

The Microgrid Simulation Tool RAPSIm: Description and Case Study

Manfred Pöchacker, Tamer Khatib, Wilfried Elmenreich
Institute of Networked and Embedded Systems / Lakeside Labs
Alpen-Adria Universität Klagenfurt, Austria
manfred.poechacker@aau.at, tamer.khatib@aau.at, wilfried.elmenreich@aau.at

Abstract—This paper presents a free and open source microgrid simulation framework for better understanding of power flow behavior in smart microgrids with renewable sources. It is able to simulate grid-connected or standalone microgrids with solar, wind or other renewable energy sources. The proposed software calculates the power generated by each source in the microgrid and can conduct a power flow analysis. This software is helpful for optimal placement of distributed generation units in a micro grid. The software RAPSIm is designed for use in science and classroom with a simple to use graphical interface. It is an easily extendable framework that supports users in implementation of their own gridobject models and grid controlling algorithms.

Keywords Microgrids, Power system simulation, Load flow, Renewable energy sources

I. INTRODUCTION

Renewable energy sources installation in electrical power systems plays an important role worldwide due to the fact that renewable energy sources are clean, environment friendly and secure energy sources. However many renewable energy sources as Photovoltaic (PV) or wind power are dependent on momentary meteorological conditions and therefore less predictable and/or controllable than traditional energy sources. Consequently, modeling and simulating these sources in the power system is very important in order to study their impact on the power flow and quality of the power system [1].

In order to assess the overall energy of renewable energy production the natural fluctuation can be averaged according the simulated time resolution. Even if this approximation is sufficient it might be necessary to refer to special weather and climate models which are usually not within the scope of power-grid simulation. For this reason specific software tools for modeling and simulation of renewable energy sources have been developed separately to address specific problems like sizing, outcome prediction or economic analyses. A summary of them is given in section I-A. Software tools for (smart) grid simulation, as reviewed in [2], can perform a variety of analysis and functions but often they leak on specific models for single renewable sources. Many common simulation models refer to averaged values from a large ensemble or over long time periods. These statistical models are not adequate on the microgrid scale because of the few

involved entities. This is not only true for sources but also for models of loads which means an average household load profile is no longer applicable. These are, for instance, scenarios of just-in-time and just-in-place energy services as pointed out by Ilic in [3].

In this paper, the software tool RAPSIm is presented for the simulation of smart microgrids [4]. The software provides basic models for simulation of various renewable energy sources and load demands within a microgrid. Moreover, it is able to simulate the performance of the applied renewable energy sources considering some uncertainty of the meteorological conditions. The simulator is further able to conduct power flow analysis for the microgrid which helps in analyzing the impact of the renewable energy sources on the power system. Finally, the user can easily implement own models or algorithms and modify existing ones. This software is helpful in simulating smart microgrids, model its components as a part of a self-organizing system [5] and for optimal placement of renewable energy sources in the power system to achieve the best power quality and flow conditions.

The following paragraphs give a brief overview on current software tools for renewable energy sources. For an overview on power system simulation consult [2]. Section II contains some requirements for a general wished software design before the structure of the RAPSIm is presented and some simulation methods and basic models are explained more detailed. In section III we present a simple case study demonstrating the abilities of RAPSIm.

A. Simulation of Renewable Energy Sources

In [6], a software tool named as the PHOTOV-III has been developed to determine required capacity of PV array and storage for standalone and grid tied PV systems. This software generates the sizing curves but does not calculate the actual sizes of the PV system. Moreover, the software does not provide any power flow analysis for the grid connected system. In [7], a software program has been developed in FORTRAN for calculating the renewable energy source size area based on a well-defined weather profile. The limitation of the program is that it is not user friendly. In addition to that, no power flow analysis can be conducted in case of grid connected systems. Another renewable energy software tool has been developed to monitor the performance of a small renewable energy system in a remote area [8]. The software is used to monitor PV system but does not conduct an analysis of the monitored data. On the other hand, several commercially available software tools for simulating

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TABLE I. COMPARISON OF COMMERCIAL PV SOFTWARE TOOLS.

