Cyprus University of Technology
Faculty of Engineering and Technology

Doctoral Dissertation

GRID-CONNECTED PHOTOVOLTAIC SYSTEM IN BUILDINGS WITH HYBRID ENERGY STORAGE

Maria Argyrou

Limassol, June 2021

CYPRUS UNIVERSITY OF TECHNOLOGY

FACULTY OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF ELECTRICAL ENGINEERING, COMPUTER ENGINEERING AND INFORMATICS

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Approval Form

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PUBLICATIONS

List of publications (peer-reviewed journals and conferences):

- **M. C. Argyrou**, C. C. Marouchos, S. A. Kalogirou, and P. Christodoulides, "A novel power management algorithm for a residential grid-connected PV system with battery-supercapacitor storage for increased self-consumption and self-sufficiency," Energy Conversion and Management (submitted).

- **M. C. Argyrou**, C. C. Marouchos, S. A. Kalogirou, and P. Christodoulides, "Modeling a residential grid-connected PV system with battery-supercapacitor storage: Control design and stability analysis," Energy Reports (submitted).

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ABSTRACT

The increasing penetration of renewable energy technologies causes major problems in the power network, as their generation cannot be totally predicted. Along with fluctuations in Renewable Energy Sources (RES) production due to weather uncertainties, storage is very important for mitigating several problems that may arise, affecting the stability and reliability of the grid. Thus, storage technologies have gained an increased attention in recent years. In particular, there has been an emphasis on residential storage applications (behind-the-meter storage), with the aim of increasing the energy self-consumption and therefore reducing electricity bills.

A model containing a 3 kW_p rooftop solar photovoltaic (PV) system connected to the grid through converters and a battery-supercapacitor hybrid energy storage system is proposed. The storage devices are connected to the common 400 V DC-bus in a fully active parallel configuration through two bidirectional DC-DC converters. This configuration allows the battery and supercapacitor to have different voltages and their power flow to be controlled separately. A small-signal stability analysis is considered for the design of the current controllers for both the bidirectional converters of the battery and supercapacitor. Moreover, the small-signal stability analysis of the voltage source inverter (VSI) is considered in order to design the DC-bus voltage controller, from which a reference output current is extracted using a phase-locked loop (PLL) for grid synchronization. A new filtration-based power management algorithm (PMA) is proposed, which prioritizes the utilization of the PVs and battery-supercapacitor instead of the grid, thus increasing the self-consumption and self-sufficiency of the building. A comparison between a battery-only and a battery-supercapacitor storage application is performed in long-term operation (24 hours), verifying the effectiveness of the integration of the supercapacitor. In addition, the dynamic performance of the proposed model is verified through several simulations for different scenarios over short time periods (10–30 seconds). The results show that the model works properly and responds extremely fast during different mode transitions, exhibiting a fast DC-bus voltage regulation with a very low ripple voltage (a maximum of ± 0.625%). Also, the supercapacitor handles rapid changes that occur within 0.2 seconds, which can relieve the battery stress and, hence, extend the battery lifetime. Finally, an effective power sharing is achieved between the PV, the battery-supercapacitor storage, the building load and the grid. The proposed model is developed and simulated in the MATLAB/Simulink software environment, based on mathematical analysis and average modeling.

Keywords: grid-connected photovoltaics, battery, supercapacitor, hybrid energy storage, modeling, control, filtration-based power management