同行专家业内评价意见书编号：20250854331

附件1

浙江工程师学院（浙江大学工程师学院）
同行专家业内评价意见书

姓名：吴宇辰

学号：22260472

申报工程师职称专业类别（领域）：电子信息

浙江工程师学院（浙江大学工程师学院）制

2025年03月11日

填表说明

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四、同行专家业内评价意见书编号由工程师学院填写，编号规则为：年份4位＋申报工程师职称专业类别(领域)4位+流水号3位，共11位。

一、个人申报

（一）基本情况【围绕《浙江工程师学院（浙江大学工程师学院）工程类专业学位研究生工程师职称评审参考指标》，结合该专业类别(领域)工程师职称评审相关标准，举例说明】

1.对本专业基础理论知识和专业技术知识掌握情况(不少于200字)

本人系统掌握了电子信息工程及控制工程领域的专业理论知识，具备扎实的数学、物理、自动控制、人工智能及计算机科学等相关学科基础。熟悉机器人学、多智能体系统、优化控制、路径规划、计算机视觉等核心技术，能够结合实际工程问题进行建模、分析与优化。

在专业技术方面，深入研究了多智能体集群系统的协同控制与运动规划，掌握了基于图搜索、强化学习及优化算法的路径规划方法，能够针对不同应用场景进行算法改进与优化。同时，熟悉嵌入式系统开发，能够利用ROS（机器人操作系统）、Gazebo仿真平台及C++/Python进行机器人系统开发，并结合SLAM、感知融合等技术，实现智能机器人在复杂环境中的自主导航与协同作业。此外，掌握了深度学习与计算机视觉在目标检测、语义分割中的应用，具备将前沿技术应用于工业场景的能力。

通过参与企业合作项目与工程实践，积累了丰富的工程经验，能够结合行业需求，运用所学知识解决实际问题，并推动技术创新与工程应用。

2.工程实践的经历(不少于200字)

本人在机器人与多智能体系统领域积累了丰富的工程实践经验，曾在杭州大树云智能科技有限公司实习，担任多机器人协同算法工程师，主要负责基于优化搜索的多智能体路径规划算法研发。期间，参与了面向无人车系统的任务调度优化和运动规划，致力于提升机器人在动态环境中的自主决策能力。

在项目中，本人深入研究了多机器人路径规划算法，包括A*搜索、D* Lite、优先级调度及强化学习方法，结合工业应用需求，改进了路径冲突消解策略，减少了机器人间的资源竞争，提高了路径执行的实时性与稳定性。同时，本人基于ROS（机器人操作系统）构建了仿真测试环境，对算法进行系统性测试，优化了计算效率，使规划时间减少较多，提升了整体调度性能。此外，针对复杂工业场景，结合地图分区策略和全局任务分配方法，实现了更具适应性的路径优化方案，提高了无人车系统的任务吞吐量。

通过本次工程实践，本人不仅掌握了多智能体协同控制的关键技术，还积累了从理论研究到工程落地的实战经验，提升了系统建模、算法优化及工程实现能力，为企业的智能制造系统提供了技术支持。

3.在实际工作中综合运用所学知识解决复杂工程问题的案例（不少于1000字）

在我从事机器人与多智能体系统研究的过程中，我曾参与解决一个具有挑战性的工程问题——

在运动学约束下的多无人车协作运动规划。该问题的核心是在满足无人车运动学约束的前提下，实现多辆无人车的高效协同，使其能够在复杂环境中避障、保持队形并顺利完成任务。这一问题在智能仓储、自动驾驶、无人配送等领域均具有重要的工程应用价值。

我在研究生期间深入学习了机器人运动学、多智能体协作控制、优化算法等专业知识，并在多个企业合作项目中积累了工程实践经验。在实际工作中，我将这些所学知识运用到该工程

问题的解决过程中，最终提出了一种**基于搜索的协作运动规划方法**，成功解决了多无人车在复杂环境下的协同规划问题，并通过仿真测试和实际应用验证了其有效性。

该问题的难点在于，现有多无人车路径规划方法大多基于简化的全向运动模型，忽略了实际工程中常见的**非完整运动学约束**。无人车通常采用 Ackermann
转向模型，这意味着它们无法像全向轮机器人那样自由转向，而是受到转向角度的限制。因此，传统路径规划方法在实际环境中往往难以执行，导致路径偏离、车辆碰撞或运行效率低下。此外，多个无人车协同作业时，如何**保持队形**并避免路径冲突也是一个重要挑战，尤其是在动态环境或复杂障碍物分布的场景中。