Software	Powerflow Calculation	Source Simulation Capability	Design Capacity
RETScreen	-	-	-
PV F-Chart	-	✓	✓
SolarDesignTool	-	✓	✓
INSEL	-	✓	-
TRNSYS	-	✓	-
NREL SAM	-	✓	-
PVSYST 4.33	-	✓	✓
SolarPro	-	-	-
PV DesignPro-G	-	✓	✓
PV*SOL Expert	-	✓	✓
HOMER	-	✓	✓
PV.MY	-	✓	✓

renewable energy systems and smart grids can be found in [9]. These commercial software tools are RETScreen, PV F-Chart, SolarDesignTool, INSEL, TRNSYS, NREL Solar Advisor Model, ESP-r 11.5, PVSYST 4.33, SolarPro, PV DesignPro-G, PV*SOL Expert, HOMER and PV.MY. These software tools have been developed for analyzing various types of renewable energy systems. Table 1 shows a comparison made on the capability of the software tools in simulating renewable energy sources. As indicated, the ability of conducting a power load flow for smart power grids is missing in all of them.

The RETScreen software tool analyzes the economic aspects of renewable energy systems. However, the simulation techniques employed in the software are rather limited. The PV F-Chart software provides analysis for designing standalone renewable energy systems. However, the option of simulating hybrid renewable energy system in one microgrid is not included. Moreover, the software provides a monthly performance estimation which may not be as accurate as the daily performance estimation. The SolarDesignTool software provides design recommendations for grid connected renewable energy systems but it does not predict their performance and impact on the grid. The INSEL software has the capability of simulating renewable energy systems but the power flow analysis is not considered. The TRNSYS is a simulation program used for simulating renewable energy systems. An example for application of the simulation program is performing dynamic simulation of a solar hot water system for a typical meteorological year so that the long-term cost savings of such a system could be ascertained. However, the impact of the simulated renewable energy sources on the power system is not analyzed. The PVSYST 4.33 software has the capability of determining the sizing of standalone and grid connected renewable energy systems but not for hybrid PV systems and it is not able to simulate such systems, while the PV DesignPro-G only deals with grid connected renewable energy systems design. Meanwhile, the Solar Pro incorporates calculations that consider shading effects, I-V curve and power and financial analysis. The PV*SOL Expert provides visualization capability useful for visualizing all roof parallel and roof integrated PV systems and also calculates shading on the basis of 3D objects. The HOMER software program is a very good optimization

and simulation tool and it has been widely used by many researchers. This software provides direct optimization for all types of renewable energy systems and performs emission and economic analyses for the designed system. Moreover, HOMER software is able to predict the performance of the designed renewable energy system. As with the other tools, the power flow analysis of the microgrid is not considered. PV.MY software presented in [10] calculates the optimal renewable energy sources size. In addition, the PV.MY is able to predict daily performance of the designed system for one year. However, the PV.MY is also not able to conduct power flow calculation for micro power grids.

Beside explicitly dedicated software for renewable energy simulation there exist power system simulators contributing to this field. GridLAB-D [11], as one example, offers import functions for meteorological data and detailed models for distribution grid devices and residential houses. Unfortunately it is completely tailored to the conditions in the US. But national differences exist not only in the technical standards and the prevailing grid design. The current and even more the upcoming energy systems are affected by the local climate, geographical, legal and cultural conditions, as demonstrated in [12]. They determine availability of other (alternative) sources and they shape price policies and consumer behavior. And in the same way a simulator must be adoptable to local conditions of the microgrid under investigation.

II. PROPOSED SOFTWARE DEVELOPMENT

The proposed software tool for microgrid simulation combines models for renewable energy sources and power grid simulation methods. The main application field are considered to be microgrids, from the household level up to distribution grid, on low and medium voltage level. As many power system simulators analyze the state of the grid under certain conditions they do not require any time specification. For temporal simulation of meteorologically dependent sources the simulation of daytime and weather condition is absolutely required. That type of time-based simulation is as well required for evaluation or calibration of models with measured data.

