# Real-time simulation of Distributed Generators, for testing a Virtual Power Plant software

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**Abstract:** Virtual Power Plants (VPPs) are designed to monitor and schedule a large number of decentralized producers and consumers via intelligent software. A possible way to test the VPP functionality is to interface its software with simulated producers and consumers under various scenarios. This paper presents the development of the real-time simulation platform "OpSim" and its first application as a testing environment for VPPs. A test case is described, in which the VPP from Bosch Software Innovations is connected to a simulated CHP plant on the OpSim platform. It is shown that the VPP can monitor this plant via a standardized interface "VHPready 3.0". Time shifts in the signal between VPP and OpSim are observed. Moreover, a future outline is given, for applying real-time simulations as a testing method for VPP software.

## 1. Introduction

The vast installment of renewable energy sources has led to a significant amount of decentralized power sources in German power grids [1]. Unlike conventional power plants, these distributed generators (DGs) are chiefly located in the distribution grid at medium and low voltages. This poses control challenges for distribution grid operators, who now have to monitor and handle a multitude of small generators. Moreover, single DGs may be too small to bid into energy- and ancillary service markets, creating challenges for DG-operators who aim for optimal profits.

A way to mitigate these problems is by pooling the DGs together with storages and flexible loads (collectively referred to as "units") to so-called "Virtual Power Plants" (VPPs) [2, 3, 4]. The VPP contains intelligent software, which monitors and schedules the operation of a large number of decentralized units. The pool can be marketed optimally and provide ancillary services, e.g. frequency control [4], similar to an ordinary power plant.

The VPP-software must be thoroughly tested, to ensure an optimal scheduling of its vast pool of units. For example, it should be verified that the VPP can manage a large portfolio and deal with large quantities of status information from each unit in the pool. Such tests could be performed partially offline, with simulated DGs, storages and loads, as simulations have the advantage that various scenarios can be tested before new hardware is connected to the VPP. Yet, to ensure that testing conditions are realistic, the simulations should run in real-time and communicate to the VPP software via the same interface that a real DG, storage or flexible load would use. Hence, an ordinary offline simulator would be insufficient for this task.

In this paper, we introduce a prototype development of a real-time simulation platform "OpSim" [5, 6], for testing aggregation and grid operation strategies. In a first functional test, we use this platform to simulate a DG and connect it via a standardized interface to the VPP of Bosch Software Innovations. Hence, OpSim provides a first functionality to test VPP software. Through this test, we validate (A) if the VPP can monitor the simulated DG and (B) if there are any latencies between simulation and interface.

The paper is structured as follows: first, related research on real-time simulations is reviewed. Second, the OpSim platform is introduced. Third, results of the test run with the VPP from Bosch Software Innovations are evaluated. Finally, future applications and follow-up works are outlined.

## 2. Related Work

This section reviews existing works, in which real-time simulations are used to test Smart Grid control strategies (each strategy is marked by italic text). In our nomenclature, such strategies could be a VPP, but also e.g. a voltage control algorithm.

- The OFFIS institute released the co-simulation platform "mosaik 2.0", to combine different simulators and controllers. One application was the combination of a grid simulator *with an agent-based voltage control strategy* [7].
- Faschang et al. introduced a rapid control prototyping platform for networked Smart Grid systems [8]. It comprised of a message bus architecture, to connect *prototype grid controllers (in the example, a controller for tap changers and reactive power in low voltage grids)* to grid simulators. Its purpose was to test the controller under increasingly realistic conditions, up to a field test implementation.
- In [9], a real-time simulation of two medium voltage feeders with nine controllable DGs was established, to evaluate an *online voltage optimization algorithm* for DGs and tap changers. Apart from demonstrating the algorithm's ability to run in real-time, the grid simulations showed that the algorithm improved the voltage in three exemplar simulations.
- A real-time testbed for *wind park controller soft- and hardware* was developed in [10]. The testbed consisted of detailed turbine, grid and wind field models, which were solved with parallelization methods on multiple computers.
- Georg et al. [11] designed a hybrid architecture to enable a combined simulation of both power systems and communication architectures. Its aim was to validate real-time capabilities of *power system protection and control algorithms*.
- In the Project "SIEM", a real-time simulation of electric vehicles is developed [12]. In particular, the simulation is used to test a number of *smart charging strategies* on simulated electric vehicles, to evaluate if such strategies relieve loading peaks in the grid.