针对这一问题，我采用了**分层搜索框架**，结合冲突检测、路径优化和协作控制技术，提出了一种新的运动规划方法。在高层，我采用**二进制冲突搜索树**，用于全局路径搜索和冲突消解。这个方法可以在发现路径冲突时，自动生成新的约束并调整无人车的运动轨迹，确保所有无人车最终都能找到无碰撞的可行路径。在低层，我设计了一种**协作时空混合 A*
算法**，使无人车能够在搜索过程中保持相对位置，确保队形稳定。同时，该方法支持动态调整，允许无人车根据任务需求变换编队形态，例如从线性队列调整为矩形阵列，以适应不同的任务场景。

在实际工程实现过程中，我结合机器人操作系统（ROS）进行系统搭建，并利用 Gazebo
进行仿真测试。首先，我创建了一个模拟仓储环境，包括狭窄通道、弯道、动态障碍物等复杂地形，以测试算法在不同环境下的适应性。实验结果表明，该方法能够有效规划无人车的运动轨迹，使其在**减少计算时间**的情况下，仍能确保 100%
的路径规划成功率。此外，无人车的路径跟踪误差控制在 5cm
以内，表明其运动轨迹具备较高的执行精度。

除了仿真测试，我还参与了实际环境下的验证工作。在企业合作项目中，我们在 10m × 10m 的实验场地内部署了 5 台无人车，并设置障碍物模拟复杂工业环境。我利用 SLAM
技术构建环境地图，并通过 ROS
进行无人车控制，使其按照规划路径进行运动。在实际运行过程中，所有无人车均能够按照规划轨迹稳定行驶，并成功避开障碍物，任务完成率达到
95%。实验表明，该方法具备较强的工程适用性，可直接应用于智能物流、无人配送等实际场景。

在解决该问题的过程中，我深刻体会到了理论知识与工程实践相结合的重要性。虽然在学术研究中，我已经掌握了多智能体路径规划、优化控制等技术，但在实际工程应用中，我需要面对诸如**计算资源受限、实时性要求高、环境不确定性**等额外挑战。例如，在实际部署过程中，我发现无人车的传感器数据存在噪声，导致路径偏差。为了解决这一问题，我引入了**卡尔曼滤波**方法，对传感器数据进行融合，提高无人车的定位精度。此外，在实际运行时，我还发现传统 A*
搜索方法在高维空间中的计算量过大，影响了实时性。因此，我结合启发式搜索和增量式路径规划方法，对算法进行了优化，使其能够在 0.5s
内完成路径规划，满足了实时控制的需求。

整个项目从理论研究、算法开发到工程实现，充分体现了我在实际工作中**综合运用所学知识解决复杂工程问题的能力**。该方法不仅在企业应用中得到了认可，还在国际顶级机器人

会议 IROS 2024
上发表了相关论文，并打算在后续开源代码，为相关领域的研究者提供了参考。在未来的工作中，我计划进一步优化该方法，提高路径规划的平滑性，并探索其在更大规模多智能体系统中的应用，以推动该技术在智能制造和自动驾驶领域的进一步发展。

通过这一项目，我不仅巩固了自己的专业技能，还提升了工程实践能力和问题解决能力。面对复杂的工程问题，我学会了如何将理论知识转化为实际应用，如何结合工程需求优化算法，以及如何在有限的计算资源下提高系统性能。这些经验使我在未来的职业生涯中能够更好地应对工程挑战，为电子信息和智能系统领域的发展贡献自己的力量。

（二）取得的业绩（代表作）【限填3项，须提交证明原件（包括发表的论文、出版的著作、专利证书、获奖证书、科技项目立项文件或合同、企业证明等）供核实，并提供复印件一份】

