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Torque control of three phase PMSM motor by Direct Torque Control technique and Torque ripple cancellation

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ABSTRACT – This paper torque control of three-phase PMSM motor direct torque control technique and torque ripple cancellation. This thesis presents the study and the design analysis of a permanent magnet synchronous motor (PMSM) for the traction application of an electric vehicle. An existing induction traction motor for an electric forklift benchmarks the expected performances of the proposed PMSM design. Further, the possibility of using the identical stator as the one used in the induction motor is explored for the fast prototyping.

Key Words: Direct torque control, PMSM, DC voltage control.

I. INTRODUCTION

In the modern world, the industrial manufacturing centers require different kinds of variable torque and speed drives to run the conveyor belts, arms of the robot, and overhead cranes of paper manufacturing industries, steel industries, fiber, and plastic processing industries. For such applications mentioned above, the industries used Direct Current (DC) and Alternating Current (AC) motors drives. The paper presents constituents of the mathematical model developed for PMSM motors with the most popular diagram of the PMSM field-oriented control based on the dq-axis operations. The practical implementation of the electronic commutator is presented. Experiments were carried out to plot the characteristic curves for the motor torque and efficiency as functions of its rpm. With the recent inventions and advancements in high flux density and high performance, permanent magnets like neodymium the boron iron, and samarium cobalt Permanent Magnet Synchronous Motor (PMSM) came into existence. The control complexities of PMSM have been overcome by the continuous advancement of power electronics and microelectronics. Today, PMSM has gained popularity and replaced the conventional DC brush and induction motors. Also, PMSM are now becoming more and more attractive for industrial applications.

One of the most popular control methods of three-phase motor drive systems, which developed during the last decade, is Field Oriented Control (FOC), usually realized with a digital PWM controller in rotating, d-q (or dq0 for unbalanced systems) coordinate space. Field-oriented vector-controlled PMSM drive affords improved dynamic response and minimum torque ripples and requires a constant switching frequency for working. To minimize the torque ripples, many methods are proposed in the literature. The methods can be classified into two types, one based on proper motor design and the other based on active control schemes. There are instances where proper motor design is not sufficient to achieve the required level of torque ripple reduction. For such instances, an active torque control scheme plays a vital role in minimizing the torque ripples. The major challenge is to develop a new active torque control scheme to minimize the torque ripples to suit the application requirements.

This paper is organized as follows: Section I presents the overall structure and related work Section II discusses the design specification of the proposed system and architecture of the system. Section III implementation of the proposed system and simulation results.

1.1. Related Work

Hao Zhu et al (2012) proposed a control scheme for minimizing the non-sinusoidal flux density distribution in the PMSM motor drives. The DTC scheme of permanent-magnet synchronous motors receives growing attention due to its merits in reducing the current controllers and quicker dynamic response output than the other motor control algorithm schemes. This means that large stator voltage and current harmonic contents exist in the PM motors. Since the variation of motor electromagnetic torque is related to the voltages that are applied to the motor by analyzing the relationships between the stator flux, torque, and voltages such a scheme is proposed. A torque dynamic equation is developed for the analysis of torque real time behavior. The prediction scheme uses incremental changes in the stator flux and the stator current, together with voltage vectors to achieve accurate torque control. Instead of using the increment of stator flux magnitude that might introduce deviation to the calculation, the voltage vector is directly handled in the prediction of voltage control angle. The control voltage is accurately oriented according to the rotor flux vector. This scheme simplifies the calculation and improves the accuracy of the calculation. Combined with flux control criteria that follow the principle of DTC, the voltage vector control angle is carefully selected to deliver high control performance of both the torque and the stator flux.

To minimize the torque ripples, many methods based on proper motor design and active control schemes, have been proposed by Jahns and Soong (1996) and Panda et al (2008). Even though the proper motor design is most effective in minimizing torque ripples, there are instances where it is insufficient to achieve the required level of torque ripple reduction.

Petrovic et al (2000) propose a new feedback structure for torque ripple minimization in PMSM drive. The structure has an improved and newly adopted feedback model with slight variation from the conventional model. The main advantages of the model are that it has been found compatible and suitable for control applications. All the parameters of the model structure have physical interpretation and can be measured directly by using a numerical reliable technique. Also, it has been found that a speed tracking unit is installed to reduce the torque ripples. The main issues that introduce an upper-speed limit were found to be the sampling of the controller inputs and holding of the outputs. The lower speed limit mainly occurs due to increased delay in speed measurement. Several approaches for extending these limits are also discussed in the paper. The results show that there is a significant reduction of 6th (by 27 dB) and 12th (by 4 dB) torque harmonics in the output response.

