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Hybrid Microgrid for Solar PV and Battery Storage Integration

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Abstract

In modern society, an increasing number of electrical loads in buildings, such as computers, consumer electronics, light emitting diodes (LEDs), or variable speed motors, are supplied by dc power. At the same time, distributed renewable sources such as photovoltaics (PV), as well as batteries for electric vehicles and on-site storage, are based on dc. To integrate these technologies into existing ac power systems, complicated dc/ac inverters and controllers are required to synchronize with ac systems and to provide high-quality ac currents without harmonics. DC power systems can integrate dc renewable generation, storage, and building electrical loads easier and more efficiently than conventional ac based systems. A key challenge for the successful market adoption of these systems is the integration with existing electrical loads and power grids in buildings. Hybrid ac/dc microgrids combine advantages of both ac and dc systems and may facilitate the integration process of dc power technologies into existing ac systems. In this work, the performance of a hybrid building microgrid coupling on-site PV generation with ac and dc loads of a residential building is investigated in simulation. An experimental dc network prototype, coupling PV electricity generation to LED lighting in a building, has been built and tested. Theoretical and experimental results are used for the design of a hybrid microgrid, planned to be implemented together with the PV system of a residential research buildings.
Keyword- Hybrid Microgrid, Solar PV, Battery Storage Integration

I. INTRODUCTION

One of the reasons for the success of ac over dc was the invention of the transformer, which can easily convert power from transmission to distribution systems at different voltage levels. An advantage of dc over ac has been recognized for long distance power transmission, because high-voltage dc lines suffer from lower electrical losses and provide better control of power flows. To integrate these technologies into existing ac power systems, complicated dc/ac inverters and controllers are required to synchronize with ac systems and to provide high-quality ac currents without harmonics [1]. Previous work indicated that dc distribution in buildings in conjunction with PV generation and battery storage would eliminate ac/dc and dc/ac conversion stages, resulting in a significant reduction of power conversion losses, lower cost of components, as well as higher system reliability. Hybrid ac/dc microgrids have been proposed for improved interconnection of distributed energy systems including multiple renewable sources (ac and dc), loads, electrical storages, and the power grid[2] .Hybrid ac/dc microgrids exploit the advantages of both ac and dc systems and may facilitate the integration process of dc power technologies into existing ac systems.

Previous research identified advanced control and power management schemes for the efficient operation of hybrid ac/dc microgrids. This work focuses on hybrid microgrids implemented in buildings. Simulation results of a hybrid microgrid coupling PV generation, battery storage, and building loads are presented. The model enables detailed analysis of system performance, influence of component sizes and advanced battery control strategies. Further to the theoretical analysis, initial experimental results of a dc network prototype, coupling PV electricity generation to LED lighting in a building, are discussed. Finally, the design of a hybrid microgrid for a residential research building is presented.[3]

II. HYBRID BUILDING MICROGRID

Dc building microgrids promise significant efficiency improvements and cost reductions, in particular if implemented together with on-site PV generation and battery storage. Despite these advantages, there are several challenges, which hinder the adoption of dc microgrids in buildings. These challenges are related to lack of standardized equipment (dc network components are missing, end use appliances are lacking dc connectivity) and little industrial experience. Our approach therefore focuses on hybrid power networks, which consist of ac and dc networks connected by a bidirectional converter. Hence, both ac and dc loads can be connected. The system topology is designed as flexible as possible, in order to facilitate the successive integration of dc power technologies into existing ac systems. [4]

