LABLINK – A NOVEL CO-SIMULATION TOOL FOR THE EVALUATION OF LARGE SCALE EV PENETRATION FOCUSING ON LOCAL ENERGY COMMUNITIES

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ABSTRACT

The rising penetration of distributed generation, electric energy storage and battery electric vehicles (BEVs) leads to new challenges and opportunities in the energy system. Local intelligences such as home energy management systems (HEMS) are a possible solution for the synergies between these distributed actors. In order to evaluate the large-scale deployment of these approaches, sophisticated test systems are needed. This paper presents a novel co-simulation middleware called Lablink which is used to test the large-scale deployment of HEMS and BEVs in a low-voltage distribution grid. Photovoltaic (PV) generation as well as controllable storage is also included. Two example HEMS implementations are evaluated with respect to their grid sustainability. Results show that the combination of HEMS with distributed storage systems can mitigate voltage magnitude issues.

INTRODUCTION

Distributed generation, local electricity storage and other actors such as Battery Electric Vehicles (BEVs) will play an essential role in low voltage grids. Due to the ongoing reduction of battery prices [1], applications utilising batteries become more and more economic.
While today, most Austrian domestic Photovoltaic (PV) systems are grid-connected [2], new applications take advantage of the synergies between the PV production and a local electric energy storage. Instead of directly coupling the PV with the distribution grid, the locally produced power can be stored and used within the household microgrid. An increased self-consumption of PV power raises the economic viability of the PV system [3]. Solutions combining local PV generation with energy storage systems prove to be economic, and will be even more so in future scenarios. These new business cases are expected to result in an increased penetration for PV, battery storage systems and BEVs.
Due to the shift in the generation from conventional powerplants to renewables and distributed energy generation (DER), a higher demand for flexibility services arises.
This development can be addressed by the expansion of demand side management (DSM). DSM aims at providing flexibilities to local loads at the consumer side [4]. An enabling technology for DSM can be a Home Energy Management System (HEMS) at the household level of the local energy community [5].
A HEMS can be implemented in a variety of ways. Examples include local smart charging, load-shifting and peak-shaving approaches for large power- and electrical energy-consumers such as BESSs and BEVs. Some examples for HEMS implementations and smart charging algorithms can be found in [6][7].
The testing of such systems and algorithms can be done in different approaches, as for example, pure software simulation, controller hardware-in-the-loop or power hardware-in-the-loop. Each of these approaches provides a subset of benefits and disadvantages.
Co-Simulation is a different approach combining multiple of the above. It provides an ideal approach to simplify the overall system by distributing the complex logic of the sealed actors among multiple independent simulators [8].
Several protocols exist that support co-simulation, such as the Functional Mock-up Interface (FMI) [9] and Mosaik [10].
The Lablink middleware presented in this contribution provides a tool which meets extensive requirements for co-simulation and offers various ways to implement the communication between hardware components, user applications and commercial simulations.
As an example implementation for this paper multiple home energy management systems that include PVs, BEVs and storage systems are simulated and connected to different nodes of a large low voltage grid. The impacts of a near-future BEV penetration scenario are evaluated by utilising a precise BEV model [11] whose charging process can be controlled by the implemented algorithms of the HEMS.

LABLINK

Besides the implementation of control interfaces for each actor, a managing middleware-software is needed which exchanges data between the actors and takes care of the synchronisation.
In this work, a middleware called Lablink is introduced and implemented in a complex co-simulation setup consisting of various comprehensive simulators. Lablink provides easy to use interfaces and services for any software that intends to exchange data with other actors. It enables a modular co-simulation control that supports hardware-in-the-loop (HIL) approaches as well as a simple data-exchange between simulators. Several types of actors are linked to form an interoperable communication environment.