In various applications, one particular type of controller (e.g. protection, voltage optimizer) is the main focus, though some works aim for an architecture which allows multiple control strategies to be active at the same time. "OpSim" also belongs to this category.
In particular, real power systems are controlled by multiple mechanisms, some being market-driven (e.g. VPP) while others are crucial to maintain the grid within acceptable operating conditions (e.g. technical VPP [13]). Investigating them in a holistic simulation environment is the goal of our project.

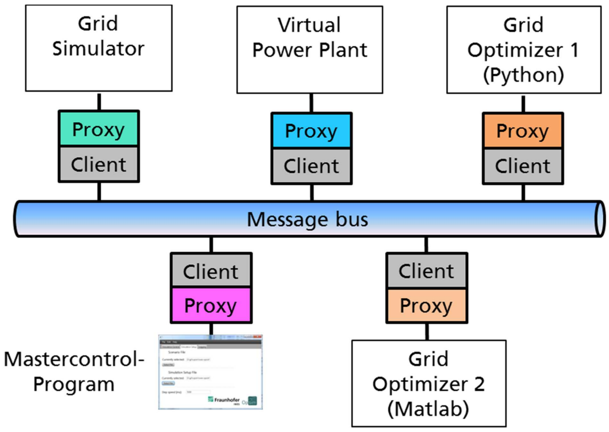


***Fig.1**:The OpSim platform for distributed simulations of power systems.*

## 3. The OpSim platform

OpSim is a platform for real-time simulation of power systems which interacts with multiple control systems, such as voltage optimizers and VPPs. The system architecture is motivated by the concept in [8] and consists of three parts, which will be briefly explained in the next subsections.

### 3.1. Components

As shown in Figure 1, OpSim connects several distinct components to emulate a power system with multiple control strategies. In this context, the word "component" has two meanings: (A) it can be a simulation (e.g. Opal-RT [14]) to emulate the electric grid with its variety of generators, storages and loads and (B) it can be a controller, which is either a simulation itself (e.g. a control block in Simulink) or a fully developed software (e.g. a VPP). Combining multiple components enables us to model a complex power system, in much more detail than an ordinary grid simulator provides.

### 3.2. Message bus

Components exchange information via a message bus, which forms the center of the OpSim platform and runs as a server application. Since each component is a different software with its own variables, programming language and interface, the components are not directly connected to the message bus. Rather, a client and proxy (written in Java) govern this interaction.

### 3.3. Proxy/Client architecture

Each component in OpSim is situated behind a client and a proxy. This architecture is motivated by the concept in [8]. The client is highly generic and handles the (dis)connection, synchronization and information filtering of a component. The proxy on the other hand, is component-specific and serves as "translator" for data between a component and the message bus. Hence, when a new component (e.g. a VPP) is connected, only a new proxy needs to be created, whereas an existing client can be used.

## 4. Connecting VPP and OpSim

This section demonstrates the first stage of using OpSim as a testing platform for VPP software; a simulated CHP plant model is connected to the VPP of Bosch Software Innovations, via the standardized interface "VHPready 3.0". This section discusses the components of this test, as shown in Fig. 2.

### 4.1. VPP of Bosch Software Innovations

The VPP from Bosch Software Innovations is designed to support many different scenarios, depending on local and national rules, regulations and constraints. The common requirement is a supervising software that pools/groups the units connected to the VPP. Hence, a modular VPP was designed to enable varying business cases by utilizing a flexible software. The main functions of the Virtual Power Plant Manager are:

- Master data management
- Time series management
- Asset control interfaces
- Forecasting capabilities
- Optimization of varying business cases
- Monitoring of operational business
- Reporting for business and audit requirements