Naturally the combination of power grid simulation and renewable source simulation requires a two level structure: One level for the single grid-objects, e. g., a renewable source, and another one for the grid. Between these two levels it is essential to define an interface so that different models can be easily exchanged. Flexibility on usage of different object-models is further important for elaborate load simulation, for instance the case of a smart house that can perform demand response [13], [14] or a charging station for electric vehicles. Many of the existing tools described in the previous section bring well developed functionality in their field. It would be, of course, beneficial to reuse some of them as far as possible. In the best case the suggested software tool can preform co-simulation with already existing tools. A publication under a public software license is highly welcomed as it would be for other promising tools as [15].

A. The Smart Microgrid Simulator RAPSIm

RAPSIm is developed at the Institute of Networked and Embedded Systems of the Alpen Adria University Klagenfurt. Raps is further the German word for the plant colza or

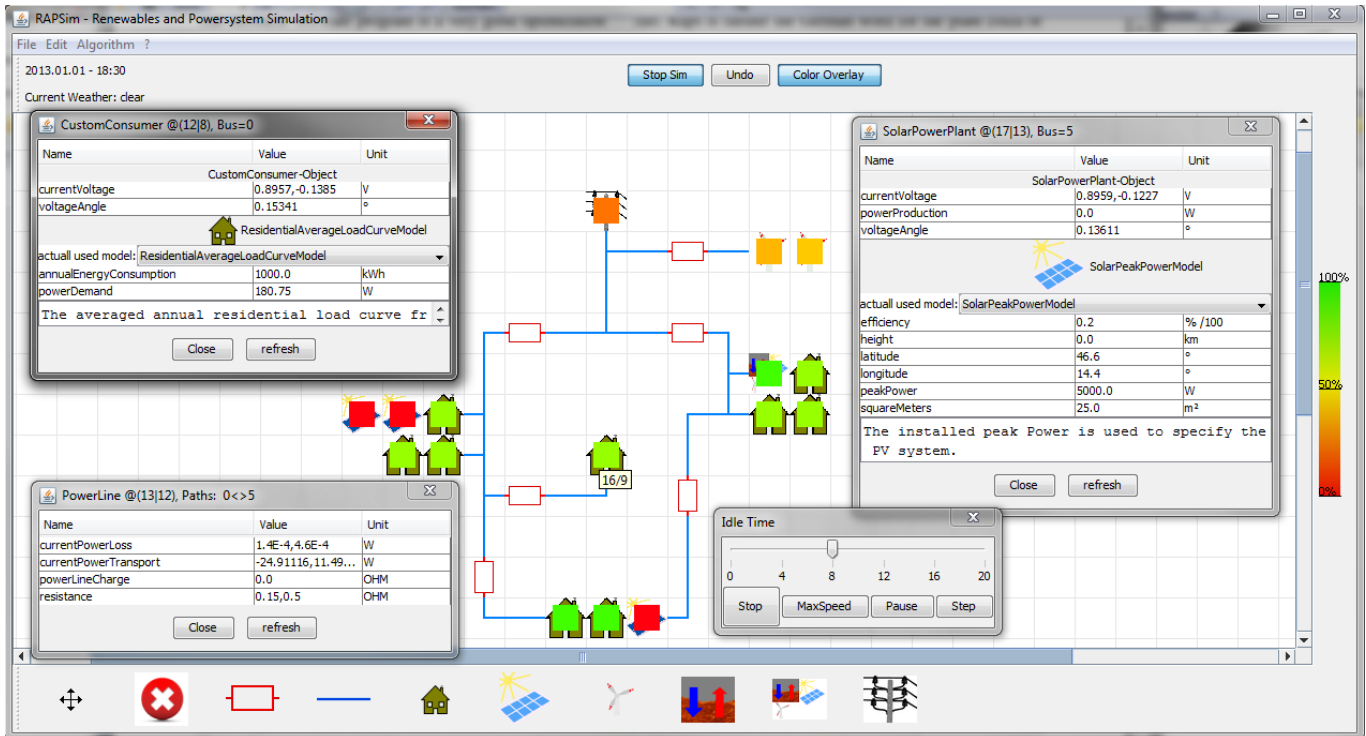


Fig. 1. The main window of RAPSIm is showing the lattice-like simulation field where objects can be placed and connected as needed. By the property window object parameters could be displayed and edited. The shown power line do not have a model, for the house and the solar power plant are different models selectable. The color overlay provides direct feedback on the current state of objects by use of heat-maps. A tool-tip gives the objects position in the grid. There are several control options for the running time thread, e. g., setting the idle time, stepwise incrementation or continuation without time delay.