Structure and Services

Based on Message Queuing Telemetry Transport (MQTT)-communication, Lablink adds high-level communication layers to the basic MQTT messaging schemes.
By providing different communication services for the

data-exchange, the development of any software-project that needs co-simulation is strongly facilitated.
Lablink builds up a hierarchy that assigns application-, group- and client-names to the participating actors and thereby supports the routing of exchanged data.
There are three ways to communicate via Lablink:

- **Messaging**: Lablink messages are implemented similarly to the publish- and subscribe-schemes used in MQTT, but with the additional support for complex datatypes. The message containing a hierarchical topic and the individual payload is published to the MQTT broker and forwarded to the subscribing participants.
- **Remote Procedure Calls (RPC)**: An RPC is a request-reply pattern that is established between specific actors. The requester directs a message to a recipient who must reply within a certain time-period. RPCs also support variable payload-types and are often needed in simulations that need synchronous communication in addition to asynchronous methods.
- **Datapoints**: Implemented by hidden RPCs, Lablink datapoints provide an automatic synchronisation of primitive datatypes between several actors. One actor is the owner of the datapoint (e.g. a temperature sensor), and the others create a consumer object and connect to it. Their common value stays synchronised, and it is configurable who may update it.

When using Lablink RPCs and messages, complex payloads can be created to encapsulate related data and to speed up the encoding- and decoding-processes needed for the MQTT protocol. In comparison to Lablink datapoints, messages and RPCs provide more flexible publish- and subscribe-methods during the simulation runtime.
Datapoints, however, are the easiest way to keep simple data of several actors synchronised over time. For example, the simulators do not have (but are allowed) to implement event-handlers for the synchronisation of their variables. Physical devices that provide measuring data can thereby quickly be coupled with other simulators.

<u>Synchronisation</u>

In order to perform a co-simulation that connects different actors, a synchronisation of the simulation time is necessary, especially if the environment is intended to be used for HIL. Lablink provides a Sync-Service which enables such a central control of all simulators. If the simulation participants (Sync-Clients) implement the Lablink Sync interface, then a central simulation manager (Sync-Host) can initialise any predefined simulation scenario by sending client-specific scenario-information to the participants.

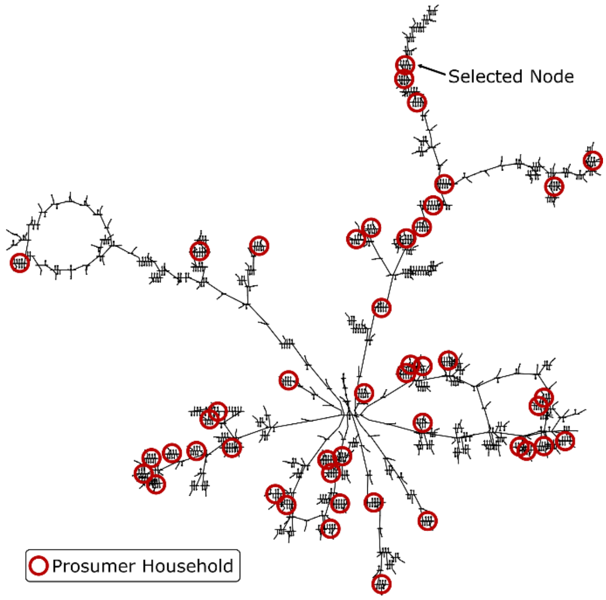

Figure 1 Topology of the simulated low-voltage grid

CO-SIMULATION SETUP

A large low-voltage grid, depicted in Figure 1, as well as the household load data were implemented in a grid simulation and connected to other simulated actors via a Lablink co-simulation. The peak load of the transformer is 680 kVA. Out of the 280 households connected to the selected grid, 46 were chosen to represent future prosumers who utilise HEMS [6].
Each of these simulated HEMS consists out of a central management and control agent, as well as an independent simulator for each included HEMS component. Every defined prosumer household includes PV generation, a BESS and an electric vehicle supply equipment (EVSE). This results in a penetration of 16,4 % for prosumer households.
Utilising the virtualisation software Docker, which provides a significant performance boost for high performance computations [13], the entire setup of a HEMS instance was incorporated. As a result, 46 individual instances were generated.
In order to implement battery electric vehicles in the co-simulation, the instances of a BEV model were connected to the nodes equipped with an EVSE. This corresponds to a BEV penetration of 13.1 % assuming an average of 1.25 passenger vehicles per household.
The BESS and BEV charging process can be dynamically controlled depending on the implemented HEMS logic.
The peak generation of the local PV was chosen according to a typical size distribution in rural Austrian low voltage grids. The BESS capacities were distributed according to home energy storage systems found on the market today.
The utilised BEV model [11] reacts to EVSE control functions (e.g. by smart charging algorithms) and can simulate the precise charging characteristics of commercial vehicles. This includes EV-specific reaction

