

A COMPARATIVE OVERVIEW TO DTC FOR PMSM DRIVEN PURE ELECTRIC VEHICLES

Fatih Korkmaz

Department of Electric-Electronic Engineering, Çankırı Karatekin University,
Uluyazı Kampüsü, Çankırı, Turkey

ABSTRACT

For many industrial applications that including electric motor, selecting of the appropriate motor type is keypoint for the application success and efficiency. This paper presents a comparative performance evaluation between direct torque controlled Brushless AC and Brushless DC motors which have been considered as traction motor on electric vehicles. Moreover, a short review to brushless AC and brushless DC motor technology and vector driver systems are also included. The main structure of the direct torque control method is presented and small-scale pure electric vehicle model is integrated to the motor control model. To make a fair comparison, the brushless AC and brushless DC motors modeled as having the same electrical parameters and simulated with same control model parameters. The simulation studies have shown that direct torque controlled brushless AC and brushless DC motors have similar performance as vehicle traction motor, and both motor types can be considered as a good candidate for electric vehicles applications.

KEYWORDS

PMSM motors, BLAC motor control, BLDC motor control, Electric vehicles, Direct Torque Control

1. INTRODUCTION

In 1950s, the availability of high energy density permanent magnets (PMs) and developments in power switching technologies led the development of PM motors[1]. Two typical classifications of permanent magnet synchronous motors (PMSMs) have been presented in literature by scholars according to shape of the induced emf (also known as back emf). One is called as brushless AC (BLAC) which has a sinusoidal-wave back-emf and the other is brushless DC (BLDC) motor which has a trapezoid-wave/square-wave back-emf. A BLDC motor can be defined as a electronic commutated self synchronous rotary motor, where the rotor contains permanent magnet with rotor position sensors. [2] But, it's obvious that same definition easily can be used for the BLAC motors. So far, there has not been a unified standard about the classification or definition of the BLDC motors or BLAC motors.

The main question that should be asked about the PMSMs is “Why are the PM motors happening more and more popular with every past day?” A PMSM incorporates starting characteristic of serious excitation DC motors and speed-torque characteristic of shunt excitation DC motor. Furthermore, the PMSMs have structural advantages of conventional brushless AC motors[2]. The PMSMs have great advantages like high efficiency, simple structure, high power densities, high starting torque, wide speed ranges, linear torque and speed characteristics, low maintenance and works in any condition. Due to absence of mechanical brushes and commutator, PMSMs can be acceptable as best choice for high performance drive applications[3]. Hence, it has been preferred motor type in many field such as robotics, vehicle propulsion, aerospace, industrial control, machine tools, etc.

This paper presents an overview to PMSMs and vector drive technologies. Moreover, a comparative performance investigation has been occurred between DTC controlled BLAC and BLDC motors which have been considered as traction motor on electric vehicles. The main structure of the DTC method is presented and small-scale pure electric vehicle model is integrated to the motor control model. The BLAC and the BLDC motors modeled with Simulink as having the same electrical parameters and simulated with same control model parameters to make a fair comparison.

2. BRUSHLESS SYNCHRONOUS MOTORS

The AC drive systems can be grouped under two major heading – induction drive systems and synchronous drive systems. Not far, about 3 decades ago, the induction drive systems almost monopolized the whole market, but with the advent of high magnetic permanent magnets, synchronous drive systems, include the PM brushless motors, are becoming popular. [4]

A BLDC motor is designed to be supplied with a trapezoidal shape current while a BLAC with sinusoidal as can be seen in Figure 1. [5]

