A Novel Method to Minimize Torque Ripple, Mechanical Vibration, and Noise in a Direct Torque Controlled Permanent Magnet Synchronous Motor Drive

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The Direct Torque Control (DTC) technique of the Permanent Magnet Synchronous Motor (PMSM) receives increasing attention due to its simplicity and robust dynamic response compared with other control techniques. The classical switching table based DTC presents large flux, torque ripples, and more mechanical vibrations in the motor. Several studies have been reported in the literature on classical DTC. However, only limited studies exist that actually discuss or evaluate the classical DTC. This paper proposes a simple DTC method/switching table for PMSM, to reduce flux and torque ripples as well as mechanical vibrations and noise. In this paper, two DTC schemes are proposed. The six sector and twelve sector methodology is considered in DTC Scheme I and DTC Scheme II, respectively. In both DTC schemes, a simple modification is made in the classical DTC structure by eliminating the two-level inverter available in the classical DTC and replacing it with a three-level Neutral Point Clamped (NPC) inverter. To further improve the performance of the proposed DTC Scheme I, the available 27 voltage vectors are allowed to form different groups of voltage vectors such as Large-Zero (LZ), Medium-Zero (MZ), and Small-Zero (SZ), whereas in DTC Scheme II, all the voltage vectors are considered to form a switching table. Based on these groups, a new switching table is proposed. The proposed DTC schemes are comparatively investigated with the classical DTC and existing literatures from the aspects of theory analysis and computer simulations. It can be observed that the proposed techniques can significantly reduce the flux, torque ripples, mechanical vibrations, and noise and improve the quality of current waveform compared with traditional and existing methods.

1. INTRODUCTION

Around 40 years ago, in 1972, Blaschke proposed the concept of Field Oriented Control (FOC) for Induction Motor.[1] Since then, the FOC dominates in the advanced AC drive market, even though it has a complicated structure. Thirteen years later, a new control technique for the Torque Control of Induction Motor was proposed by Takahashi and Noguchi as Direct Torque Control (DTC).[2] Two years later, Depenbrock presented another one control technique named Direct Self Control (DSC).[3] The first follows circular trajectory, and later follows hexagon trajectory. Both of them proved that it is possible to obtain a good dynamic control of the torque without any sensor on the mechanical shaft. Thus, DTC and DSC can be considered a sensorless type control technique.

The DTC scheme is normally preferred for low and medium power applications, whereas the DSC scheme is preferred for high power applications. In this paper, attention is focused on the DTC scheme, which is best suited for low and medium power applications. DTC overcomes the drawbacks of FOC such as the requirement of current regulators, co-ordinate transformations, and PWM signal generators. DTC also provides high efficiency, high power/torque density, and high reliability. Due to its simplicity, DTC allows a good torque control in steady states and start-up transient states.

In recent years, DTC has been popular for a variety of electrical machines. In 1997, Zhong et al. proposed the concept of DTC for PMSM.[4] Some of the researchers proposed this technique for Synchronous Reluctance Machines.[5] On the other hand, the classical DTC has some disadvantages and major disadvantages are as follows:

1) Difficulty to control torque at very low speed;

2) High current/torque ripple;

3) More mechanical vibrations.

Most of the literature surveyed has analysed classical DTC using two-level inverters, and all have presented a high degree of torque ripple in the results under dynamic conditions; this will reflect in the speed and current too.[6–10] In this paper, the possibilities for minimization of torque ripple and mechanical vibration in DTC is focused. The minimization of torque ripple is achieved by improvements in the areas such as inverters and switching tables.

In this paper, the conventional two-level inverter is replaced by the three-level Neutral Point Clamped (NPC) inverter which will have 27 voltage vectors, where only 8 voltage vectors are