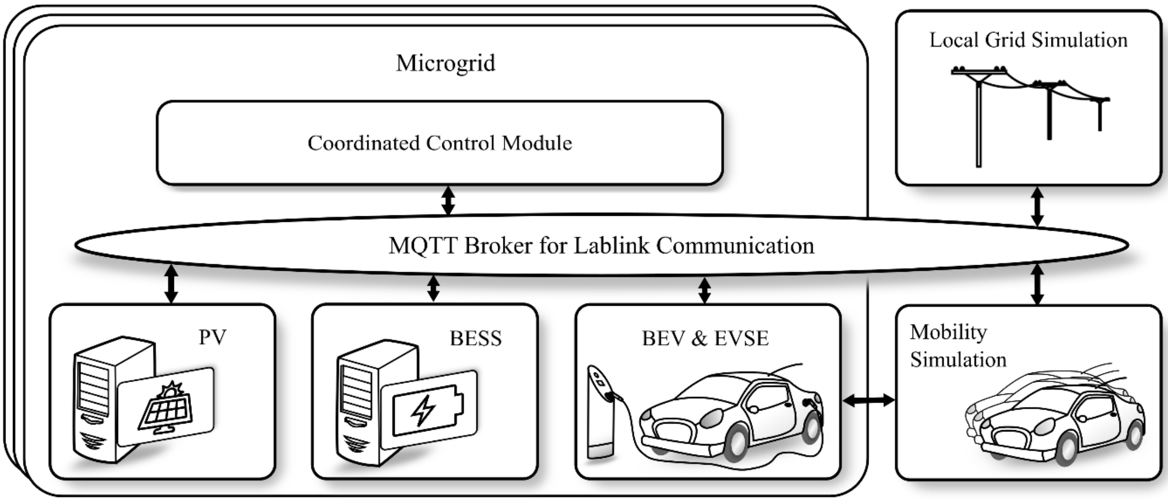

Figure 2 Large-scale co-simulation setup using the Lablink framework

delays, charging initialisation phases, the constant-current and the constant-voltage phases of Li-ion battery charging.

A mobility simulation was used to schedule the driving-behaviour of these different BEVs. The individual driving-profiles were calculated with a statistical distribution model that simulates typical mobility patterns based on real driving behaviour.

The whole co-simulation setup can be seen in Figure 2.

Implemented HEMS Control Algorithms

The presented large-scale grid scenario was simulated using two different control algorithms for the household that included a HEMS. For the first implemented control strategy, the goal was to maximise the self-consumption of in-house produced PV electrical power. Therefore, it implemented charging of the BESS whenever excess PV power was available and discharging at times when fewer PV power was being generated than consumed. Also it always allowed charging of the BEV with the minimal charging power, and increased charging power whenever surplus PV power was available.

The second algorithm used, controls the whole charging and discharging process of the BESS and the BEV as a function of the local node voltage level.

These two algorithms are compared with a scenario of equal EV penetration without any smart charging algorithms implemented. Referred to as 'No Optimising Control' in Figure 3 and Figure 4.

In this case, the households with a BEV and PV generation did not include a BESS.

RESULTS

The results presented in Figure 3 show how the BESS power, the EVSE power and the voltage level developed at a specific critical node throughout such a large-scale simulation. It can be seen that the BESS is charged as soon as PV power is available, and discharged as soon as the power is needed to charge the BEV.

In the case of the first algorithm, Figure 3 shows that as soon as the PV generation exceeds the local consumption the battery is being charged. Respectively as soon as the EV is connected the BES discharges in order to charge the EV.

For the second algorithm, the results depicted in Figure 3 show that the charging and discharging power of the EV and the BESS follow the grid voltage.