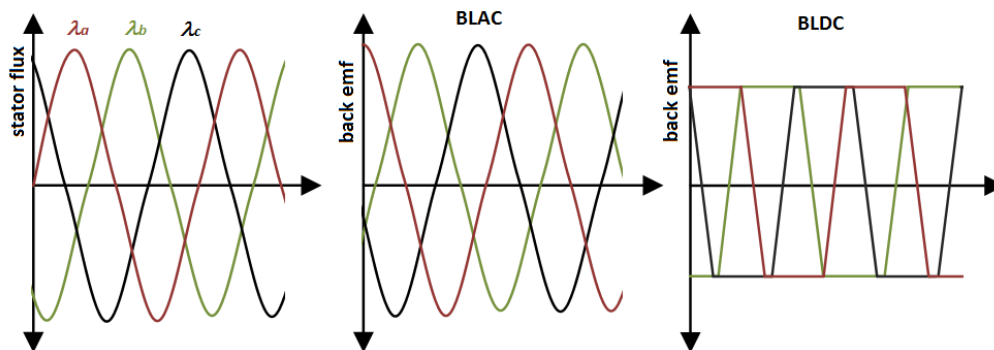


Figure 1. Back emf waveforms of BLAC and BLDC motors

The PM-BLAC motors fed by sinusoidal AC sources and produce an essentially constant torque, or so-called smooth torque. On the other hand, the PM-BLDC motors fed by rectangular or trapezoidal AC waves and have significant torque pulsations. However, due to interaction between a rectangular field and a rectangular current, the BLDC motors can produce higher torque than the BLAC motor [4].

Torque ripples issue is major problem for the many kind of systems, include EVs. The torque ripples causes torsional vibration and also acoustic noise. Due to vibration systems, mechanical parts of the system can be damage, even all system can be breakout [6]. For many years, reduction of the torque ripples in motor control systems have been major research subject and many kind of methods have been proposed by scholars and engineers to overcome this problem [7-9].

3. DIRECT TORQUE CONTROL

Direct torque control (DTC) is the name of reliable and energy efficiency vector control method. Although the DTC was originally proposed for asynchronous motors by Takahashi in 1986[10], over the years, it has been applied for various motor type such as linear motor, reluctance motor and also PM motors[11].

Another vector control method which has been preferred in high performance control of motors, is field oriented control (FOC). Almost half a century ago, the FOC method was also firstly proposed for asynchronous motors [12], but today, the FOC has been completely developed and it has been implemented for motor types such as PM motors. Conventional DTC method for AC motors with equations is given in Figure 2.

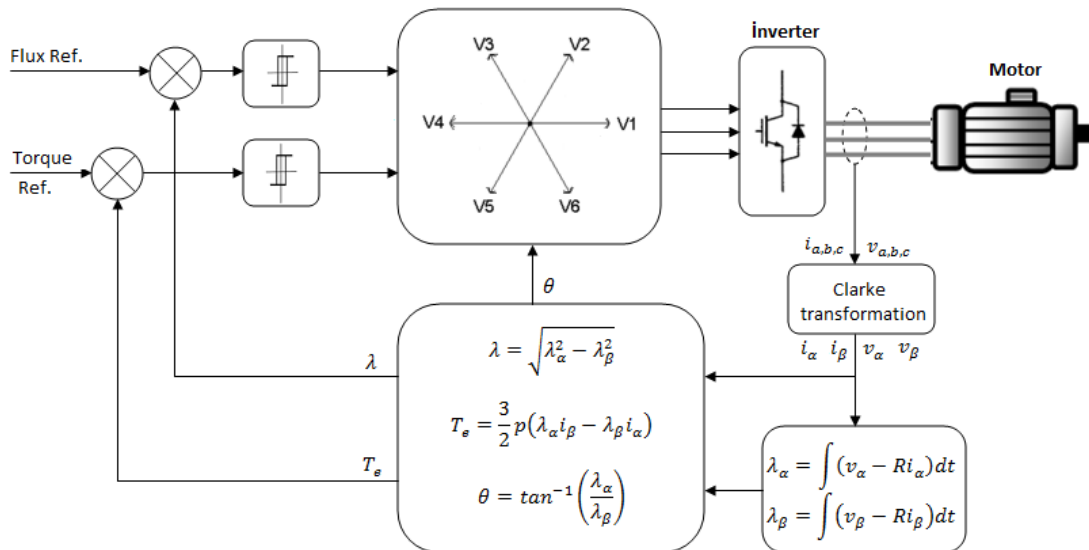


Figure 2. Conventional DTC motor scheme for AC motors

Over the last 40 years, many articles have been published about FOC and DTC of different motor types. However, few articles have focus on similarities or differences of between these methods. [13-15]

Some main structural advantages of the DTC can be listed as follow;

- Does not require current regulator
- Does not require PWM modulator

- Does not require rotor position measurement
- Does not require complex coordinate transformation
- Less parameter depended

To summarize, it can be pointed out that the DTC has simple structure when compared the FOC. On the other hand, the DTC method has some disadvantages and most important differences against to the FOC is high torque ripples[16].

In [13], the authors presented comparative analysis between two control methods for PMSMs. Advantages and disadvantages of the both methods were compared and discussed. Moreover, simulation based tests were performed for different working conditions. The authors claimed that the DTC had fast dynamic response while the FOC had better torque response and when selecting control method application requirements should be considered.