PM Synchronous Motor Drive demo circuit in The Math- Works Incorporation (2011), used the AC6 block of Simplot- systems library. It modeled a permanent magnet synchronous motor drive with a braking chopper. The PM synchronous motor was fed by a PWM voltage source inverter, which was built using a Universal Bridge Block. The speed control loop used a PI regulator to produce the flux and torque references for the vector control block. The vector control block computed the three reference motor line currents corresponding to the flux and torque references and then fed the motor with these currents using a three-phase current regulator. Motor current, speed, and torque signals were available at the output of the block.

II. DESIGN SPECIFICATION OF THE PROPOSED CONVERTER

In this paper, we have to implement a system to control the torque of an electric vehicle using a PMSM motor. The speed of the vehicle depends on the weight and road structure. PMSM will control the torque by adjusting the rotor current and rotor speed. By adjusting the speed gate pulse are used that will be generated by the Direct Torque Controlling method. DC voltage controller is used for steady DC supply. The block diagram of the proposed system is shown in figure1.

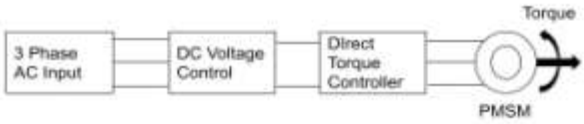

Fig -1: Block Diagram of Proposed Converter

2.1. DC Voltage control

In a power system, the voltage at various buses tends to increase or decrease during its daily operation. To ensure the constant voltage to consumers, various techniques are utilized. When the voltage is below the required level, reactive power produced by inductance needs to be offset by capacitance. When the voltage is above the required level, reactive power produced by capacitance needs to be offset by inductance. Voltage control in an electrical power system is important for the proper operation of electrical power equipment to prevent damage such as overheating of generators and motors, to reduce transmission losses and to maintain the ability of the system to withstand and prevent voltage collapse. We always practice reducing reactive power to improve system efficiency. These are acceptable at some level, if the system is purely resistivity or capacitance it makes cause some problem in the Electrical system. Reactive power has a profound effect on the security of power systems because it affects voltages throughout the system. Voltages can be maintained constant by using compensation techniques. The voltage fluctuations between the sending end and receiving end voltages can be maintained by controlling the reactive power in the system.

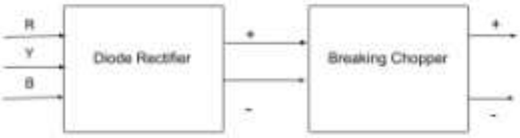

Fig -2: DC Voltage Controller

1). Diode Rectifier:

AC power is available at a low cost. DC power is more expensive to produce; therefore a method of changing ac to dc is needed as an inexpensive dc source. AC power can be converted to DC power using rectifiers when ac power is converted to dc power using rectifiers, dc output contains unwanted alternating current components known as ripple. Many rectifier applications need that the ripple do not exceed a specified value. If the ripple exceeds the specified value, different unwanted effects appear in the system. Some of the unwanted effects are stray heating and audible noise. The ripple can be reduced using an output filter non-linear loads such as controlled and uncontrolled, single phase and three phase rectifiers injects a considerable amount of lower order harmonics into the grid and distorts the voltage at the point of common coupling [1], [2]. Harmonics cause excessive heating, pulsating, and reduced torque in motors and generators increased heating and voltage stresses in the capacitor, malfunction of switch gears and relays and reduces the life of products [3], [4]. It is, therefore, necessary to reduce harmonics in electric power systems. Also in the case of dc loads, it is important to get a low ripple in output dc voltage for its proper functioning [5]. So it is necessary to provide dc output at low ripple keeping the harmonics injected in the line to a reasonable low-value Passive Front End (PFE) rectifiers followed by Power Factor Correction (PFC) stage, and Active Front End (AFE) rectifiers maintain dc bus voltage at desired level and harmonics injected, at switching frequency, can be filtered out using first order filters [6], [7], [8]. Using the above-mentioned topologies, for low power applications such as LED lighting, increases the cost as it requires active switches such as MOSFET or IGBT and additional sensors, for controlling dc bus voltage and input current.

