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硕士学位论文

开关电容型多电平逆变变流方法的研究与实现

Research and Implementation of Switched-Capacitor  
Multilevel Inverters

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## 摘要

相较于含有电感元件的传统逆变变流器,开关电容型变流器由于不含磁性元件,对于提高系统功率密度、减轻系统重量、实现高变比升压大有裨益。将开关电容电路应用于并网逆变器,对于推动并网发电系统向小型化、轻量化、集成化、高效化发展具有重要意义。

第二章讲述两级式开关电容的变流方法。首先提出了一款用于两级式逆变器前端的桥式多电平开关电容模块,分析了拓扑结构与工作模态,实现了多电平输出。接着在此基础上提出了谐振型开关电容 DC-DC 变流模块,设计了移相+PWM 的控制策略,实现了输出电压可调和软开关技术,并分析了开关电容纹波与输出电压纹波等性能。随后提出了一款两级式开关电容型七电平逆变器拓扑,分析了拓扑结构,基于此拓扑,采用优化单极性倍频 SPWM 控制策略,并设计了相位参数。两级式逆变器 DC-DC 环节开关电容模块的应用,保证了 DC-DC 变流的高效率和高电压增益;DC-AC 环节将多电平阶梯波作为母线电压,通过优化倍频控制方法有效提升了输出波形质量。针对并网系统存在的二次功率扰动问题,文中提出将逆变器直流侧电容等效部分解耦电容,降低了逆变系统对解耦电容容值的要求,为缩小系统体积、减小开关损耗提供了条件。

第三章讲述单级式开关电容的变流方法。首先,基于开关电容模块提出了单极式开关电容型五电平逆变器拓扑。文中分析了开关电容型五电平逆变器的拓扑结构与工作模态,优化了载波层叠 PWM 控制方法,计算了调制比与输出电压幅值的关系。该拓扑具备了开关电容的升压特性和电容钳位型电路开关组合方式灵活的特点,运用优化载波层叠 SPWM 控制策略,在维持开关电容升压运行的同时实现了母线电容电压平衡,复合结构有效减少了元件数量,增强了系统的运行的可靠性,提高了系统效率,多电平结构提升了输出波形质量。

文章最后对两级式七电平逆变器与单极式五电平逆变器系统的软硬件进行了设计,建立了 Saber 仿真模型与实验样机,对拓扑与基于拓扑的控制策略进行了验证。

**关键词:** 开关电容; 多电平; 逆变; 均压

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## ABSTRACT

Compared to the traditional inverters with bulky inductance components, the switched-capacitor circuits which contain no magnetic components could effectively realize not only higher power density, smaller size and lighter weight, but also higher boost ratio. The grid-connected inverter system based on switched-capacitor circuits is a great significance to promote the development of grid-connected power system to miniaturization, integration and high efficiency.

Chapter. 2 describes the two-stage switched-capacitor converters. A bridge multilevel modular switched-capacitor DC-DC converter for the front end of a two-stage inverter is proposed firstly, which can output three levels voltage. Then the resonant bridge modular multilevel switched-capacitor topology is given, where the distributed inductance is treated as a resonant inductor. With the phase shift plus PWM control strategy, the resonant converter ensures that all switching devices are soft switching and the output voltage is adjustable. And the analysis of switched-capacitor ripple and output ripple is given. Then the paper proposed a seven-level inverter based on above switched-capacitor circuits with its superiority in conversion efficiency and power density. The topology is composed of DC-DC and DC-AC stages, aiming to improve system stability and simplify the control method. The DC-DC stage, which can be expanded to synthesize more levels, not only features multilevel voltage gain but also partially replaces the original bulk input capacitor and functions as an active energy buffer to enhance power decoupling ability between DC and AC sides. In DC-AC stage, the ladder wave used for inversion helps improve the quality of output waveform. Meanwhile, the multilevel voltage phase has been optimized to reduce the power loss further.

A single-stage switched-capacitor five-level inverter topology is proposed in Chapter. 3. And the analysis of topology and control strategy is given. The

five-level inverter features the switched-capacitor module with DC-DC boost ability and the multilevel flying-capacitor-clamped inverter topology with flexible switching combination. Compared with traditional multilevel inverter, the component number of this topology is cut down due to the special composite structure. Moreover, the switching loss is reduced as a result of the part of the switches' operation under line voltage frequency. Then the carrier-based phase disposition PWM method is employed to help balance the capacitor voltage and achieve the output of the five levels. Based on the working modes and control method analysis, the relationship between modulation ratio and output voltage amplitude is calculated.

At the end of the paper, the hardware and software based on DSP of the seven-level inverter and the five-level inverter are designed. The simulation model on Saber and experimental prototype is built to verify the effectiveness and advantages of above topologies and topology-based control strategies.

