EEEE3001

Final Year Individual Project Dissertation

Diode Clamped Inverter for Vehicle AC Machine Drive

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DATE: 9 May 2024

This third year project Dissertation is submitted in part fulfilment of the requirements of the degree of Bachelor of Engineering.

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**Abstract**

**Chapter 1: Introduction**

* 1. **Background and Summary of Literature Review**
     1. **Introduction to PMSM**

Permanent Magnet Synchronous Machines (PMSMs) are a class of electric motors that utilize permanent magnets embedded in the surface of the motor's rotor. This design is fundamental in creating a magnetic field that synchronizes with the rotating magnetic field of the stator. Efficiency is one of the distinguishing characteristics of PMSMs; the permanent magnets provide a steady magnetic field without the stator current, which is normally needed in other kinds of motors to maintain the field via the rotor windings.

The PMSM stands out for its high-power density, which is the amount of power generated per unit volume of the motor. This feature is particularly beneficial in the applications where space and weight are constrained, such as in automotive or aerospace industries. Another advantage of PMSMs is their high operational efficiency throughout a wide range of speeds and loads. This adaptability is complemented by their remarkable torque-to-weight ratio, which allows them to produce more torque per unit of motor weight than many other motor types. Moreover, PMSMs are also noted for their quiet operation and low maintenance requirements due to the lack of brushes and slide rings, which are prone to wear and strain.

The PMSM's torque generation capability is a direct consequence of the electromagnetic interaction between the stator's rotating magnetic field and the rotor's permanent magnets. This interaction produces torque that is precisely controllable, which is why PMSMs are ideal candidates for variable speed and position control applications.

* + 1. **Introduction to Diode Clamped Inverter**

The diode clamped inverters, also known as Neutral Point Clamped (NPC) inverters, can convert direct current (DC) to alternating current (AC) in a variety of applications. They are characterized by their multilevel output, which can generate voltage waveforms with steps at several voltage levels, not just the two levels produced by traditional two-level inverters. This ability to approximate sinusoidal waveforms more closely results in lower total harmonic distortion (THD). Due to their superior waveform quality, these types of inverters are commonly used as the drives for high frequency motors [1]. This intrinsic feature enables it to generate high-frequency AC voltages for the PMSM with significantly less harmonic distortion, and thus, the pulsations caused by these harmonics is significantly reduced.

In the three-phase diode clamped inverter topology, each phase leg includes several power semiconductor switches (could be MOSFET or IGBT) and clamping diodes. The clamping diodes are critical components that allow the inverter to maintain the voltage balance of the DC-link capacitors during operation, thereby ensuring the generation of the desired multi-level AC waveform. In this project, a three-phase three-level diode clamped inverter is used as the drive of PMSM motor, the topology is shown in the **Figure 1.1** below. Three-level means each phase of the inverter can generate three different levels of voltage, which are , 0V, and .

图示, 示意图

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**Figure 1.1** Topology of Three-Phase Three-Level Diode Clamped Inverter

* + 1. **Field-Oriented Control (FOC)**

Field-Oriented Control (FOC), also known as vector control, is an advanced method of motor control that treats the electric motor as a controllable entity in two orthogonal components [2, 3]. This control technique allows for separate control of the magnetic flux and torque in AC machines (such as PMSM), by aligning the reference frame of the control system with the vector space of the motor’s magnetic field. Essentially, FOC decouples the PMSM's torque and magnetic flux into two independent variables that can be controlled as if the motor were a direct current (DC) motor.

* + 1. **Review of Existing Technologies and Developments**

Inverter technology has advanced significantly, especially in the area of electric vehicle (EV) propulsion. Innovations in semiconductor materials, such as Silicon Carbide (SiC) and Gallium Nitride (GaN), have been critical in spawning a new generation of inverters. These new inverters offer increased power densities and efficiency, as well as the extraordinary ability to perform optimally at high frequencies and temperatures. The consequence is a significant reduction in the physical bulk and weight of inverter systems, as well as an increase in their dependability and operational lifespan.

Meanwhile, for control algorithm, there is also a technique called sensorless control, which eliminate the need for physical sensors in the motor by using estimators and observers to infer the rotor position. However, due to the complexity of algorithm, and issue of robustness, it would not be covered in this report.

* 1. **Aims and Objectives**

The aim of this project is to achieve current and speed control of the PMSM motor (300V, BSM90N-175AA) through a three-phase three-level diode clamped inverter in PLECS and in reality. The inverter is controlled by TI’s F28379D Launchpad. For safety concerns, only low power situation (2kW) would be considered.