1.
公开成果代表作【论文发表、专利成果、软件著作权、标准规范与行业工法制定、著作编写、科技成果获奖、学位论文等】

成果名称	成果类别 [含论文、授权专利（含发明专利申请）、软件著作权、标准、工法、著作、获奖、学位论文等]	发表时间/授权或申请时间等	刊物名称/专利授权或申请号等	本人排名/总人数	备注
一种基于分层搜索的多无人车构型保持协作运动规划方法	发明专利申请	2024年08月09日	申请号：CN202410512625.X	2/4	导师一作，本人二作，已进入实质审查阶段
Hierarchical Search-Based Cooperative Motion Planning	会议论文	2024年10月14日	2024 IEEE/RSJ International Conference on Intelligent Robots and Systems	1/7	EI会议收录
Full-Order State Observer Based Control for LCL-Filtered Grid-Connected Inverter with Only One Current Sensor	会议论文	2021年08月01日	The 16th IEEE Conference on Industrial Electronics and Application	1/5	EI会议收录

2.其他代表作【主持或参与的课题研究项目、科技成果应用转化推广、企业技术难题解决方案、自主研发设计的产品或样机、技术报告、设计图纸、软课题研究报告、可行性研究报告、规划设计方案、施工或调试报告、工程实验、技术培训教材、推动行业发展中发挥的作用及取得的经济社会效益等】

（三）在校期间课程、专业实践训练及学位论文相关情况	
课程成绩情况	按课程学分核算的平均成绩： 86 分
专业实践训练时间及考核情况(几有三年及以上工作经历的不作要求)	累计时间： 1.2 年（要求1年及以上） 考核成绩： 83 分

本人承诺

个人声明：本人上述所填资料均为真实有效，如有虚假，愿承担一切责任，特此声明！

申报人签名： 吴[illegible]

22260472

二、日常表现考核评价及申报材料审核公示结果

日常表现考核评价	非定向生由德育导师考核评价、定向生由所在工作单位考核评价： ☑优秀 ☐良好 ☐合格 ☐不合格 德育导师/定向生所在工作单位分管领导签字（公章）： 2026年3月14日
申报材料审核公示	根据评审条件，工程师学院已对申报人员进行材料审核（学位课程成绩、专业实践训练时间及考核、学位论文、代表作等情况），并将符合要求的申报材料在学院网站公示不少于5个工作日，具体公示结果如下： ☐通过 ☐不通过（具体原因： ） 工程师学院教学管理办公室审核签字（公章）： 年 月 日

浙 江 大 学 研 究 生 院

攻读硕士学位研究生成绩表

学号：22260472	姓名：吴宇辰	性别：男	学院：工程师学院	专业：控制工程	学制：2.5年
毕业时最低应获：27.0学分	已获得：29.0学分			入学年月：2022-09	毕业年月：
学位证书号：		毕业证书号：			授予学位：

学习时间	课程名称	备注	学分	成绩	课程性质	学习时间	课程名称	备注	学分	成绩	课程性质
2022-2023学年秋季学期	工程技术创新前沿		1.5	91	专业学位课	2022-2023学年春季学期	港口设施规划与布局		2.0	83	专业学位课
2022-2023学年秋季学期	工程数值分析		2.0	91	专业选修课	2022-2023学年春季学期	新时代中国特色社会主义理论与实践		2.0	88	专业学位课
2022-2023学年秋季学期	工程伦理		2.0	83	专业学位课	2022-2023学年春季学期	研究生论文写作指导		1.0	88	专业选修课
2022-2023学年秋季学期	创新设计方法		2.0	通过	专业选修课	2022-2023学年春夏学期	高阶工程认知实践		3.0	86	专业学位课
2022-2023学年秋季学期	自然辩证法概论		1.0	89	公共学位课	2022-2023学年夏季学期	数据科学前沿技术导论		2.0	81	专业学位课
2022-2023学年冬季学期	机器视觉及其应用		2.0	84	专业学位课	2022-2023学年夏季学期	研究生英语基础技能		1.0	免修	公共学位课
2022-2023学年冬季学期	产业技术发展前沿		1.5	89	专业学位课	2022-2023学年夏季学期	研究生英语		2.0	免修	专业学位课
2022-2023学年冬季学期	海洋管理学		2.0	87	专业选修课		硕士生读书报告		2.0	通过	