brassacia norpus. As the plant contains a lot of energy, its oil is very prominent as alternative, green fuel for engines. The software is meant to be an alternative for green energy as well and should grow successively. Besides the application in science and engineering the usage in the classroom is essential. The software has a user friendly graphical interface with direct feedback on running simulations and support for graphical outputs. Users without programming skills can use the basic algorithms and models for renewable energy sources as they are implemented by the graphical interface. Advanced users with programming skills can add their own models or extend and modify existing ones according their needs. Further it is intended to keep the software modular and open to use in combination with other tools. That could be specific power system simulation or renewable energy source software, import of meteorological data, an optimization tool or a hardware interface with a laboratory [16]. The programming language for implementation is Java. The simulator runs on various platforms such as Windows, Linux or MacOS. Figure 1 shows the main window of the Smart Microgrid Simulator.

The basic simulation field is a lattice where different objects could be placed and edited. Objects are power generation, transportation, and consumption entities. Each object in the simulation holds a set of parameters. These parameters are used as an interface to the rest of the grid and to the algorithms which are running on the grid level. The parameters could be accessed through the property window that opens by right click on the object. More complex objects

that require additional calculations, like the power production of a PV generator, own a *Model*. The Model wraps all calculations and specifications of the object that are not of interest for the rest of the grid. The desired Model is selectable in the property window where also model variables and a description are displayed. The property window for the solar power plant in Figure 1 holds also information about the position of the object in the lattice. All the objects form the grid in the simulation field. Grid analysis and calculations, e. g., power flow, are done by *Algorithms*. The wished Algorithm can be chosen at the menu bar.

The software is an easy useable framework where the user can focus on implementing Models and Algorithms. Models capture different behavior for the same object. Algorithms manage all grid wide occurrences between the objects, like the power flow analysis. The simulation framework cares about other functions which includes

- the graphical interface,
- provision of a time and a weather thread,
- topological grid analysis,
- managing of Models and Algorithms,
- save and load of Scenarios and
- output of results.

All these functions are accessible by the graphical interface. The graphical interface allows placing, moving and editing of each single object by the specific icon. Further it supports displaying of color overlays, i. e., color maps that are cross-faded with the Grid-Objects. So the user can get direct visual feedback on current running simulations by use of easy

understandable heat-maps.

The state of the time and weather thread is displayed in the main window. The time thread is specified when starting a simulation, by entering start-, end-date and the time increment in minutes resolution. The running simulation can be controlled directly by functions for hold, stepwise increment and setting time delays. As well the objects properties can be modified during run-time. The weather thread is currently running on a simple random model which is meant to serve the Models of renewable generators. Import of external weather data for a specific place is planned to be integrated.

Power flow analysis, which is one of the implemented algorithms, does work on busses and paths instead of single objects. The busses and paths are defined by the topology of the grid and contain different number of objects. RAPSIm performs a topological grid analysis to identify busses and paths. They are returned as a set of aggregated parameters and a list containing the involved objects. This is a valuable service for any algorithm implementation.

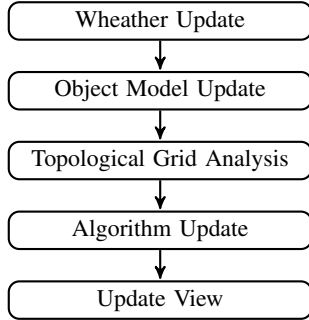


Fig. 2. This tasks are executed in this order within each simulation step.

The implementation of new Models and Algorithms is simple but requires some Java programming skills. An abstract Java class needs to be extended and the specific methods implemented. An additional Model (or Algorithm) is automatically recognized and selectable via the graphical interface. Grid-scenarios, i. e., all the placed objects and their parameters, are stored in compressed .xml format and can be loaded later on. Time series over a simulation run can be gathered in a result file. Values for the specified parameters of selected objects are written at each time step in .csv format.