2). Breaking Chopper:

A chopper is a static power electronic device that converts fixed dc input voltage to a variable dc output voltage. A Chopper may be considered as dc equivalent of an AC transformer since they behave identically. As chopper involves one stage conversion, these are more efficient. Choppers are now being used all over the world for rapid transit systems. These are also used in trolley cars, marine hoist, forklift trucks and mine haulers. The future electric automobiles are likely to use choppers for their speed control and braking. Chopper systems offer smooth control, high efficiency, faster response, and regeneration facility. The power semiconductor devices used for a chopper circuit can be force commutated thyristor, power BJT, MOSFET, and IGBT.GTO-based chopper is also used. These devices are generally represented by a switch. When the switch is off, no current can flow. The power semiconductor devices have on the state voltage drop of 0.5V to 2.5V across them. For the sake of simplicity, this voltage drop across these devices is generally neglected. Like a transformer, a chopper can be used to step down or step up the fixed dc input voltage.

2.2. Direct Torque Control

The DTC is one of the high performance control strategies for the control of AC machine. In a DTC drive applications, flux linkage and electromagnetic torque are controlled directly and independently by the selection of optimum inverter switching modes of operation. To acquire a faster torque output, low inverter switching frequency and low harmonic losses in the model, the selection is made to restrict the flux linkages and electromagnetic torque errors within the respective flux and torque hysteresis bands. The required optimal switching vectors can be selected by using the 31 optimum switching voltage vector look-up table. This can be obtained by simple physical considerations involving the position of the stator-flux linkage space vector, the available switching vectors, and the required torque flux linkage.

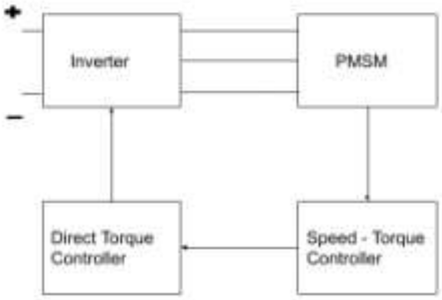

Fig -3: Direct Torque Controller

2.2. PMSM Drive

Permanent Magnet Synchronous Motor (PMSM) drive is a field of intense academic and commercial interest for the past three-decades. PMSM-drive is extensively applied in low as well as in mid-power applications. This drive is specially used in robotics, computer peripheral equipment, adjustable speed drives and electric vehicle applications. Reasons are: ease of maintenance, simple structure and its high efficiency [1-3]. The nonlinear behavior, resulting largely from load-characteristics, motor-dynamics and the uncertainties present in it make their control an exceptionally tough job. Therefore, the approach of speed-control should be robust and adaptive for effective industrial-applications.

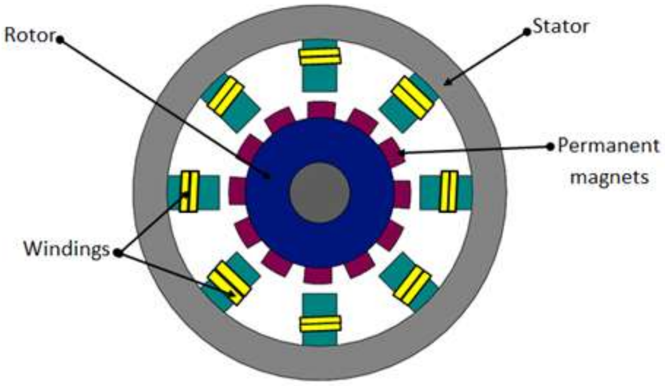

Fig -4: PMSM Motor

Generally, two methods of speed control are employed to achieve the torque control and in turn speed control. In the first method, the PMSM drive makes use of the concept of inherent decoupling quality similar to that of DC motor drive. T The speed control schemes commonly used in PMSM drive can be broadly categorized in to scalar control, Vector Control (VC) or Field Oriented Control (FOC) and Direct Torque Control (DTC). The recent advancements in the speed control schemes have superseded the conventional scalar control method. The scalar control is simple to implement but does not take into consideration the decoupling effect in the motor resulting in an inferior performance, poor transient response and nonlinear control behavior. It considers magnitude part only, whereas, FOC considers both angle and magnitude. The VC and DTC control schemes produce fast dynamic response. They are simple and provide linear speed control of PMSM drive. The problems associated with the DTC control scheme are difficulty in torque control and increased noise level at negligible or near zero speed, high ripples in torque and currents and inconstant switching-frequency.