DISCUSSION

Figure 4 shows a zoom to the simulation results between 17:30 and 19:30, the peak time regarding the charging of the BEVs. The depicted results show the same node as Figure 3. When several households use the grid voltage level aligned control strategy and are located at neighbouring nodes in the grid, oscillations between the

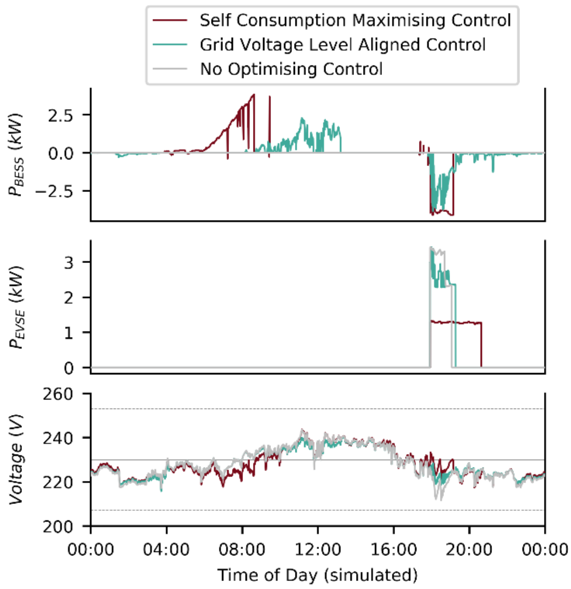

Figure 3 Active power and voltage of one phase for a critical grid node throughout a 24-hour simulation

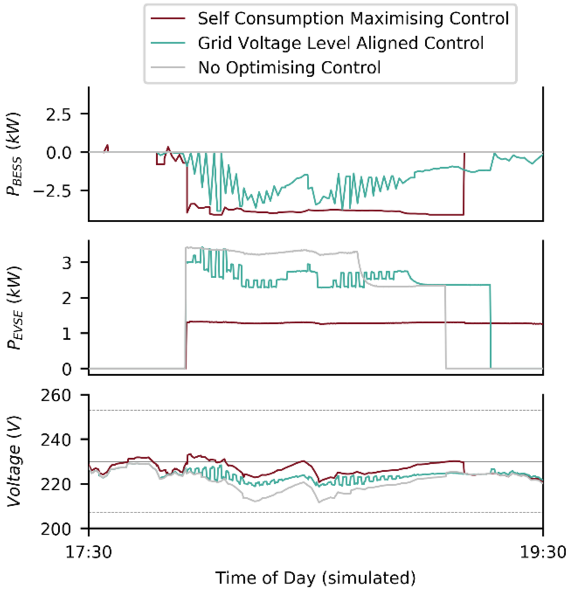

Figure 4 Oscillations occur when dis-/charging of BESS and BEV are controlled using the current grid voltage level

voltage level and the charging power for the different actors in these households occur. This is a very definite danger for smart charging algorithms whose control depends on the local node voltage. Such effects would even further increase with a higher penetration of prosumer households that involve local electric energy generation and storage in combination with an EV for transportation. The implemented algorithm for this contribution did intentionally not include time delays or other methods to mitigate oscillations as these oscillations show that the interconnection of multiple independent simulations via the Lablink is working. If a time delay for the control of single HEMS would be implemented, it is very likely that the oscillations could already be mitigated to a certain extent. Other approaches might even have a more beneficial impact. The proposed test environment can be used to evaluate exactly this kind of behaviour and/or implementation.

Both implemented algorithms were able to increase the voltage level at critical grid nodes for times with a lot of EV charging, as well as reducing the voltage level during times with a lot of PV power feed-in to the grid. The algorithms provided here are definitely not market ready, but were an attempt to represent prominent approaches to home energy management and demand response measures with simple algorithmic procedures.

CONCLUSION

This contribution presents a novel co-simulation middleware, the Lablink. This middleware allows for an easy implementation of large scale scenarios by coupling multiple individual simulators. The implemented algorithms for this contribution are designed in a simple way to demonstrate the functionality of the framework as such.

Lablink has proven to be an effective tool to evaluate large scale integration scenarios for smart grid technologies and the resulting effects on power networks. Future work will include more sophisticated control algorithms and in-depth analyses of different penetration scenarios for BEV's and future prosumer households.

An extended co-simulation including power hardware-in-the-loop will also be conducted. Thereby, the charging process of a real BEV and BESS can be controlled by a HEMS instance which is connected to one of the multiple simulated grid nodes. In this way, precise real-life feasibility checks of proposed smart charging algorithms are possible.

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