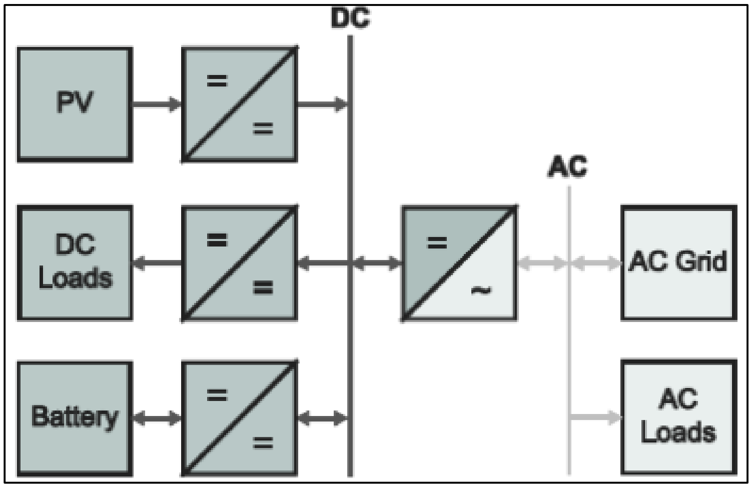

Fig. 1: Hybrid ac/dc building microgrid model

The model uses an electric load profile representative of a single-family home with a time resolution of 10 seconds and a detailed breakdown by appliance type. We find that in the case of a PV system sized to meet annual building demand (with an installed PV power of 7.4 kWpeak), a dc microgrid reduces power conversion losses by approximately 20% without and 30%with battery storage, corresponding to 2-4% of the total electricity demand of the building. Furthermore, the effect of PV and battery storage size on system performance is evaluated, avoided losses of the dc system increase with PV system size. The increase of avoided losses is the highest up to an installed PV power of about 10 kWpeak and a battery capacity of 10 kWh. It levels off at higher values. Further analysis reveals that avoided lossesand accuracy i.e. the share of the total building electrical demand which is covered by PV electricity generated on-site, are close to linearly dependent.[5,6]

III. HARDWARE IMPLEMENTATION

A prototype dc microgrid coupling PV electricity generation to building dc loads has been setup to test the technical feasibility and to measure its efficiency relative to a conventional system.[7] The installation allows direct coupling ofa central rectifier and PV modules to building loads on a dc bus. The main appliance tested in the prototype setup is LED lighting. The lighting control uses a standard DALI (Digital Addressable Lighting Interface) interface to facilitate building integration. A wireless control and monitoring interface enables LED dimming and measurement of dc power consumption.

An additional data logger measures ac power consumption in 5 second intervals. In both cases, ac and dc system, the dimmers enable connection to most LED types (at constant voltage and constant current) for broad building implementation. Experimental results showed that, depending on the dimming level and the amount of supplied dc power, the efficiency of ac/dc conversion is 4-8% higher for the central rectifier used in the dc system compared to the ac/dc power supply of the reference system [8].

Depending on the type of electricity supply (ac power grid or PV), overall system efficiencies at full load of approximately 82-86% for the reference and 90-96% for the dc system are expected. System efficiency at full and partial loads will be further investigated in future measurements. In addition to LED lighting, other dc loads such as variable speed motors, can be powered from the 24 Vdc bus. System performance under these load conditions will be analysed.[9]

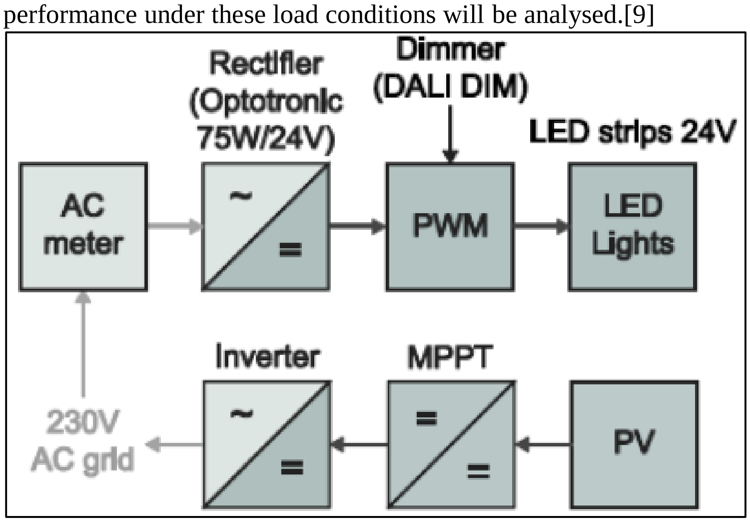

Fig. 2: Main components and power flows from PV supply to LED lighting in the reference ac system

IV. Conclusion

This paper presented research on hybrid ac/dc microgrids for improved integration of PV and battery storage in buildings. Simulation results showed that power conversion losses can be reduced by 20-30% for residential buildings with a net-zero energy balance. The benefits of hybrid microgrids may be even larger for commercial and office buildings with integrated PV, due to a higher share of dc internal loads and increased self-consumption of PV electricity. PV and battery size are important parameters for the evaluation of hybrid microgrid performance. We find that dc networks are most efficient for buildings with a high degree of autarky enabled by a high share of dc renewable sources. Initial results of an experimental prototype indicate that dc microgrid coupling of PV and LED lighting leads to significant efficiency improvements compared to a conventional system.

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