### 4.2. VHPready and SIP Component

In order to connect the VPP and a simulated CHP plant, OpSim must provide the same communication interface as real CHP plants. The SIP (Standard Interface Preparator) is the link layer for this purpose. It provides different functions for external systems, such as data collection and operating control (e.g. interpreting VPP schedules). In the present setup, an interface has been realized which

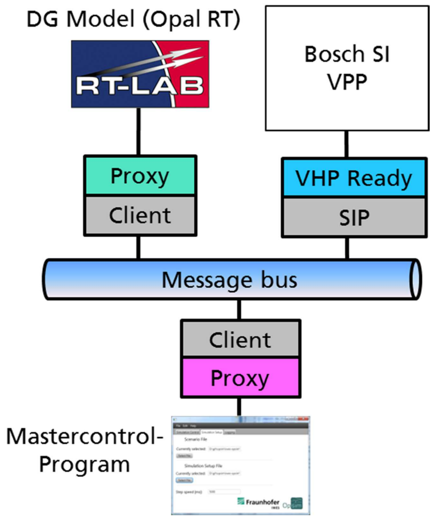


***Fig. 2***: *Setup to connect a VPP software to a simulated DG (CHP plant), using the OpSim Platform. Source of Opal-RT image: [14].*

prepares a VHPready 3.0 server to interact with the simulated CHP plant. VHPready is a popular open industrial standard for the connection of DGs and flexible loads to a VPP [15], based on either IEC 60870-5-104 or IEC 61850-7-420.

### 4.3. Simple CHP plant model

A CHP plant is modelled in real-time on an Opal-RT simulator [14]. The model is kept very basic, as its main purpose is to test the connection between VPP and OpSim. However, it does provide all variables of VHPready, including 15 minute energy-meters and status information. The dynamic behavior of the model is captured by the following equations:

$$T_{ramp}\frac{dP_{el}(t)}{dt} = P_{set}(t) - P_{el}(t), \qquad (1)$$

$$P_{th}(t) = P_{el}(t)\cdot\frac{P_{th,nom}}{P_{el,nom}}, \qquad (2)$$

$$\frac{dE_{th}(t)}{dt} = P_{th}(t) - P_{disturbance}(t), \qquad (3)$$

$$P_{fuel}(t) = \frac{P_{el}(t)+P_{th}(t)}{\eta_{total}}, \qquad (4)$$

in which Eq. (1) describes the dynamic response of the electric power $P_{el}$ of the plant to a power setpoint $P_{set}$. Equation (2) describes the thermal power output, which is simply scaled with the electric output. Equation (3) describes the energy $E_{th}$ in the thermal storage of the plant, due to thermal production $P_{th}$ and disturbances $P_{dist}$ (=heat consumption, here assumed to be zero) and finally,

| Symbol | Meaning | Value | Ref. |
|---|---|---|---|
| $T_{ramp}$ | Response time of CHP | Variable | - |
| $P_{th,nom}$ | Nominal thermal power | 97 kW | [16] |
| $P_{el,nom}$ | Nominal electric power | 50 kW | [16] |
| $\eta_{total}$ | Total plant efficiency | 87% | [16] |
| $E_{th,max}$ | Thermal storage size | 194 kWh, thermal prod. of 2 hours | [17] |

***Tab.1:*** *Main parameters of the CHP plant model.*

Equation (4) describes the fuel (e.g. natural gas) consumption by a total efficiency parameter $\eta_{total}$. The parameter values are motivated by a number of references, shown in Table 1.

Finally, the simulation is started and stopped through the “Mastercontrol-Program”, which is also connected to the message bus (Fig. 2). Once the simulation has started, the VPP can connect via VHPready and receives real-time measurements from the simulated CHP plant. The entire test setup as shown in Fig. 2 is performed on geographically distinct computers:

- The message bus runs on a server at Fraunhofer IWES in Kassel. The SIP component and VHPready interface run on a distinct server, also at Fraunhofer IWES.
- The Opal-RT System, with the plant model, runs on a host PC and OP-5600 hardware at the University of Kassel.
- The Bosch VPP is being operated in a Bosch data center. The VPP runs on standard AMD- or Intel-based server hardware and Windows or Linux as the operating system.

