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South China University of Technology

博士留学生学位论文

并网逆变器并联运行方法研究

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A study on the methods of operation of the connected parallel inverters network

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摘　要

将三相逆变器并联运行，可大大提高系统的灵活性,使电源系统的体积缩小、重量减轻，还也可大大减少开关器件的电流应力，从而提高系统的可靠性、降低成本和提高功率密度。由于可实现冗余供电，逆变电源的并联技术可以实现 N+1 (N=1,2,3….) 冗余并联运行方式，当系统中任一个模块由于故障而失效时，其余的 N 个模块仍然可以继续提供 100%负载功率，可以以较小的功率冗余为代价获得容错冗余功率，大大提高了系统的可靠性。并联冗余控制是实现高可靠性、大功率电源系统的优选方案。因此，逆变电源并联技术在航空航天、大型计算机供电系统、通讯电源系统和银行电源系统等对电源可靠性要求较高的领域具有广泛的应用前景。逆变电源的并联控制技术是近年来电源领域研究的一个热点课题，具有实际应用意义。

控制并联逆变器系统通常使用传统 PID 控制器来控制电流电压。传统的 PID 控制器设计成熟，控制效果良好，但也存在参数设计不精确，对系统参数变化敏感，其动态性能和谐波因数往往难以达到要求等不足。分数阶 $PI^{\lambda}D^{\mu}$控制器具有对被控对象的参数变化具有较强的鲁棒性，其控制效果优于传统的 PID 控制器，且实现难度与传统 PID 相近等优点。本文将分数阶 $PI^{\lambda}D^{\mu}$ 控制器替代传统 PID 控制器，研究控制器的设计方法，并对设计的控制器在相关系统中进行并得到应用和验证。

论文主要研究内容包括以下几点：

1) 分析了课题研究背景和意义，介绍了逆变器及其并联技术技术的发展应用研究现状。

2） 分析了三相逆变器的拓扑结构、数学模型和控制方法，在此基础上进一步分析了逆变器并联系统的模型，逆变器并联运行的机理，介绍了各种并联控制方式。

3）分析和研究了 PWM 逆变器直接电流控制方法、双闭环矢量控制原理、PWM 逆变器的空间矢量算法；引入电流前馈控制方法，设计了 PWM 逆变器的并联系统，并进行了系统的建模与仿真分析。

4）分析了并联逆变器系统的环流产生机理、环流抑制技术、均流控制技术以及对输出电压的影响，介绍了常用的几种均流控制方法，在此基础上提出了最大电流自动均流法，并进行了仿真验证。

5）介绍了分数阶基本理论，包括分数阶微积分定义、分数阶微积分性质、分数阶微积分的积分变换，分析了分数阶系统典型环节的特性。

6）研究了分数阶 $PI^{\lambda}D^{\mu}$ 控制器，介绍了分数阶控制器的离散化实现方法，在此基础上研究了三相 PWM 逆变器分数阶控制系统，设计了 FO-PID 控制器，研究了其参数整定方法，并分析了各环节特性及其对控制性能的影响。仿真结果分析证明了基于 FO-PID 的直接电流控制能够实现预定的控制效果，网侧电流接近正弦，功率因数单位化，而且 FO-PID 控制器对系统参数变化不敏感，直流侧电压能够快速稳定在给定值，控制精确，具有更强的鲁棒性。

7）设计了 PWM 逆变器并联系统的硬件平台和软件算法，并进行了相关实验。实验结果证明，本文设计的系统，系统运行稳定，在谐波因数、功率因数等方面可满足并联并网系统的要求，同时可以实现冗余运行，提高了系统的安全性和可靠性。

关键词：三相并网逆变器；并联运行；环流；均流；直接电流；最大电流；分数阶 $PI^{\lambda}D^{\mu}$

ABSTRACT

A study on the methods of operation of the connected parallel inverters network is significant in control not only for our country but also for China and other countries in the world. Three phase inverters have become the main power supply systems, such as office automation, hospital, bank, play an important role in the field of communications, defense. Parallel inverter technology is a potential market and has great potential, can be studied extensively and has many specialized applications. Some recent years, one phase parallel inverter became mature, and 3-phase connected parallel inverter is gradually becoming a new research focus of the scientific research.