In another paper [17] the FOC and the DTC controlled PMSM was compared and discussed in detail. As a result, the authors claimed that there were no meaning differences in the main characteristics of the motor for both control method.

A comparisons between the FOC and the DTC controlled PMSMs had also been presented in [14] by numerical simulations. The paper supports almost same the claims with [13]. In other words, numerical simulations proved that the FOC was better on overall torque performance and the DTC had faster dynamic responses.

4. MOTORS AND CONTROLS ON EVS

Small-Scale Electric Vehicles (SSEV) are used in personal transportation for short distances. The SSEVs are powered by only battery packs and they only driven by electric motors-pure electric vehicle (PEV)- such as bicycles, scooters, skateboards, toy cars, rail cars, watercraft, forklifts, golf cars, and city cars, etc. The synchronous motors with PM-(BLAC/BLDC) are leading choice for vehicle propulsion in EVs due to advantages that mentioned earlier sections [18].

The DTC method is very useful and appropriate for EVs due to its great advantages such as; controlling torque directly, simple structure and easy applicable, low parameter sensitivity. [19]. To compare of the BLAC and BLDC traction motor performances on the DTC controlled system, Matlab/Simulink models of the controller has been created. Small-scale EV model has also included to model to obtain reference torque parameter for the DTC system. Figure 3 shows Small-scale EV Simulink model.

5. SIMULATIONS AND RESULTS

In simulations, BLAC and BLDC driven EV is accelerated to 0-2000 rpm motor speed, and the torque reference value is produced by EV model. Road angle is 0° for both motor. Matlab/Simulink block diagram of the DTC model for BLDC motor is given in Fig. 4.

The model and vehicle parameters which have been used in simulation as follows: Vehicle mass: 100kg, wheel radius: 0.4 m, Ratio of shaft: 1/10, BLAC/BLDC stator resistance: 0.4578 ohm,

BLAC inductances (d-q): 0.003173 H-0.003507 H, Bus voltage of inverter :300V, Flux reference:0.22 Wb, Flux Hysteresis band:±0.01, Torque hysteresis band: ±0.1.

The speed (in rad/s) and the torque responses of the motor are presented in Figure 5 – Figure 7.