The speed control schemes commonly used in PMSM drives are broadly categorized into scalar control, Direct Torque Control (DTC) and Vector Control (VC) or Field Oriented Control (FOC). The recent advancements in the controlling schemes of speed have superseded the conventional scalar control method. The scalar control is simple to implement but does not take into consideration the decoupling effect in the motor resulting in inferior performance, poor transient response

III. RESULT AND DISCUSSION

Based on the MATLAB simulation controlling the torque of the vehicle using PMSM motor. Figure 5 shows the electromagnetic torque generated based on the rotor current and rotor speed of PMSM. The PMSM will adjust the torque-based DTC technique, the gate pulse generated by the DTC controller is shown in figure 6. The DC voltage controller will control the DC power supply that will show in figure 7. The final output of controlling torque is shown in figure 8.

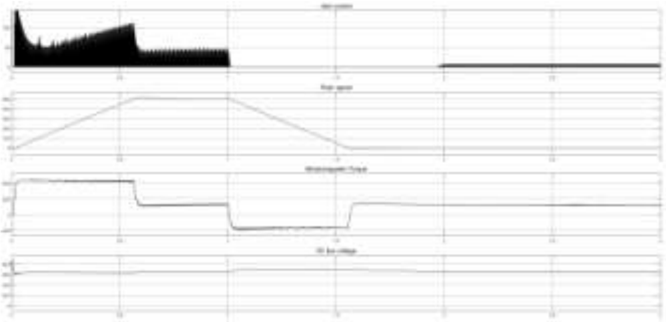

Fig -5: PMSM Output

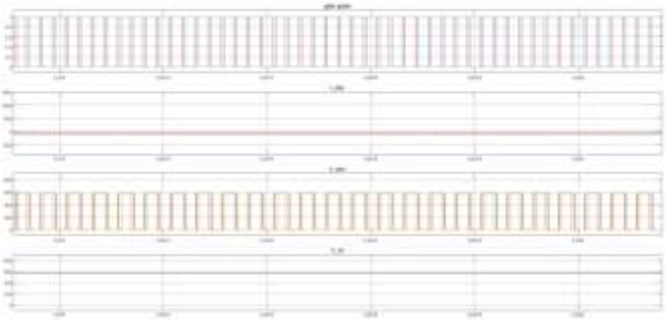

Fig -6: Gate Pulse Generated from DTC

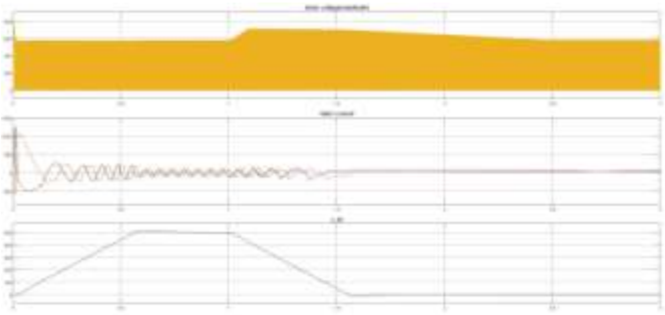

Fig -7: DC Link Voltage Controller Output

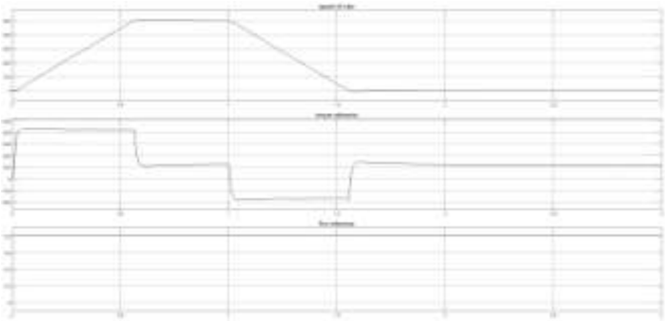

Fig -8: Final Result

IV. SUMMARY

This paper gives an overview of implementation for Direct Torque Controlling of an electric vehicle using a PMSM motor. The digitally implemented DTC leads to an accurate dynamic performance of the electromagnetic torque of the PMSM with the benefit of easy digital implementation and excellent control speed. The use of a DC voltage controller will produce a constant DC supply. For the road structure, the torque controlling is difficult by the use DTC technique gate pulse is generated that will use to control the rotor speed of PMSM. The evaluated PMSM-drive offers a real alternative for EV applications.

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