DIGITAL TWIN OF DISTRIBUTED ENERGY DEVICES

P.Tugarinov, F.Truckenmüller, B.Nold, Reutlingen University, Germany

A digital twin - a replica of energy devices - was established in the computing environment of MATLAB and Simulink. It simulates continuously their operation and is time synchronized and connected to the central energy management and control system of a virtual power plant. The model can be used as a platform for testing device performance in various conditions, working schedules and new optimization options.

Up until 2010, it was technically impossible to create computerized systems that repeated the characteristics of physical objects in almost real time. Only a development of digital technologies, which allowed increasing computing power and lowering the price of their use, has led to a major leap in the digitalization of production processes, in which physical or analogue resources could be replaced by information or digital resources [1].

Digital twins are digital replicas of physical objects. They can be used to optimize the operational process of the corresponding physical objects.

The "digital twin" concept is the part of the fourth industrial revolution and was designed for faster detection of physical problems and better prediction of physical results [1]. Companies seeking both operational and strategic benefits, started to combine information technology with operational processes to create digital twins [2].

Implementing models of machines in operation allows to the industrial companies use more data and algorithms to make better decisions. Which is followed by improving processes, reducing costs and improving customer experience.

A demonstration platform for virtual power plants has been built at Reutlingen University [3] [4]. It is used for the study of different approaches of operation, optimization and control of distributed energy devices [5]. A number of physical energy devices have been installed at the university campus. Groups of those devices have been connected to common controllers and form so-called microgrids. The microgrid "residential" connects typical energy devices of a residential house with heat pump, thermal storages and solar systems. The microgrid "business" connects energy devices for a medium sized enterprise [4].

As a part of the demonstration platform project it was decided to create the digital twin, which could allow to change amount and capacities of distributed energy resources, therefore provide flexibility of Smart Grid energy management and wider horizon for developing new optimization solutions. As well creating the showcase for identification of problem nodes and plan actions to optimize energy consumption in production in order to reduce costs. Microgrid "business" has been chosen as a prototype for this purpose.

This microgrid consists of a Combined Heat and Power plant with maximum 20 kW electrical power production and almost 2,000 liters of high-temperature heat storage, an adsorption chiller, several fan coils, four electric cars chargers 22 kW capacity each and a photovoltaic system with a peak power 212 kW. All of the components are installed on the territory of the Reutlingen University campus and form together the equivalent of a medium sized company's microgrid. (Fig. 1)
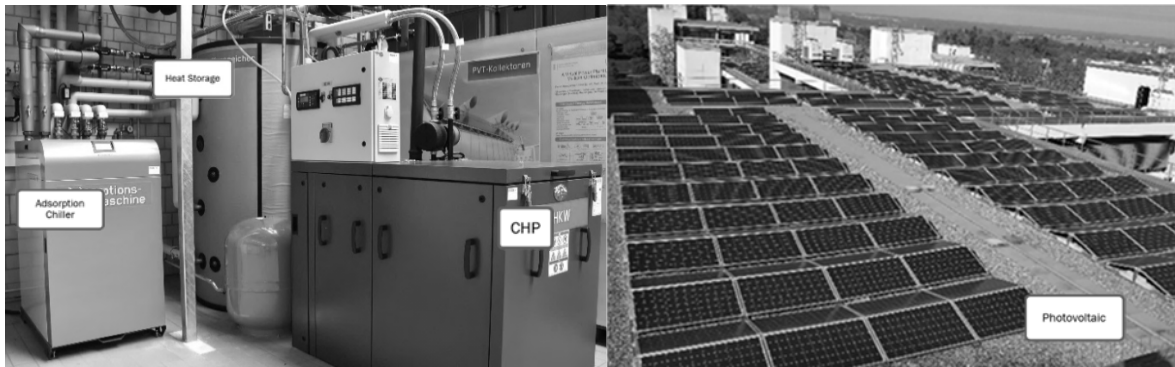
Fig. 1. Components of the microgrid „business" on the campus site of the Reutlingen University.

Digital twins need to maintain a specified level of accuracy. In the present case it is connected to the management system of the virtual power plant. The choice of the simulation environment for creating the digital twin fell on MATLAB and Simulink. In this simulation environment a wide range of possible systems can be implemented. The software was installed on a virtual machine on an university server within the secure virtual private network of the virtual power plant.

Designing a digital twin involves identifying the most important nodes of an energy device and creating a model of these nodes. The model states of the digital twin need to be calculated within a given period of time. The process of calculating model states is known as solving the model. MATLAB and Simulink include several solvers, based on different solving approaches, such as Runge-Kutta methods. However, no single method of solving a model applies to all kind of systems. Each solver embodies a particular approach to solving a model [6].