Three phase inverters in parallel can provide electricity with high capacity as well as backup power, which is an important research direction, is increasingly being recognized in the inverter control technology. Using parallel inverter enhance the flexibility of the system, reduce the volume, the size of the system, increasing the quality of the switching process, improve reliability, increase power density and reduce the cost of production systems system.

Moreover, using inverters connected in parallel may perform redundant power supply, improve the reliability of the system work. Parallel inverter technology allows pairing parallel N + 1 modules, so during operation if one module fails, the remaining N modules will generate sufficient load capacity of 100%, so the cost will be much cheaper than the equipped with redundant power supply separately, but the reliability of the system is improved.Parallel inverter control Technology is now the first choice for control systems require high performance and high reliability. Therefore, parallel inverter technology is now widely applied in many fields such as core: aviation, power supply for computer, communication systems, power supply systems for banks , the system resources required to provide quality and high reliability. Parallel inverter technology is a hot spot for the supply of energy in recent years, this study is a significant high practical application.

Parallel inverter control system traditionally use PID controller (proportional, integral, derivative) to control the voltage, the traditional PID controller has reached maturity, the resulting control good, but the design parameter is not really optimal, very sensitive to the variation of other parameters in the system, performance and features of the system is

difficult to achieve an optimal level, so that the amount of highly customizable.

This thesis introduce method using fractional $PI^{\lambda}D^{\mu}$ controller to replace the traditional PID controller design parameters for the controller fractional $PI^{\lambda}D^{\mu}$. The controller segment brought dramatic changes in the past controls, achieve better control that traditional PID controller is not reached.

Study on the methods of operation of the connected parallel inverters network has been done in following steps:

1) The first, thesis analyzes the meaning and context of the study subjects, a general introduction to the current state of development and application of inverter technology, the current state of technological development driver pairing in parallel inverter China and other countries around the world.

2) Analysis of the pattern and texture of the 3-phase inverter, inverter control method of three-phase inverter models in parallel, working principle analysis of parallel inverter, introduces the control method common parallel inverter.

3) Analysis and method research to directly control current (DCC) PWM inverter, control principle two close loop analysis method of space vector PWM inverter, analytical methods feedback current control and analysis methods to directly current control to the parallel inverter. Using matlab / simulink to setup and simulate system, simulation results analysis.

4) Analysis of balanced current system paired parallel inverter, current limiting method when paired parallel inverter, affecting the output voltage of the inverter parallel coupling. Engineering controls stratospheric parallel inverter, then analyzes some of the stratospheric control method used in parallel inverter system analysis and control methods are applied in this thesis is the method automatically current maximum average. Performance is simulated by Matlab / Simulink and analyze simulation results

5)Referring to the issues in the fractional control, the definition fractional, the nature of the area fraction, analysis changing methods in fractional control, analyze the characteristics of the stages typical volume fraction.

6) Research fractional $PI^{\lambda}D^{\mu}$ controller, introduce some approximate analytical methods of fractional controller, then design the fractional controller for 3-phase inverter

system, designed adapters FO-PID controller and its features, analysis and setting the parameters of the system, through the FO-PID control voltage is stable at a certain value, the voltage is kept constant even even when the load changes, the grid fluctuations or other parameters of the system change. Ensuring the performance of three-phase inverter and the majority of the damage reduction. Simulation results and experiments have demonstrated that the use of FO-PID control method with direct current control to achieve the results desired control, the grid current is very close to sinusoidal, power factor is high, moreover FO-PID controller is not sensitive to changes in the parameters of the system, the DC voltage stability quickly at a certain value, and the sharp correction and more accurate.

7) Finally, thesis designs main power circuit and locked loop system design experiments paired parallel inverter (including hardware and software applications), through the table experiments , analysis of experimental results and draw conclusions: experimental results have proved the thesis system design reasonable structure, precise control, efficient, results-driven requirements, meet the requirements of the grid, the efficiency of the system is improved, and has the effect of inhibiting the appearance of harmonics, grid quality is not affected, reducing heating systems, safety is enhanced, reduced maintenance workload, valuable practical application high structure was renovated parallel system, creating favorable conditions for real life production, reduce waste and conserve natural resources.

Keywords: PWM rectifiers; inverters in parallel ; Direct Current Control, balanced current; Fractional- order $PI^{\lambda}D^{\mu}$ Controller.

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