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Speed control of PMBLDC motor using DTC

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Abstract-The application of direct torque control (DTC) to brushless ac drives has been investigated extensively. This paper describes its application to brushless dc drives, and highlights the essential differences in its implementation, as regards torque estimation and the representation of the inverter voltage space vectors. Simulated and experimental results are presented, and it is shown that, compared with conventional current control, DTC results in reduced torque ripple and a faster dynamic response.

Keywords : Brushless dc (BLDC) drives, direct torque control (DTC), permanent-magnet motor.

I. NECESSITY OF PM BLDC MOTOR

Brushless dc motors are rapidly gaining popularity in the appliance, automotive, aerospace, consumer, medical and industrial automation industries. As a result of the absence of mechanical commutators and brushes and the permanent magnet rotor, brushless dc motors have many advantages over the brush dc and induction motor . Some of the advantages of brushless dc motors are:

1) High power density, low inertia and high torque to inertia ratio and high dynamic response due to the small size, low weight and high flux density neodymium-iron-boron permanent magnet rotor.
2) High efficiency due to the low rotor losses as a result of the absence of current carrying conductors on the rotor and reduced friction and windage losses in the rotor.
3) Long operating life and high reliability due to the absence of brushes and metallic commutators.
4) Clean operation due to the absence of brushes, resulting in no brush dust during operation and allowing for clean room applications.
5) Low audible noise operation due to the absence of brushes, commutators and smooth low air resistance rotor.
6) Low thermal resistance since most of the machine losses occur in the stationary stator, thereby allowing heat dissipation by the process of direct conduction. In addition, since the rotor losses are small, heat transfer to machine tools and work pieces when these motors are utilized in machine tools is minimal, thereby reducing the effects of heat on the machining operation.

The rotor position signal of BLDCM is usual provided by position sensor. But the existence of position sensor makes the configuration more complex, influences the reliance of motor operation and increases the cost of the motor. Nevertheless, in some specialized fields, it is not convenient to use position sensor, such as if there are high temperature, frozen and erosion materials, it defines the application of BLDCM. In this paper, the rotor position is detected via detecting the three phase terminal voltages. This kind of method don't use position sensor, reduced the system cost and the volume of the motor, especially improved the characteristics of the system.

Conventional DC motors are highly efficient and their characteristics make them suitable for use as servomotors [1]. However, their only drawback is that they need a commutator and brushes which are subject to wear and require maintenance. When the functions of commutator and brushes were implemented by solid- state switches, maintenance free motors were realized.

These motors are now known as brushless DC motors. The construction of modern brushless motors is very similar to the AC motor, known as the permanent magnet synchronous motor. The stator windings are similar to those in a poly- phase ac motor, and the rotor is composed of one or more permanent magnets. Brushless DC motors are different from ac synchronous motors in that the former incorporates some means to detect the rotor position (or magnetic poles) to produce signals to control the electronic switches as shown in Fig.1.1. The most common position/pole sensor is the Hall element, but some motors use optical sensors.

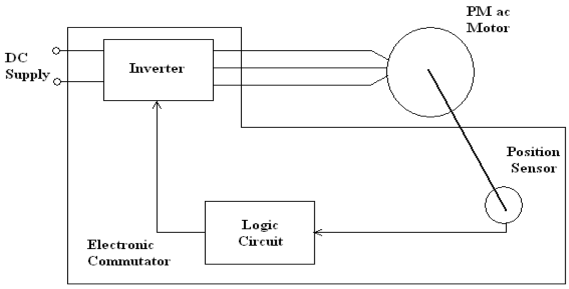

Figure1.1: Permanent Magnet Brushless DC motor

The brushless DC motor is essentially configured as a permanent magnet rotating part a set of current carrying conductors. In this respect, it is equivalent to an inverted DC commutator motor, in that the magnet rotates while the conductors r remain stationary. In both cases, the current must reverse polarity every time a magnet pole passes by, in order that the torque is unidirectional. In the DC commutator motor, the commutator and brushes perform the polarity reversal. Brushless DC motors usually come in fixed voltage types, such as 5V, 6V, 12V, 24V, 48V etc, with one of the most common ones in use the 12V type. When the rated voltage is applied to the motor it will rotate with maximum speed, but by changing this applied voltage the motor speed can be controlled. Naturally, the voltage is higher and then speed is higher and vice versa In the brushless DC motor, the polarity reversal is performed by power MOSFETS, which must be switched in synchronism with the rotor position The brushless DC motors are generally controlled using a three-phase inverter, requiring a rotor position sensor for starting and for providing the proper commutation sequence to control the inverter. These position sensors can be Hall sensors, resolvers, or absolute position sensors. Those sensors will increase the cost and the size of the motor, and a special mechanical arrangement needs to be made for mounting the sensors. These sensors, particularly Hall sensors, are e temperature sensitive, limiting the operation of the motor to below about 75 degree.

Each commutation sequence has one of the windings energized to positive power (current enters into the winding), the second winding is negative (current exits the winding) and the third is in a non-energized condition. Torque is produced because of the interaction between the magnetic field generated by the stator coils and the permanent magnets. Ideally, the peak torque occurs when these two fields are at 90° to each other and falls off as the fields move together. In order to keep the motor running, the magnetic field produced by the windings should shift position, as the rotor moves to catch up with the stator field.