In the following section, results from a first simulation with OpSim are discussed.

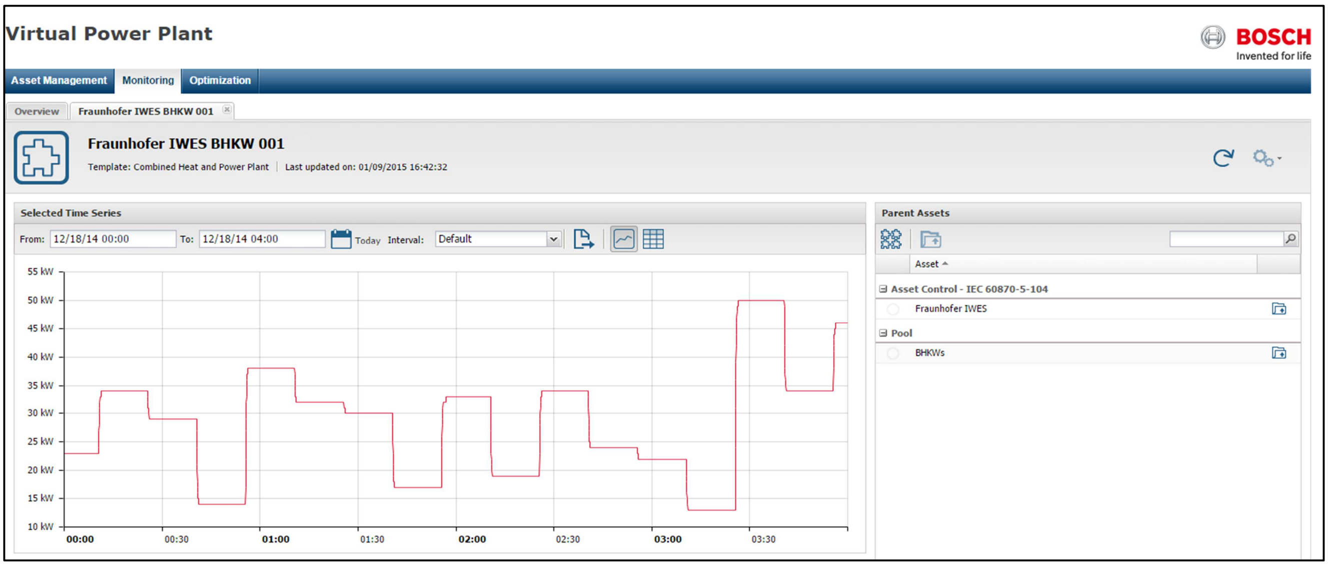


***Fig. 3****: Active power measurement of CHP model “IWES BHKW 001” on Bosch SI VPP Interface.*

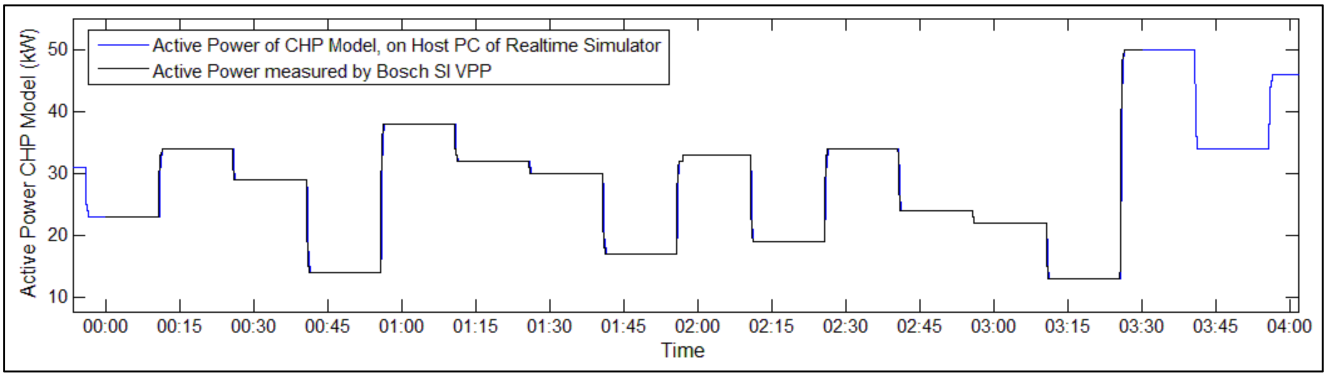


***Fig. 4****: Comparison of CHP plant model active power on the host PC of the real-time simulator (blue curve) against the active power measured by the Bosch SI VPP (black curve) on 18 December 2014.*

## 5. Results

A real-time simulation of OpSim was started on 17 December 2014 around 17:00. Briefly thereafter, the Bosch SI VPP connected to OpSim via VHPready. This test continued until 11:00 on 18 December, during which the CHP plant model was assigned a random active power setpoint every 15 minutes. This assignment was done within the model itself, as the main goals of this test were: (A) to verify if the VPP successfully received the varying output of the CHP plant model and (B) detect if there exist any remaining time lags between the simulation components.

During this 18 hour testing period, the VPP registered the active power from the CHP plant model. Figure 3 shows the monitoring of the VPP on 18 December on a four hour exemplar interval. In addition, Fig. 4 compares the electric power of the CHP plant model, running on the Opal-RT system, to the electric power measured by the VPP. On the scale of hours, the comparison appears quite well and indeed, the VPP measures the simulated CHP plant in OpSim, as if it were a part of the VPP portfolio.

Second, since the simulation is decentralized, the system is built to handle time delays between its components. Indeed, between model and VPP, time shifts have been observed. For the first application of energy marketing, these time shifts were negligible. For future applications with VPP and grid simulations, the time shifts will be investigated further.

## 6. Discussion and next steps

This paper introduced the ''OpSim'' simulation platform, a novel tool for testing smart grid control strategies on a real-time simulated power system. The discussed application was a test of a Virtual Power Plant software; on OpSim, a model of a CHP plant was simulated in real-time, while the platform offered a standardized interface (VHPready 3.0). To this interface the VPP software by Bosch Software Innovations was connected, to monitor the simulated CHP plant as if it was real hardware.