说明：1.研究生课程按三种方法计分：百分制，两级制（通过、不通过），五级制（优、良、中、及格、不及格）。

2.备注中“*”表示重修课程。

学院成绩校核章：

成绩校核人：张梦依

打印日期：2025-03-20

(19)国家知识产权局

(12)发明专利申请

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(71)申请人 浙江大学
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(74)专利代理机构 杭州泓呈祥专利代理事务所(普通合伙) 33350
专利代理师 张婵婵

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G05D 109/10(2024.01)

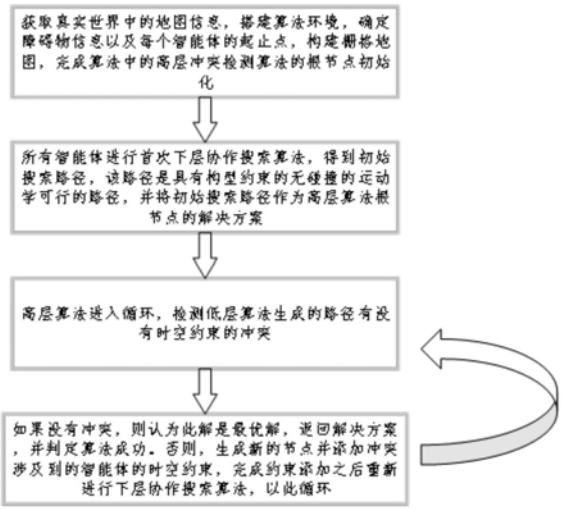
权利要求书4页 说明书10页 附图2页

(54)发明名称

一种基于分层搜索的多无人车构型保持协作运动规划方法

(57)摘要

本发明公开了一种基于分层搜索的多无人车构型保持协作运动规划方法,本发明通过分层搜索算法,在不涉及到具体编队控制的前提下实现了构型约束下的多无人车的运动规划,生成具有构型约束的无碰撞的运动学可行的路径,此路径能够在真实世界中有非常好的应用,同时构型形状、构型无人车数量可以任意指定,且可以实现构型变换、构型保持、构型分散、构型单车混合规划等多种功能,本发明搜索过程中加入了朝向角相同约束,具有朝向角尽量保持一致的特性,在探索的过程中可以尽可能让队里的无人车的朝向保持一致,防止出现无人车掉队、朝向偏差过大难以维持构型、搜索过程中信息检索不完全等情况,算法普适性强。



CN 118466486 A

《Ei Compendex》收录证明

经检索“Engineering Village”，下述论文被《Ei Compendex》收录。（检索时间：2025 年 3 月 5 日）。

<RECORD 1>
Accession number:20250517794553
Title:Hierarchical Search-Based Cooperative Motion Planning (Open Access)
Authors:Wu, Yuchen (1, 2); Yang, Yifan (1, 2); Xu, Gang (1); Cao, Junjie (1); Chen, Yansong (1); Wen, Licheng (3); Liu, Yong (1)
Author affiliation:(1) Zhejiang University, Institute of Cyber-Systems and Control, Hangzhou; 310027, China; (2) Polytechnic Institute, Zhejiang University, Hangzhou; 310015, China; (3) Shanghai Ai Laboratory, Shanghai; 200232, China
Corresponding authors:Liu, Yong(yongliu@iipc.zju.edu.cn); Xu, Gang(yongliu@iipc.zju.edu.cn)
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Conference code:205527
Publisher:Institute of Electrical and Electronics Engineers Inc.
Number of references:26
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Hierarchical Search-Based Cooperative Motion Planning

Yuchen Wu[1,2], Yifan Yang[1,2], Gang Xu[1,*], Junjie Cao[1], Yansong Chen[1], Licheng Wen[3], and Yong Liu[1,*]