B. Simulation of Renewable Energy Sources

At the current state of development, the proposed software is able to simulate photovoltaic systems as well as wind turbine in the microgrid. The output power of a PV array depends on the available solar radiation G and the ambient temperature T . The output power of a PV array increases linearly as the solar radiation increases, and decreases as the ambient temperature increases. Thus, the instantaneous output power of a PV array can be given by,

$$P_{PV}(t) = P_{peak} \frac{G(t)}{G_{standard}} - \alpha_T [T_c(t) - T_{standard}] \quad (1)$$

where $G_{standard}$ and $T_{standard}$ are the standard test conditions for solar radiation and ambient temperature, respectively and α_T is the temperature coefficient of the PV module

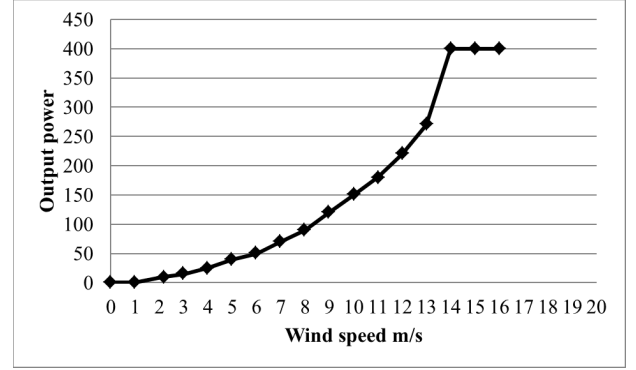


Fig. 3. An example for a common wind turbine characteristic with 400W of rated power, P_{rated} , and wind speed parameters of $v_{cutin} = 1\text{m/s}$, $v_{rated} = 14\text{m/s}$ and $v_{cutout} = 16\text{m/s}$.

power which can be obtained from the datasheet. P_{peak} is the rated power of the PV array while T_c is the cell temperature and it is given by,

$$T_c - T_{ambient} = G(t) \frac{NOCT - 20}{800} \quad (2)$$

The abbreviation NOCT stands for Nominal Operating Cell Temperature. It is measured in normalized condition of 800 W/m² radiation, 1 m/s wind-speed and 20°C of ambient temperature.

Figure 3 shows an example of the power curve of a wind turbine. The output power of any wind turbine is a function of the wind speed. From Figure 3, the characteristic of this wind charger can be described as follows:

$$P = \begin{cases} 0, & v_{cutout} < v < v_{cutin} \\ P_{rated}, & v_{rated} < v < v_{cutout} \\ C_1 e^{C_2 v} + C_3 e^{C_4 v}, & v_{cutin} < v < v_{rated} \end{cases} \quad (3)$$

Where, v_{cutin} is the speed that the turbine start working at, v_{cutout} , the wind speed at which the turbine stop working at and v_{rated} the wind speed that the wind turbine generate its rated power. The coefficients, C_1 to C_4 can be calculated by fitting tools based on actual measurements.

C. Power Flow Calculation of a Microgrid

The power flow analysis is important in order to analyze the impact of the added renewable energy sources on the microgrid variables. The power flow analysis is usually done using simplified notation namely a one-line diagram and per-unit system, and aims to calculate the values of grid bus voltages and phasor angles as well as real and reactive power. Power flow analysis is usually done for the study of transient states of the microgrid. Power flow analysis is extremely important for designing a smart grid whereas it is an essential step finding the optimal size and place of any renewable energy based distributed generation. In the power flow problem, it is assumed that the real power and reactive power at each load bus are known. However, for generator buses, it is assumed that the real power generated and the voltage magnitude is known. For the slack bus, it is assumed that the voltage magnitude and voltage phase are known.

Therefore, for each load bus, both voltage magnitude and angle are unknown and must be solved for. In the meanwhile, for each generator bus, the voltage angle must be solved for. While, there are no variables that must be solved for the slack bus. In a system with N buses and R generators, there are then

$$2(N - 1) - (R - 1)$$

unknown variables. In order to solve for these unknowns the power balance equations are used. These equations can be written for real and reactive power for each bus. The real power balance equation is:

$$\sum V_i V_k (G_{ik} \cos \theta_{ik} + B_{ik} \sin \theta_{ik}) - P_i = 0 \quad (4)$$

