

System Identification and Predictive Control for Energy Management of Solar-Powered LED Lighting under Variable Solar Irradiance and Occupancy

Český název

Identifikace systému a prediktivní řízení energetického hospodaření solárně napájeného LED osvětlení při proměnlivém slunečním záření a obsazenosti

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Abstract:

Solar-powered LED lighting systems offer a practical solution for reducing dependence on conventional electricity, particularly in locations where grid electricity is limited, expensive, or unavailable. However, their operation is strongly influenced by the intermittent nature of solar energy generation and by variations in lighting demand caused by human occupancy and environmental illumination. Changes in solar irradiance, weather conditions, battery state of charge, and user demand make it difficult to achieve both reliable illumination and efficient use of the available solar energy. Conventional solar lighting systems commonly rely on fixed schedules, fixed LED brightness levels, or simple threshold- and motion-based control strategies. These approaches primarily react to current conditions and do not adequately account for future energy availability or anticipated lighting demand.

This dissertation aims to develop and experimentally evaluate an intelligent control framework based on system identification and predictive control for a stand-alone solar photovoltaic (PV)-battery-LED lighting system. The research will consider a laboratory-scale experimental system incorporating a photovoltaic panel, battery energy storage, LED lighting, light and occupancy sensors, and measurements of relevant electrical and environmental variables. Experimental data will be used to identify mathematical models describing the dynamic relationships between solar irradiance, battery state, occupancy, lighting demand, and energy consumption. Candidate models will include input-output models such as ARX and ARMAX, state-space models, and, where necessary, nonlinear or adaptive models.

The identified model will be integrated into a predictive-control framework that will determine appropriate LED lighting levels and battery charging or discharging actions over a prediction horizon. The controller will consider predicted solar-energy availability and lighting demand together with the current battery state and relevant operational constraints. Particular attention will be given to maintaining the required level of illumination while minimizing unnecessary energy consumption and avoiding undesirable battery operating conditions. Solar irradiance and occupancy will be treated as important measured or predicted disturbances affecting the future behavior of the system.

The research will investigate the accuracy and suitability of different system-identification approaches for predictive control, with particular emphasis on the trade-off between model accuracy, model complexity, computational requirements, and potential real-time

implementation. The influence of variable solar irradiance and occupancy on the identified system dynamics and control performance will also be analyzed. The proposed predictive-control approach will be experimentally compared with conventional control strategies, such as fixed-time, threshold-based, and motion-sensor-based control, in order to evaluate its potential to improve energy efficiency and system reliability.

The performance of the proposed methodology will be assessed using experimental data and relevant performance indicators, including energy consumption, solar-energy utilization, lighting availability, battery state-of-charge behavior, battery cycling, prediction accuracy, and computational complexity. The research will also investigate the feasibility of implementing the resulting control strategy on a low-cost embedded control platform suitable for practical solar-powered lighting applications.

The research will build on established methods of system identification and predictive control while extending their application to a small-scale renewable-energy system with time-varying energy generation and demand. The overall objective is to develop and validate a computationally efficient and experimentally supported predictive-control methodology capable of adapting the operation of solar-powered LED lighting to changing solar-energy availability and occupancy while maintaining reliable illumination and improving the overall efficiency of energy management.

The main research objectives of the dissertation are therefore to:

1. develop and experimentally characterize a stand-alone solar PV-battery-LED lighting system and collect relevant time-series data under varying solar irradiance, environmental conditions, and occupancy;
2. develop and compare mathematical models of the system using established system-identification methods, including ARX, ARMAX, state-space, and, where necessary, nonlinear or adaptive models;
3. evaluate the identified models in terms of prediction accuracy, complexity, computational requirements, and suitability for predictive control;
4. investigate the influence of solar irradiance and occupancy on the dynamic behavior, energy demand, and operating conditions of the solar-powered lighting system;
5. develop a predictive-control strategy that uses the identified model to coordinate LED lighting operation and battery energy management while considering energy availability, lighting requirements, battery constraints, and changing occupancy;
6. experimentally evaluate the influence of predictive control on energy consumption, solar-energy utilization, lighting availability, battery operation, and overall system performance; and
7. compare the proposed predictive-control methodology with conventional fixed-time, threshold-based, and motion-sensor-based control strategies and assess its potential for implementation on a low-cost embedded control platform.

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