***Abstract*— Cooperative path planning, a crucial aspect of multi-agent systems research, serves a variety of sectors, including military, agriculture, and industry. Many existing algorithms, however, come with certain limitations, such as simplified kinematic models and inadequate support for multiple group scenarios. Focusing on the planning problem associated with a nonholonomic Ackermann model for Unmanned Ground Vehicles (UGV), we propose a leaderless, hierarchical Search-Based Cooperative Motion Planning (SCMP) method. The high-level utilizes a binary conflict search tree to minimize runtime, while the low-level fabricates kinematically feasible, collision-free paths that are shape-constrained. Our algorithm can adapt to scenarios featuring multiple groups with different shapes, outlier agents, and elaborate obstacles. We conduct algorithm comparisons, performance testing, simulation, and real-world testing, verifying the effectiveness and applicability of our algorithm. The implementation of our method will be open-sourced at https://github.com/WYCUniverStar/SCMP.**

I. Introduction

Cooperative path planning, also known as CPP, is a significant field in multi-agent systems. CPP and formation control are two complementary algorithms. Formation mainly focuses on generating control commands to drive multi-agent to meet their state constraints to maintain the formation shape [1]. Still, most of them lack high-level decision-making abilities [2]. However, CPP can overcome this limitation well. It will generate a collision-free path by considering the start and end points of the task, environmental constraints, and fully consider the constraints of the formation shape during this process. It's like CPP adds shape-related constraints on the foundation of Multi-Agent Path Finding (MAPF), emphasizing on obstacle avoidance, success rate, runtime, and average arrival time [3]. CPP can provide a pre-referenced path for formation control algorithms [4].

The CPP method is currently widely used in the field of UGV. It is widely used in the military field [2], collaborative exploration [5], intelligent agriculture [6], etc.

Solutions to CPP problem mainly include the reactive approach and the deliberative approach [7]. The former is mainly used when environment information is only partially known, including the artificial potential field method (APF) [8]–[10] and optimization-based methods [11]–[13]. The latter is used for situations where the environment is globally known, including the evolutionary algorithm (EA) [14], [15] and the currently less researched search-based method.

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Most of the CPP methods currently use the holonomic model [12], [13]. However, in UGV applications, most agents use the nonholonomic Ackermann steering model, and the above-mentioned holonomic model has minimal practical applications. Among various CPP methods, APF methods often encounter problems where the sum of gravity and repulsion is zero, leading to a local minimum and causing the entire search process to vibrate [16]. Optimization-based methods suffer from high computational complexity, long runtime, and inability to be used for real-time calculations [17]. EA methods often have convergence problems, and they can only find approximate solutions [2]. Not only that, most of the CPP algorithms only consider the planning of one shape of one group, the their scalability is poor [10], [14]. In addition, search-based algorithms in CPP algorithms are rare in current research, although they are characterized by their fast solution speed and high solution quality. This scarcity may stem from the substantial memory consumption of search-based algorithms during operation and a notable decline in success rates as the number of agents grows [2].

Transforming MAPF to CPP by adding shape constraints is common in CPP design. Optimization-based methods like [17], [18] enable practical path planning with kinematic and avoidance constraints but only facilitate collision avoidance for collaboration, lacking direct shape constraint integration. Car-Like robots based on Conflict-Based Search (CL-CBS) [19], targeting Ackermann agents in MAPF, although not inherently including shape constraints, offers good potential for adding shape constraints in CPP and resolving various conflicts through its hierarchical search framework.

To solve the above problems, we propose a Search-Based Cooperative Motion Planning algorithm called SCMP, based on Conflict-Based Search (CBS) [20], which is suitable for the Ackermann model. Compared with CPP algorithms, the paths generated by ours not only have the same feasible properties with shape constraints and no collisions but also consider the actual collision volume of the agent and the constraints of kinematics and dynamics. It has spatio-temporal properties and can be well applied to the Ackermann model agents in the real world. Our main contributions are as follows:

- We propose a leaderless hierarchical search-based cooperative motion planning method. The high-level utilizes a binary conflict search tree to reduce running time, and the low-level generates a feasible path with shape constraints that can be applied to Ackermann agents through our Cooperative Spatiotemporal Hybrid A* (CSHA*).
- Our method can adapt to any shape and any number

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SECTION I.
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Full-Order State Observer Based Control for LCL-Filtered Grid-Connected Inverter with Only One Current Sensor