where P_i is the net power injected at bus i , G_{ik} is the real part of the element in the bus admittance matrix Y_{BUS} corresponding to the i^{th} row and k^{th} column, B_{ik} is the imaginary counter part of the same element and θ_{ik} is the difference in voltage angle between the i^{th} and k^{th} buses. As for the reactive power balance equation which can be written as follows:

$$\sum_{k=1}^N |V_i| |V_k| (G_{ik} \sin \theta_{ik} + B_{ik} \cos \theta_{ik}) - Q_i = 0 \quad (5)$$

where Q_i is the net reactive power injected at bus i . These equations describe the real and reactive power balance equations for each load bus. Only the real power balance equation is written for a generator bus, because the net reactive power injected is not assumed to be known and therefore including the reactive power balance equation would result in an additional unknown variable. For similar reasons, there are no equations written for the slack bus. There are several different methods of solving the resulting nonlinear system of equations. The most popular methods are Newton-Raphson method, Gauss-Seidel method and Fast-decoupled-load-flow method. Within RAPSIm is used Gauss-Seidel method to solve these equations.

III. A TEST CASE FOR RAPSIM

By the use of a test scenario the reader should get an idea how the presented simulator is working and what results can be produced so far. The simple scenario with four busses is shown in Figure 4. It consists of two branches connected to a grid feeder. A photovoltaic generator is introduced which is connected to one and the other of the two branches. The results demonstrate the difference in voltage quality between this two cases of PV integration.

The three modeled loads are constant with a real power demand of 12kW (bottom position), 8kW (left) and 10kW (right position). The reactive power demand is set 10% of the real part. The power lines are modeled according the π -equivalent circuit model with a line resistance of 0.1 and a reactance of 0.2Ω without capacity to ground. The PV system is specified with a peak power of 10kW, active power only. The output of the PV system is modulated with a time dependent solar radiation factor while temperature influence is neglected. The solar radiation factor includes light of day according the position of the PV at the globe and time of the year and a random cloud factor. The cloud factor is set by

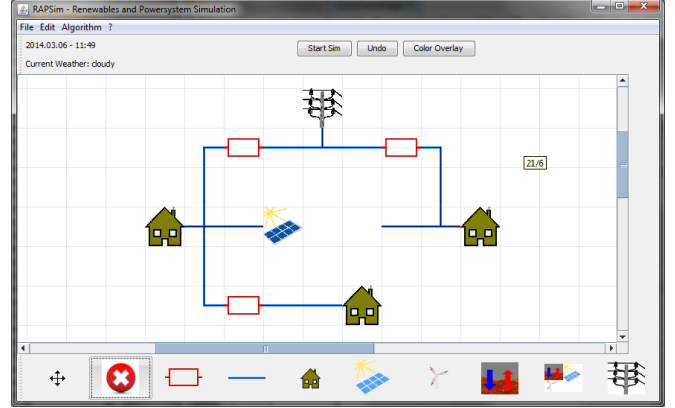


Fig. 4. This simple four bus system with grid connection is used to show the effect of changed PV position onto the voltage levels in the microgrid. The busses are numbered counter clockwise starting from the bottom. The PV is connected to bus 2 and in the second case to bus 4.

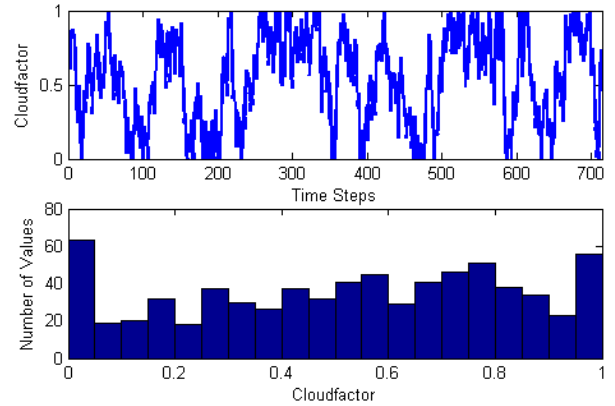


Fig. 5. The Cloudfactor is generated by an random toy model. The time line shows the hourly values as used in the simulation. The histogram characterizes the distribution produced by the implemented random process.

the weather thread. It is generated by a random toy model for hourly change of cloudiness. The exemplary timeline is shown in the upper part of Figure 5. The model is inspired by [17] and gives high occurrence of extreme values and a some-like equal distribution between them, as visible in the histogram of Figure 5.