The simulation of the model must be dynamic, i.e. the model states continuously or rapidly change over time. Therefore it was decided to imply Continuous Variable-step type of solver, which vary the step size during the simulation and uses numerical integration to compute continuous states of a model at the current time step based on the states at previous time steps and the state derivatives. The step size defines the certain time period between successive calculations of the model state (Fig. 2) [2] [6].
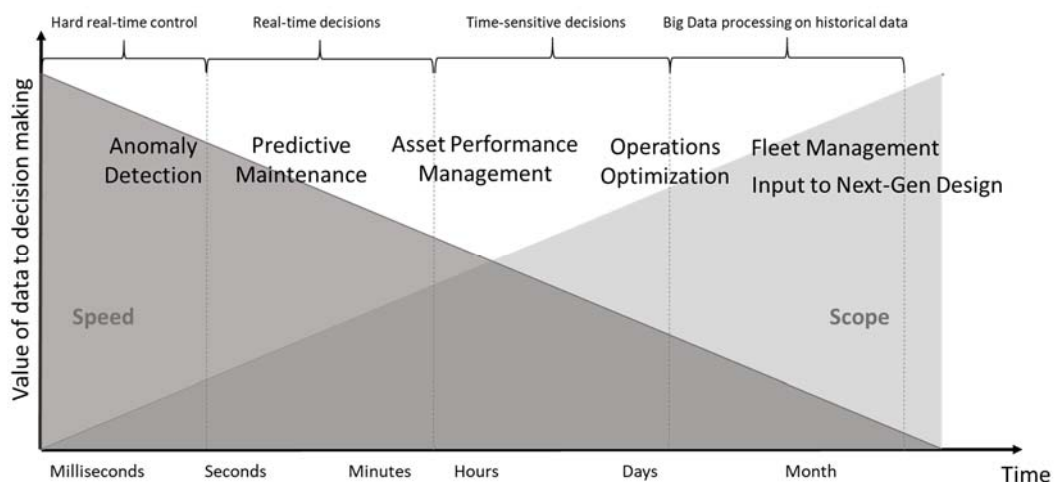

Fig. 2. Choosing the simulation step size (illustration based on [2]).

The variable-step type of the solver determines the simulation step automatically. Despite this, a determination of the maximum simulation time step is required. For this purpose, various ratio options of calculation speed to model accuracy were tested, ranging from 10^{-5} sec to a quarter of an hour.

The best test results were between a second and a minute. Due to limitations in the input data, such as weather data or communication signal from system management, the choice was made in favor of the minute option. In the case of precise simulation periods, the missing input data is linear interpolated.

In addition to the MATLAB and Simulink standard routines, the following toolboxes and libraries were used to model the system: Simscape, Simulink Desktop Real-time, Simulink Real-Time, Stateflow, Powertrain Blockset, Real-Time Kernel, Financial Toolbox. For the correct operation of SimScape, Powergui with Simulation type Phasor and Frequency 50Hz were used.

The digital twin of distributed energy devices from microgrid "business" consists of a main Simulink model, several auxiliary models and a number of MATLAB scripts that perform different functions (Fig. 3).
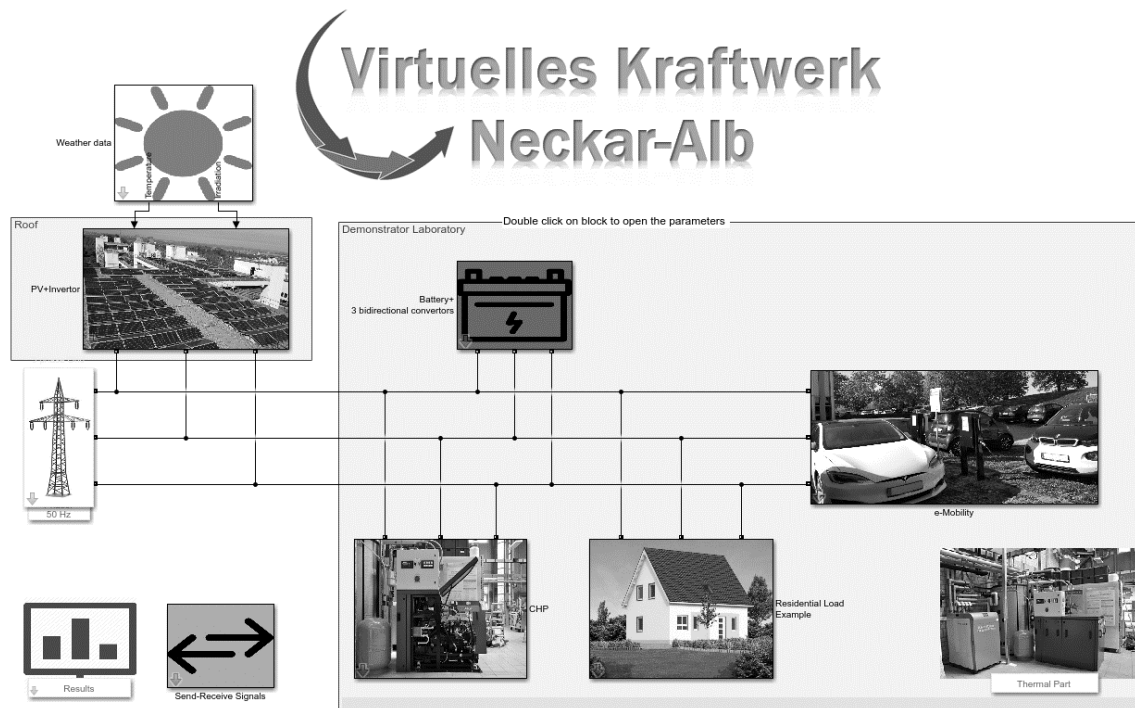