**KEY WORDS:** Switched-capacitor, multilevel, inverter, voltage balancing

## 目 录

|  |    |
|--|----|
| 第一章 绪论.....                            | 1  |
| 1.1 选题背景及研究意义.....                     | 1  |
| 1.2 开关电容型变流技术研究现状.....                 | 3  |
| 1.2.1 开关电容型变流技术.....                   | 3  |
| 1.2.2 开关电容控制方法.....                    | 4  |
| 1.3 开关电容型 DC-AC 变流技术研究现状.....          | 4  |
| 1.3.1 两级式开关电容型 DC-AC 变流技术.....         | 5  |
| 1.3.2 单级式开关电容型 DC-AC 变流技术.....         | 7  |
| 1.3.3 开关电容型多电平 DC-AC 控制方法.....         | 9  |
| 1.4 论文主要研究内容.....                      | 11 |
| 第二章 两级式开关电容型逆变变流技术研究.....              | 13 |
| 2.1 两级式前端多电平开关电容型 DC-DC 变流技术研究.....    | 13 |
| 2.1.1 拓扑结构与控制策略分析.....                 | 13 |
| 2.1.2 拓扑工作模态分析.....                    | 14 |
| 2.2 两级式前端谐振型多电平开关电容型 DC-DC 变流技术研究..... | 16 |
| 2.2.1 拓扑结构与控制策略分析.....                 | 17 |
| 2.2.2 拓扑工作模态分析.....                    | 17 |
| 2.2.3 软开关的设计分析.....                    | 21 |
| 2.2.4 开关电容纹波与变流器输出电压纹波分析.....          | 22 |
| 2.3 两级式开关电容型七电平逆变变流技术研究.....           | 25 |
| 2.3.1 开关电容型七电平 DC-AC 变流器拓扑分析.....      | 25 |
| 2.3.2 控制策略分析.....                      | 26 |
| 2.3.3 开关电容型七电平 DC-AC 变流器相位参数设置.....    | 27 |
| 2.4 开关电容型七电平 DC-AC 变流器功率解耦技术研究.....    | 29 |
| 2.4.1 功率解耦原理概述.....                    | 29 |

|   |           |
|---|-----------|
| 2.4.2 基于开关电容功率解耦分析 .....                | 31        |
| 2.5 本章小结 .....                          | 33        |
| <b>第三章 单极式开关电容型逆变变流技术研究 .....</b>       | <b>35</b> |
| 3.1 拓扑结构与工作模态 .....                     | 35        |
| 3.1.1 单极式开关电容型五电平 DC-AC 变流器结构分析 .....   | 35        |
| 3.1.2 工作模态分析 .....                      | 36        |
| 3.2 均压原理 .....                          | 39        |
| 3.3 控制策略分析 .....                        | 40        |
| 3.3.1 基于单极式开关电容型 DC-AC 变流器的控制策略 .....   | 40        |
| 3.3.2 载波层叠 PWM 下的开关电容型五电平输出分析 .....     | 43        |
| 3.4 本章小结 .....                          | 46        |
| <b>第四章 逆变系统设计 .....</b>                 | <b>47</b> |
| 4.1 主电路设计 .....                         | 47        |
| 4.1.1 逆变电路器件选型 .....                    | 47        |
| 4.1.2 谐振型开关电容型 DC-DC 变流器参数设计与器件选型 ..... | 48        |
| 4.2 辅助电路设计 .....                        | 49        |
| 4.2.1 驱动电路设计 .....                      | 49        |
| 4.2.2 滤波电路设计 .....                      | 51        |
| 4.2.3 采样电路设计 .....                      | 53        |
| 4.3 软件程序设计 .....                        | 54        |
| 4.3.1 反相载波层叠 SPWM 的实现 .....             | 54        |
| 4.3.2 大周期 PWM 输出的实现 .....               | 56        |
| 4.3.3 ePWM 模块死区设置 .....                 | 57        |
| 4.4 本章小结 .....                          | 58        |
| <b>第五章 仿真与实验结果分析 .....</b>              | <b>59</b> |
| 5.1 两级式前端谐振型开关电容型 DC-DC 变流器仿真与实验 .....  | 59        |
| 5.1.1 输出电压控制特性验证 .....                  | 59        |

---

|                                   |           |
|-----------------------------------|-----------|
| 5.1.2 软开关验证 .....                 | 60        |
| 5.1.3 效率测试 .....                  | 61        |
| 5.2 两级式开关电容型 DC-AC 变流器仿真与实验 ..... | 61        |
| 5.2.1 输出波形验证 .....                | 62        |
| 5.2.2 功率解耦验证 .....                | 64        |
| 5.2.3 效率测试 .....                  | 66        |
| 5.3 单极式开关电容型 DC-AC 变流器仿真与实验 ..... | 67        |
| 5.3.1 输出波形验证 .....                | 67        |
| 5.3.2 电容电压平衡验证 .....              | 70        |
| 5.3.3 输出电压调节特性验证 .....            | 71        |
| 5.3.4 效率测试 .....                  | 72        |
| 5.4 本章小结 .....                    | 72        |
| <b>第六章 总结与展望 .....</b>            | <b>75</b> |
| 6.1 研究总结 .....                    | 75        |
| 6.2 工作展望 .....                    | 76        |
| 参考文献 .....                        | 77        |
| 攻读硕士学位期间取得的科研成果 .....             | 83        |
| 致 谢 .....                         | 85        |