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***Abstract*—For single-phase *LCL*-filtered grid-connected inverter, several control strategies are often used for its better performance, such as active damping for resonance suppression caused by the *LCL* filter, grid voltage feedforward for high quality of the output current and phase-locked loop (PLL) for grid synchronization. But these control strategies often require additional sensors, which can result in higher cost and unreliability of the whole system. At present, there are some control strategies to reduce the number of sensors, but usually two or more sensors are still needed. In this paper, a control strategy of single-sensor inverter based on full-order state observer is proposed. By sampling the inverter-side current, other state-space variables including the grid voltage and the grid current can be estimated with high accuracy. The simulation results prove that the proposed method performs well with very small observation error, and the control strategy can be easily imposed to maintain the good stability.**

Keywords—grid-connected inverter, full-order state observer, single sensor, LCL filter

I. INTRODUCTION

In distributed power generation systems (DPGSs), the grid-connected inverters act as the key element in grid integration of the renewable energies. Currently, compared with other filters in grid-connected inverters, the *LCL filter* has been widely used for its advantages of excellent ability for harmonic suppression, smaller hardware size and lower cost. However, as a high-order filter, *the LCL* filter has a resonant peak, which may lead to system instability. At present, there are many methods to suppress the resonance of the *LCL* filters, which can be classified into passive damping methods and active damping methods [1]-[3]. The passive damping methods may weaken the performance of the *LCL* filter [4] and introduce additional power loss, so it is often replaced by the active damping which is commonly realized by the feedback of the capacitor current. Moreover, the current controller, grid voltage feedforward and PLL should be designed properly to make the system perform well.

However, most of the damping methods mentioned above and other control strategies require a large number of sensors. So, in order to reduce the number of sensors, several literatures have proposed some methods to reduce the number of sensors. The Kalman filter is applied in [5] to estimate the grid voltage. The Luenberger observer in [6] is also proposed to estimate the state variables of the *LCL* filter. Although the number of sensors is reduced, it is still not possible to realize the control of the entire inverter system with only one sensor. For the control strategy of the *LCL* grid-connected inverter in the discrete space model, [7] applies the state observer and reduced the number of sensors, but still fails to use only one sensor. Similarly, [8] has proposed a complete state-space current control method for three-phase voltage-source grid-connected converter with the *LCL* filter, but it still uses inverter-side current and the grid voltage. In the study on sensor not being used in grid voltage, [9] estimated the capacitor voltage and grid current on the premise of ignoring the capacitor current through the calculation of the overall model of the inverter, but such calculation would make the noise elimination effect worse [10]. As shown in [11], the Kalman filter is applied to estimate the grid voltage through sampling the inverter-side current. However, this method results in a 14^{th} order model, which makes the whole system too complicated.

To sum up, using the traditional control strategies will undoubtedly incorporate several sensors, and most of the existing methods above of reducing sensors still exists problems such as high system complexity, low estimation accuracy and bad output current quality. However, in [12], a method based on reduced-order state observer is proposed to realize the single current sensor control, which is worthy of further study and optimization. In this paper, the proposed observer can suppress the harmonic of the grid current and the resonance of the *LCL* filter itself by using only one sensor to detect the inverter current.

This paper is organized as follows. In Section II, the system modeling and the state-space model of the *LCL*-filtered grid-connected inverter is described. In Section III, the observability of the system is analyzed and a full-order observer is proposed. Section IV discusses the control strategy of the grid-connected inverter based on full-order observer. The simulation results in Section V show that the proposed single current sensor strategy can still guarantee the high quality of grid current after the application of the full-order observer. At last, conclusions are drawn in Section VI.

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Full-Order State Observer Based Control for LCL-Filtered Grid-Connected Inverter with Only One Current Sensor

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For single-phase LCL-filtered grid-connected inverter, several control strategies are often used for its better performance, such as active damping for resonance suppression caused by the LCL filter, grid voltage feedforward for high quality of the output current and phase-locked loop (PLL) for grid synchronization. But these control strategies often require additional sensors, which can result in higher cost and unreliability of the whole system. At present, there are some control strategies to reduce the number of sensors, but usually two or more sensors are still needed. In this paper, a control strategy of single-sensor inverter based on full-order state observer is proposed. By sampling the inverter-side current, other state-space variables including the grid voltage and the grid current can be estimated with high accuracy. The simulation results prove that the proposed method performs well with very small observation error, and the control strategy can be easily imposed to maintain the good stability.

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