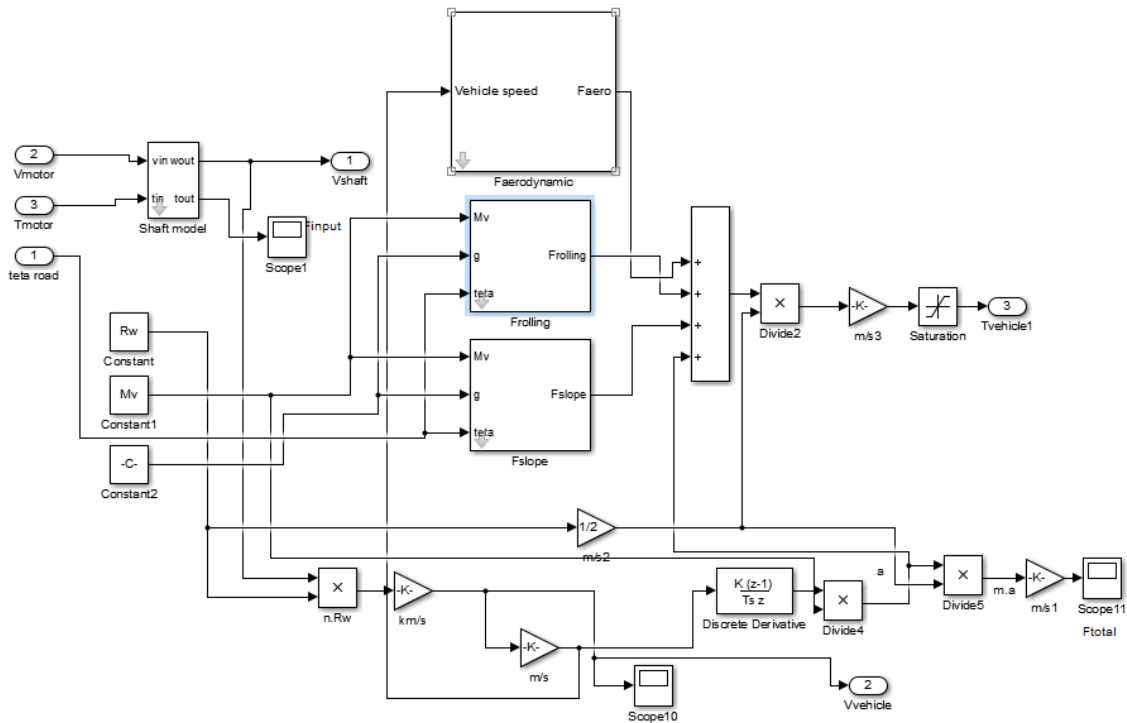


Figure 3. Small-scale EV Simulink model

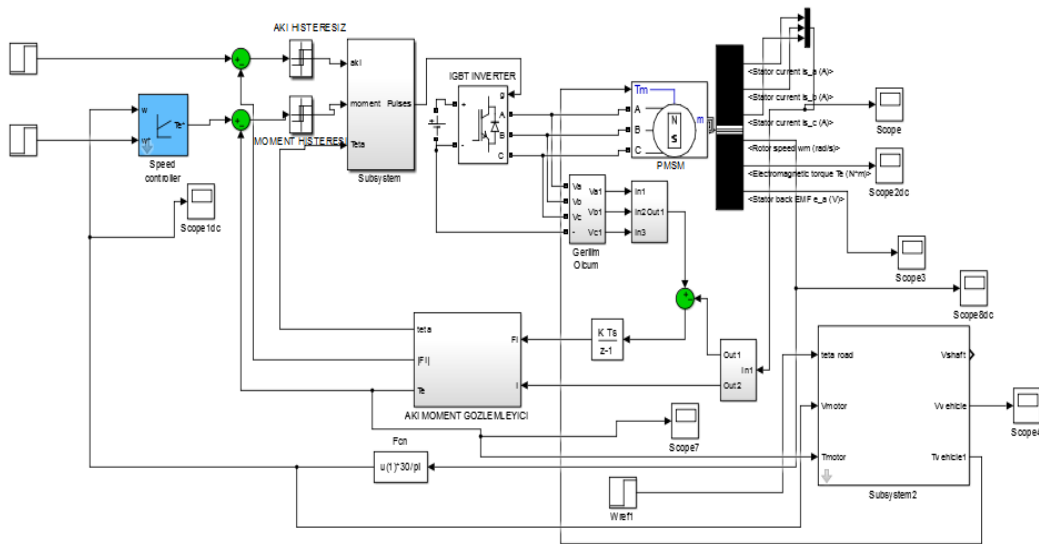


Figure 4. Matlab/Simulink block diagram of the DTC model for BLDC

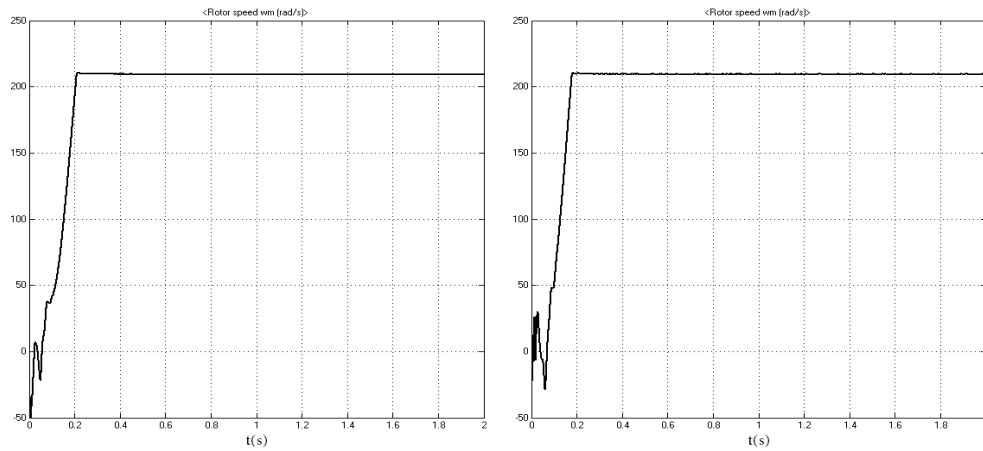


Figure 5. Overview of speed responses of BLAC (leftside) and BLDC (rightside) motors

