Towards simulation in the loop: Enabling verification of energy management control algorithms for a smart micro grid with electric vehicle fleets

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Abstract

The integration of renewable energy sources and electric vehicles (EVs) into power grids necessitates advanced energy management solutions. Smart microgrids in real estate offer a promising approach, yet their complexity demands innovative verification methods for control algorithms. This study explores the use of Simulation in the Loop (SIL) to model micro smart grids (MSG) as digital twins, facilitating the evaluation of smart control algorithms. The proposed simulation model integrates co-simulation and real-time power grid elements. It employs control algorithms to optimize EV charging processes, prioritizing photovoltaic power and utilizing battery storage for peak load management. Results demonstrate the model's capability to simulate realistic charging processes and integrate dynamic data without interruption.

Introduction and Motivation

The increasing integration of renewable energy sources and EVs into the power grid presents both opportunities and challenges for energy management [1]. In real estate MSGs [2] become a solution to optimize the local grid. As these systems grow in complexity, the need for smart control algorithms becomes vital to ensure reliability and sustainability. But traditional verification methods for algorithms often are difficult to implement in physical grids and therefore other verification methods need to be developed. SIL [3] – based on the concept of Hardware in the Loop (HIL) [4] - offers a dynamic testing environment that mimics real-world conditions and allows an iterative development and validation of algorithms. By integrating a digital twin of a given MSG with real-time data and arbitrary scenarios, this method provides an easier and cheaper evaluation of smart control algorithms, particularly in managing the variable demands of EVs. The motivation behind this research is to show the usage of SIL concepts for modelling micro smart grinds as a digital twin and evaluating smart control algorithms within existing micro smart grids. This approach not only enhances the development of smart control algorithms but also supports the transition of real estate to micro smart grids.

Applied Method

The presented simulation model is based on a SIL approach and it combines the concepts of co-simulation and real-time [5]. It provides a realistic representation of electric vehicle charging infrastructure. The essential components of this simulation model include the simulation environment, a time series mock service, an OCPP-Adapter and a Charging Station Management System (CSMS). The simulation environment, developed in Matlab Simulink, represents the core of the entire simulation model, enabling real-time simulations. It facilitates realistic simulations of EV charging processes and the power supply infrastructure. The power supply is comprised of a combination of grid connection, photovoltaic system, and battery storage system [6]. These components are integrated through a control algorithm that accounts for real-time fluctuations in power demand and generation. The algorithm is configured to prioritize photovoltaic power, strategically utilizes battery storage to mitigate peak loads, and draws on grid power when required. Vehicle charging behavior has also been modeled to simulate realistic EV charging processes. Charging process data is transmitted in real-time to the CSMS via an OCPP-Adapter, where the simulated data is processed similarly to data from real charging stations. Multiple data streams like PV profiles, charging profiles or grid operators signals were integrated from arbitrary sources outside of the simulation model.

Results

In numerous simulation runs the capabilities and feasibility of the presented model was demonstrated. Furthermore, it demonstrates that realistic charging processes can be generated and transmitted correctly to a CSMS. Additionally, charging sessions can be remotely terminated at any time via the CSMS without interrupting the simulation run to show interactivity between Simulation and Real-World. Additionally, the external PV and vehicle data can be modified or extended at will and integrated directly into the ongoing simulation. The battery storage was used for peak load smoothing and grid operator signals were simulated. Within the CSMS, all conducted charging sessions are visible and indistinguishable from regular charging sessions. Therefore, the simulation model can be utilized for multiple MSG testing purposes without the need for a physical interaction within the mimicked systems.

Conclusions

This work demonstrates that it is possible to use SIL to model MSGs as digital twins and to evaluate control algorithms on it. With the integration of the software systems of the MSG it is possible to evaluate algorithms or modifications to the grid without a direct interaction with the real grid. In future work, the focus should be to generalize this approach to enable modelling arbitrary MSGs with arbitrary components in it and with arbitrary software systems connected to it. Also, the development of new algorithms concerning grid control should be addressed.

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