II. SPEED CONTROL SCHEME

In general, neglecting the influence of mutual coupling between the direct and quadrature axes, the electromagnetic torque of a permanent-magnet brushless machine in the synchronously rotating – reference frame can be expressed as [7]

After a d–q transformation, a fundamental component of flux linkage is transformed into a dc component, while 5th and 7th harmonics transform into 6th harmonics, 11th and 13th harmonics transform into 12th harmonics, 17th and 19th harmonics transform into 18th harmonics, and so on. Torque pulsations are associated mainly with the flux harmonics, the influence of higher order harmonics in the stator winding inductance usually being negligible. Therefore, for machines equipped with a surface-mounted magnet rotor (i.e.,nonsalient), it can be assumed that and are constant.

A. DTC control circuit

Fig. 2.1 shows a schematic of a DTC BLDC drive, which is essentially the same as that for a DTC BLAC drive, except for the switching table and torque estimation. By sampling the stator phase currents and voltages and employing a stationary reference transformation, the stator flux linkage in the stationary reference frame can be obtained. The rotor flux linkage in the stationary reference frame can be calculated from (2.7), while the magnitude of the stator flux linkage and the electromagnetic torque can be obtained from (2.5). The speed feedback derived from rotor position sensors is compared to the speed command to form the torque command from the proportional–integral (PI) speed regulator. The stator flux-linkage and torque commands are obtained from hysteresis controllers by comparing the estimated electromagnetic torque and stator flux linkage with their demanded values. As can be seen from Table I, the switching pattern of the inverter can be determined according to the stator flux-linkage and torque status from the outputs of two regulators shown in Fig. 2.1, and the sector in which the stator flux linkage is located at that instant of time. In each sector, if the actual stator flux linkage is the same as the commanded stator flux linkage($\varphi=0$) , only one nonzero-voltage space vector and a zero-voltage vector are used to control the increase($\tau=1$) or decrease ($\tau=0$) of the torque.

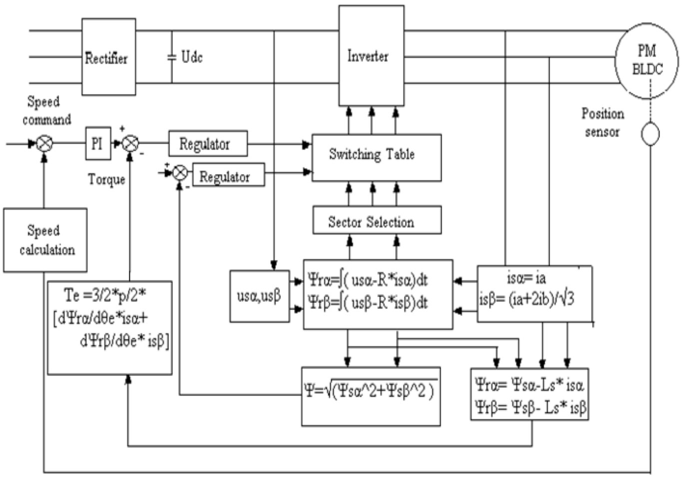

Fig. 2.1: Schematic of a DTC BLDC drive

Since during any 60 electrical period only two phases are excited and controlled in a BLDC drive as indicated in Table I.

In addition, when the actual flux linkage is smaller than the commanded value($\varphi=1$), the nonzero-voltage space vector is used to increase the flux linkage, while when the actual flux linkage is greater than the commanded value($\varphi=\ 1$), the nonzero-voltage space vector is used to decrease the stator flux linkage. In summary, the essential difference between the DTC of BLDC and BLAC drives is in the torque estimation and the representation of the inverter voltage space vectors. However, the control algorithms for the demanded torque, the stator flux linkage, and the output voltage vectors are similar in manner.

Torque τ	Flux φ	Sector					
		I	II	III	IV	V	VI
1	1	V1 (100001)	V2 (001001)	V3 (011000)	V4 (010010)	V5 (000110)	V6 (100100)
	0	V2 (001001)	V3 (011000)	V4 (010010)	V5 (000110)	V6 (100100)	V1 (100001)
	-1	V3 (011000)	V4 (010010)	V5 (000110)	V6 (100100)	V1 (100001)	V2 (001001)
0	1	V1 (100001)	V2 (001001)	V3 (011000)	V4 (010010)	V5 (000110)	V6 (100100)
	0	V0 (000000)	V0 (000000)	V0 (000000)	V0 (000000)	V0 (000000)	V0 (000000)
	1	V3 (011000)	V4 (010010)	V5 (000110)	V6 (100100)	V1 (100001)	V2 (001001)

Table I: Switching Table for DTC OF BLDC DRIVE

III. CONCLUSION

The applications of brushless DC (BLDC) motors and drives have grown significantly in recent years in the appliance industry and the automotive industry. DTC has been applied to a BLDC drive and its utility has been validated by simulations and measurements on two BLDC motors which have very different back-EMF waveforms. The main difference between the implementation of DTC to BLAC and BLDC drives is in the estimation of torque and the representation of the inverter voltage vectors. It has been shown that DTC is capable of instantaneous torque control and, thereby, of reducing torque pulsations.

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