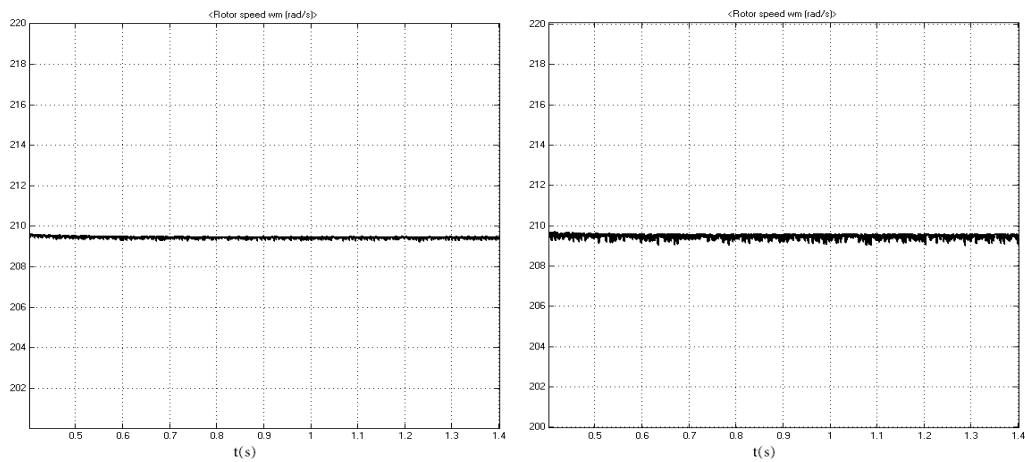


Figure 6. Zoomed view of speed responses of BLAC (leftside) and BLDC (rightside) motors

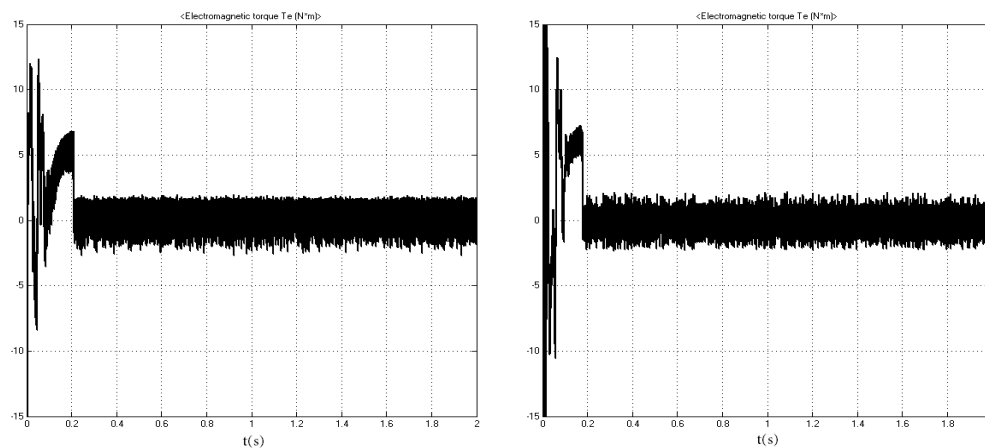


Figure 7. Overview of torque responses of BLAC (leftside) and BLDC (rightside) motors

When the speed and torque curves of the motor are compared, it can be clearly seen that motor performances are pretty close to each other for both motor types. However, the BLAC motor speed response is better than the BLDC motor due to less ripples (Figure 6.). The simulation studies proof that the DTC method is very appropriate for the BLAC and BLDC motors and vehicle designers/engineers can choice one of the two considering other physical or economical parameters.

6. CONCLUSIONS

Brushless synchronous motors are getting more and more popular every past day due to their well-known advantages like maintenance-free structures, height mass-power ratio, silent works, etc. BLAC and BLDC motors are indispensable motor types for electric vehicle traction systems. This paper aims to present a fair comparison between the BLAC and the BLDC motors for vehicle traction systems. For this purpose, direct torque controlled BLAC and BLDC motor modeled and simulated. The simulation studies show that both motors can be applicable for electric vehicle with DTC method. The speed and torque performances of the motors are almost same. So, it means, when brushless synchronous motor selection is necessary for electric vehicles or similar industrial system, some other physical or economical factors should be taken into consideration.

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AUTHORS

Fatih Korkmaz received the B.S., M.S., and Ph.D. degrees in electrical education from Gazi University, Ankara, Turkey, in 2000, 2004 and 2011, respectively. His current major research interests include design, control and applications of motor drive systems. From 2013, he is an assistant professor in Çankırı Karatekin University, Turkey