The project can be divided into following stages:

**Stage 1: Initial Simulation of FOC in PLECS**

**Aim:**

Create a mathematical model of PMSM motor in PLECS, and implement FOC in PLECS to verify the minimum acceptable capacitance of the DC-link capacitors.

**Objectives:**

* Work out the mathematical model of BSM90N-175AA motor.
* Learn the working principles of Field-Oriented Control, build the continuous control model in PLECS.
* Change the target torque current to verify the performance of the two DC-link capacitors with calculated capacitance value, then work out the minimum acceptable value of capacitance and find the most suitable capacitor on the market.

**Stage 2: Hardware Design in KiCad and Manufacturing**

**Aim:**

**Objectives:**

**Stage 3:**

**Aim:**

**Objectives:**

**Stage 4: Software Design in Code Composer Studio**

**Aim:**

**Objectives:**

**Chapter 2: Simulation and Controller Design**

***2.1* Topology Overview and Control Diagram**

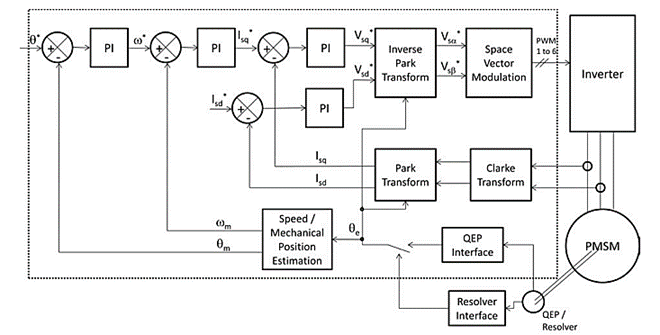
The main topology of the circuit for simulation in the PLECS is shown in **Figure 2.1**. The controller takes the 3-phase current and PMSM motor’s angle and speed as input, and output the PWM for each IGBT in the diode clamped inverter. The controller contains two closed loops in series: current loop and speed loop. The most fundamental loop is current loop, which also can be referred to as torque loop, as the torque of the PMSM motor is proportional to its stator current. This is where the FOC algorithm can be applied, combined with the PI controller to control the three-phase current in a closed loop to generate target torque based on the mechanical position of the rotor. Building upon the foundation of current closed loop, the speed loop can be implemented by using the serial PI controller.

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**Figure 2.1** Main Topology: Three-Level Diode Clamped Inverter (Three-Phase)

Control Diagram:



***2.2* PMSM Motor Modelling**

Electrical modelling parameters:

* Stator Resistance
* Stator Inductance (d-axis) and (q-axis)
* Flux induced by magnet
* Number of pole pairs p
* Electromotive force constant

Mechanical modelling parameters:

* Inertia of the rotor
* Friction coefficient
* Motor torque constant

Electromagnetic torque :

Mechanical rotor speed :

***2.3* SPWM and SVPWM**

Make comparation

***2.4* Design of Current and Speed Controllers**

The motor torque and back emf constants are equal: (represented by K)

Newton’s 2nd law:

Kirchhoff’s voltage law:

Laplace transform:

Thus, plant’s transfer function of current control:

Plant’s transfer function of speed control:

Continuous -> discrete

***2.5* Design of DC-Link Voltage Balance Controller**

***2.6* Thermal Management**

**Chapter 3: Hardware Design: Diode Clamped Inverter**

***3.1* PCB Layout**

Just figure? And how to put schematic (too big!)

* Choose of vias size, copper thickness, track width -> calculation?

***3.2* Selection of Components**

***3.3* Gate Drive Circuit**

* Why IGBT, instead of MOSFET
* Why use DC/DC converter

***3.4* DC-Link Capacitors**

* Calculation:

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* But in fact, it is hard to satisfy high voltage and larger capacitance at same time

**Chapter 4: Hardware Design: Control Board and its Peripherals**

***4.1* PCB Layout**

***4.2* ADC Sampling**

**Chapter 5: Software Design: Implementation on MCU**

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**References**

[1] B. Wu, “High Power Converters and AC Drives”, Wiley IEEE, 2nd Edition, 2016

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[3] A. Hughes “Electric Motors and Drives: Fundamentals, types, and applications”, 5th Edition, Elsevier, 2019

[4] S. N. Vukosavic, “Electrical Machines”, Springer, 2012