for the inverter, the proposed DTC scheme utilizes the information of torque only. By considering particular operating principle of motor, the instantaneous torque can be estimated only by using back EMF ratio in a unified differential equation.

Keywords: Brushless DC Motor, Direct Torque Control, Electric Vehicle.

I. INTRODUCTION

Brushless DC Motor or trapezoidal PM Motor is one of the most suitable electric motor for EV drives because of the higher power per dimension ratio than that of the other motors. The common methods to control the BLDC motor include PWM current control and direct torque control. However, in order to thoroughly utilize the fast torque generation feature of BLDC motor to be applied to EV drives, the DTC is preferable.

The DTC strategy was first proposed by Takahashi and Depenbrock for induction motor (IM) drives in the 1980s. It is based on the circular characteristic of stator flux to estimate the instantaneous torque. Hence, the most proper voltage vector will be chosen from a lookup table to supply the inverter. Several years later, DTC began to be applied to other motor drive such sinusoidal permanent magnet synchronous motors (PMSM). The DTC has been also expanded to control BLDC motor (the trapezoidal PM motor).

II. LITERATURE SURVEY

Takahashi and T. Noguchi, "A new quick response and high efficiency control strategies of an induction motor", New quick-response and high-efficiency control of an induction motor, which is quite different from that of the field-oriented control is proposed.
The most obvious differences between the two are as follows. 1] The proposed scheme is based on limit cycle control of both flux and torque using optimum PWM output voltage; a switching table is employed for selecting the optimum inverter output voltage vectors so as to attain as fast a torque response, as low an inverter switching frequency, and as low harmonic losses as possible. 2] The efficiency optimization in the steady-state operation is also considered; it can be achieved by controlling the amplitude of the flux in accordance with the torque command. To verify the feasibility of this scheme, experimentation, simulation, and comparison with field-oriented control are carried out. The results prove the excellent characteristics for torque response and efficiency, which confirm the validity of this control scheme.
R. A. Gupta, R. Kumar, Borra Suresh Kumar, "Direct Torque Controlled Induction Motor Drive with Reduced Torque Ripple", Direct torque control (DTC) drive allows direct and independent control of flux linkage and electromagnetic torque by the selection of optimum inverter switching modes. But the possibility of generation of only six non-zero voltage vectors results in the production of ripples in the electromagnetic torque and stator flux linkages. In the present paper a new torque ripple reduction strategy applicable for direct torque control is presented. This methodology involves the production of zero vectors along with a non-zero vector during a switching interval determined by the torque and flux errors. As a result 12 combinations of non-zero voltage vectors and 2 zero voltage vectors are possible. The basic DTC and the new method are simulated and the results are compared for their performances. For the same sampling frequency the new method gives much better results.

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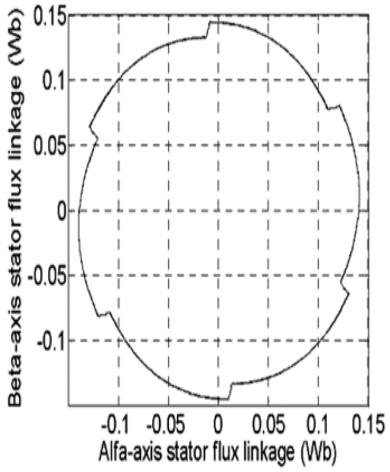

FIG: Stator flux linkage trajectory of BLDC

III. METHODOLOGY

A. WORKING

In BLDC motor however, because of two-phase conduction mode and quasi-square characteristics of currents, the locus of stator flux linkage does not keep in circular trajectory, but has sharp dips at every 60 degrees, of which the shape and size are unpredictable. This will make the estimation difficult and inaccurate. Hence, unlike the scheme proposed, the scheme presented in this paper does not control the magnitude of flux linkage but only uses the position of the flux linkage vector to determine which voltage vector is proper to supply the inverter. With three Hall sensors mounted inside the motor, the position of rotor flux linkage can be determined.

Table I show which sector the rotor flux linkage belongs to the corresponding state of Hall sensors.

TABLE I. DETERMINATION OF SECTOR NUMBER ORDERS

No. of Sector	1	2	3	4	5	6
Hall a	1	1	0	0	0	1
Hall b	0	1	1	1	0	0
Hall c	0	0	0	1	1	1

With these assumptions, the need of flux linkage can be eliminated, so we will use the below equation to calculate the instantaneous electromagnetic torque.

$$T = \frac{e_a i_a + e_b i_b + e_c i_c}{\omega}$$

Note that, for a given BLDC motor, the back EMF coefficient is Ke=E/ω, where E is effective EMF and it is quasi constant and merely depends on the construction of the motor.

A. HARDWARE DESIGN

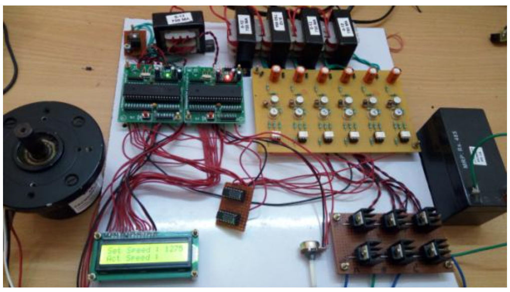

Fig -1: Hardware Design

BLDC MOTOR

- Voltage rating of 24 volts DC.
- Power rating of 60 watts
- Speed rating of 3000 rpm.
- 3 Phase 8 pole

Rectifier circuit

- Rectifier which is used is of half bridge rectifier.
- Which converts ac to dc.

Hall Sensors

- Voltage may range from 4v to 24v, Required current may range from 5 to 15milli amps.

Micro Controller

- The micro controller used is PIC16F877A.
- It is a 40 pin IC and 33 pins for input and output.
- It uses FLASH memory technology; the advantage of this technology is we can write-erase as many times as possible.
- An EEPROM is also a featured in it which makes it possible to store some of the information permanently.
- It consists of two 8 bit and one 16 bit timer.
- Capture and compare modules, serial ports, parallel ports and five input/output ports are also present in it.

Driver circuit

- It consists of both NPN and PNP transistors and optocouplers.

IV. WHY BLDC WHY NOT OTHER MOTORS?

- Electronic commutation based on hall position sensors.
- Longer life.
- High efficiency since no voltage drops across brushes.
- Higher speed range.
- Electric noise generation is low.
- Control is complex and expensive.
- No slip is experienced between stator and rotor frequencies.

V. ADVANTAGES

- Due to the reason that slot less core has low inductance it can run at very high speed. Fast response.
- Heat generated in stator is easy to remove.
- High torque.
- High reliability.
- Good high speed performance.
- Precise speed monitoring and regulation is possible.
- Noiseless operation, low maintenance.

VI. APPLICATIONS

- It is very suitable for Electrical vehicle drives which need fast and precise torque response.
- High end white goods (refrigerators, washing machines, dishwashers etc)….
- High end pumps, fans and other applications that require high reliability.
- This method is widely used for industrial automation equipment and instrumentation.
- Used for medical applications like artificial heart , microscopes surgical tools & organ transport pump system.
- In Compressor drives.

VI. RESULTS AND CONCLUSION

This paper presents a new scheme of direct torque control of BLDC motor drives. This scheme utilizes only the Torque information and it requires three Hall sensors which are mounted inside the motor to sense the position and angular speed of the motor. The estimation of instantaneous torque is based on the back EMF ratio. Simulation results have shown the effectiveness of proposed scheme in terms of low frequency ripple reduction, fast response and small peak. Therefore this scheme can be applied to electric vehicle drives where fast and precise torque response is required.

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