The first test results appeared promising: on a simulation test interval of 18 hours, the active power of the model was registered by the VPP. A closer investigation of the timing on a four hour exemplar interval showed that between the time stamps of the model and the VPP, there exists a time shift. The origin of this time shift will be investigated further in subsequent works.

### 6.1. Future applications for VPP tests

On the short term, real-time simulations from OpSim could be used to test the connection between VPP and multiple units on a technical level, e.g. under normal operation conditions or emulated communication failures in the units. Also, a pool of simulated units can be used to test which VPP optimization gives the optimal economic result when scheduling the pool.

On the longer term, the VPP can expand into a Grid Optimization Manager (GOM), which monitors conventional units (e.g. generators, storages, loads), but also grid voltages and transformers, to provide ancillary services for grid operators. For this GOM, OpSim could be a testing environment, to emulate large grid models with a high amount of households, renewables and storages (e.g. electric vehicles). In such an environment, the GOM could be tested under normal operating conditions or during grid faults, for development and training purposes.

### 6.2. Future applications for grid control

Besides the discussed VPP applications, OpSim will be used as test and simulation platform in other applications, such as grid operation strategies. For example, to test new distribution management systems (DMS) on vast simulated HV/MV/LV grid areas – one could reduce the timing and amount of data exchanged between a grid simulator and DMS, and evaluate if the DMS can still keep the grid within desired technical boundaries. Also, a more sophisticated coordination between distribution- and transmission grid operators, via provision of ancillary services between their grid areas, promises considerable room for improvement.

## Acknowledgments

This work presents selected results from the project, ''OpSim'', performed by Fraunhofer IWES and University of Kassel, funded by the Federal Ministry for Economic Affairs and Energy under grant no. 0325593A and 0325593B, based on a decision of the Parliament of the Federal Republic of Germany. The authors take full responsibility for the content of this paper.

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