厦门大学博硕士学位论文摘要库

## Table of Contents

|   |    |
|---|----|
| <b>1. Introduction</b> .....  | 1  |
| <b>1.1 The Background and Significance of The Study</b> .....             | 1  |
| <b>1.2 Research Status of Switched-Capacitor Technology</b> .....         | 3  |
| 1.2.1 Switched-Capacitor Conversion Technology .....                      | 3  |
| 1.2.2 Switched-Capacitor Control Method.....                              | 4  |
| <b>1.3 Research Status of Switched-Capacitor DC-AC Conversion</b> .....   | 4  |
| 1.3.1 Two-Stage Switched-Capacitor DC-AC Converter.....                   | 5  |
| 1.3.2 Single-Stage Switched-Capacitor DC-AC Converter .....               | 7  |
| 1.3.3 Multilevel Switched-Capacitor DC-AC Control Method .....            | 9  |
| <b>1.4 Research Work</b> .....  | 11 |
| <b>2. Two-Stage Seven-Level Switched-Capacitor Inverter</b> .....         | 13 |
| <b>2.1 Multilevel Switched-Capacitor DC-DC Converter</b> .....            | 13 |
| 2.1.1 Analysis of Topology and Control Strategy .....                     | 13 |
| 2.1.2 Analysis of Operational Modes.....                                  | 14 |
| <b>2.2 Resonant Multilevel Switched-Capacitor DC-DC Converter</b> .....   | 16 |
| 2.2.1 Analysis of Topology and Control Strategy .....                     | 17 |
| 2.2.2 Analysis of Operational Modes.....                                  | 17 |
| 2.2.3 Analysis of Soft-Switching .....                                    | 21 |
| 2.2.4 Analysis of Capacitor Ripple and Output Voltage Ripple.....         | 22 |
| <b>2.3 Two-Stage Seven-Level Switched-Capacitor Inverter</b> .....        | 25 |
| 2.3.1 Analysis of Topology .....  | 25 |
| 2.3.2 Analysis of Control Strategy .....                                  | 26 |
| 2.3.3 Design of Phase Parameter.....                                      | 27 |
| <b>2.4 Research on Switched-Capacitor Inverter Power Decoupling</b> ..... | 29 |
| 2.4.1 Power Decoupling Principle Introduction.....                        | 29 |
| 2.4.2 Power Decoupling Based on Switched-Capacitor Circuit .....          | 31 |

|       |  |    |
|-------|--|----|
| 2.5   | Chapter Summary .....  | 33 |
| 3.    | Single-Stage Five-Level Switched-Capacitor Inverter .....      | 35 |
| 3.1   | Analysis of Topology and Control Strategy .....                | 35 |
| 3.1.1 | Topology Analysis of Flying-Capacitor-Clamped Inverter .....   | 35 |
| 3.1.2 | Analysis of Operational Modes .....                            | 36 |
| 3.2   | Capacitor Voltage Balancing Principle .....                    | 39 |
| 3.3   | Control Method Analysis .....                                  | 40 |
| 3.3.1 | Carrier Disposition PWM Control Method .....                   | 40 |
| 3.3.2 | Output Voltage Analysis under Carrier Disposition PWM .....    | 43 |
| 3.4   | Chapter Summary .....  | 46 |
| 4.    | Inverter System Design .....                                   | 47 |
| 4.1   | Main Circuits Design .....                                     | 47 |
| 4.1.1 | Inverter Circuit Design and Devices Selection .....            | 47 |
| 4.1.2 | Resonant Circuit Parameter Design and Devices Selection .....  | 48 |
| 4.2   | Auxiliary Circuits Design .....                                | 49 |
| 4.2.1 | Drive Circuit Design .....                                     | 49 |
| 4.2.2 | Filter Circuit Design .....                                    | 51 |
| 4.2.3 | Sampling Circuit Design .....                                  | 53 |
| 4.3   | Software Design .....  | 54 |
| 4.3.1 | Software Design of Carrier Disposition PWM .....               | 54 |
| 4.3.2 | Software Design of Large Cycle PWM .....                       | 56 |
| 4.3.3 | ePWM Dead Band Module Settings .....                           | 57 |
| 4.4   | Chapter Summary .....  | 58 |
| 5.    | Simulation and Experimental Results and Analysis .....         | 59 |
| 5.1   | Simulation and Experiment of Resonant DC-DC Converter .....    | 59 |
| 5.1.1 | Output Voltage Characteristics Simulation and Experiment ..... | 59 |
| 5.1.2 | Soft-Switching Simulation and Experiment .....                 | 60 |
| 5.1.3 | Efficiency Test .....  | 61 |



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