The scenario was simulated for 29 days with 60 minutes resolution starting from the first of July. The simulation was executed two times with the different PV connection, i.e., Bus 4 and Bus 2. The random seed for the weather thread was fixed to reproduce the same cloud conditions. The global position of the PV generator is specified by the default values (Latitude 46.6° , Longitude 14.4°) at mean sea level. The implemented AC-Power Flow uses the grid connection as the slack bus. All other busses are assigned to be of generator type, in case the net power is above zero, or a load bus otherwise. Figure 6 shows the four bus voltages normalized to the slack bus (Bus 3). For the upper graph the PV is connected to Bus 4, the bottom one shows the scenario as depicted in Figure 4. The used model does not consider any voltage control unit for the PV system. The produced power is just fed into the grid and so the alteration of the bus

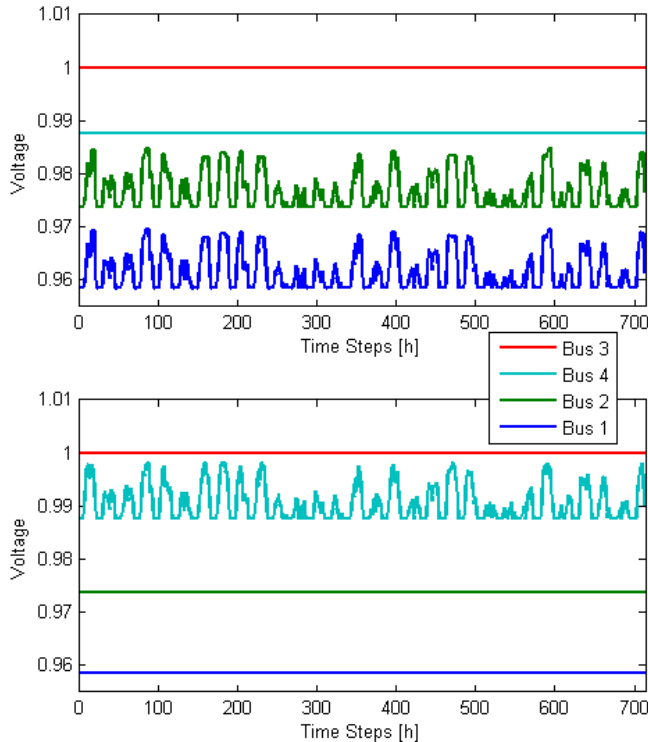


Fig. 6. Bus Voltages for different position of the PV system with one month of simulation time by hourly timesteps. The lower graph shows bus voltages for the scenario as shown in Figure 4. For the upper graph the PV is connected to the right house, bus number 4. For the PV is no voltage control considered.

voltages match exactly the fluctuation in the PV production driven by the weather condition, or more specifically the sun radiation factor.

IV. CONCLUSION AND FOLLOWING WORK

We introduced RAPSIm, an open-source software tool for simulation of renewable sources within a microgrid. RAPSIm can be used in simulating grid-tied and off-grid scenarios and combines power system analysis methods and models for different renewable energy sources. The simulation report generated by the software contains power flow analysis of the microgrid as well as information about the generated power by the renewable energy sources in the grid. An example for utilizing the proposed software is presented showing its ability to find the optimal placement of a distributed generation unit in a microgrid. A main emphasis for this system is on a comprehensive user interface and easy extendability. In the current stage the simulation framework offers a number of basic models. Implementation of further, more elaborate models is continually going on. The software design supports implementation of grid-object models and grid-wide algorithms by the user. It provides functionality for time and weather simulation, for data output and scenario management. Currently planned tasks include the improvement of the weather and climate simulation and to increase the variety of implemented models, including data

import. The graphical interface will provide possibilities for data file specification and selection of different predefined color overlays. The graphical output of time-series will be an additional step. This simulation software will be released as open-source software for all who are interested in smart grids and distribution generation. The public release of RAPSIm is hosted at <http://rapsim.sourceforge.net>.

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