Fig. 3. Digital Twin of distributed energy sources.

Initially, the digital twin was launched and operated continuously in real time, sending a signal to the central system management every minute. Later on, the drawbacks of this method of operation were revealed, such as possible desynchronization with the real time of the computer, as well as the inability to make corrections and changes to the already running model, etc. Therefore, it was changed into a program script that is called every minute, adjusts the start and end time of the simulation according to the server time, and then starts the simulation. During the simulation, Simulink calculates all required intermediate results for a time period equal to one minute, which is the same as periodicity of data transmission to the energy management and control system. This method has made working with the model more convenient.

Since establishing of the digital twin started shortly after all the devices were purchased and installed, integration of historical data from past machine usage is not possible.

The model includes electric and thermal parts with representatives of several distributed energy resources installed it the laboratory, such as combined heat and power plant, photovoltaics, electrical car charging station, heat storage, etc.

A representative electrical network interconnects all electrical components of the model. The network consist of the Three-Phase Unlimited Voltage Source element from the library of Simscape Electrical. The network parameters are 50Hz Frequency and 230V Phase-to-ground voltage and

equivalent to the typical German electricity distribution grid parameters.

Standard annual consumption profiles, as well as real consumption data of the campus or partner companies, can be used as electrical load and heat demand (Fig. 4).
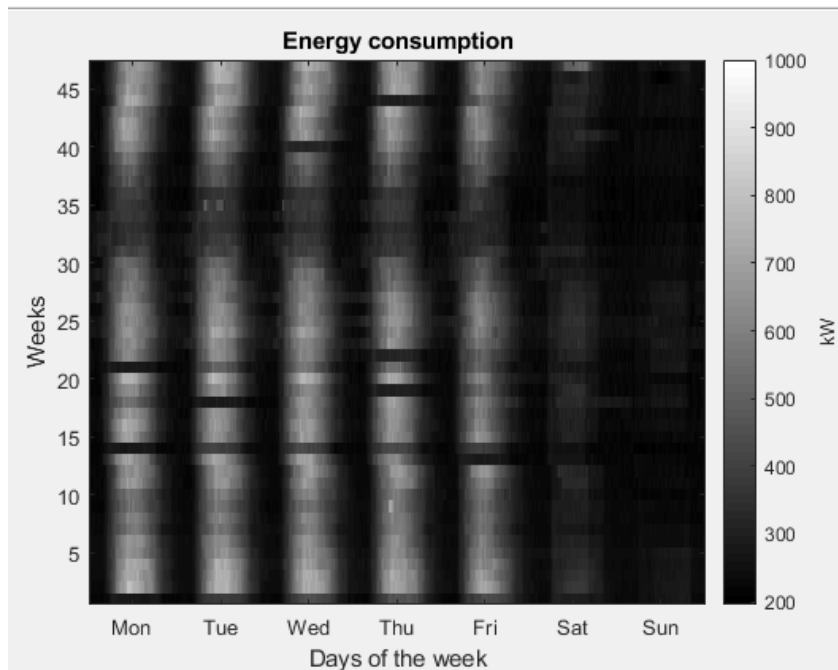

Fig. 4. Example of an industrial annual energy consumption profile.

The model of each electrical device calculates the amount of power produced or consumed at each time index. Afterwards, the power value is transformed into a Simscape-Electrical signal and connecting to the common grid.

For example, the model of photovoltaic solar panels takes the input values of temperature and solar radiation and calculates the corresponding output power (Fig. 5).
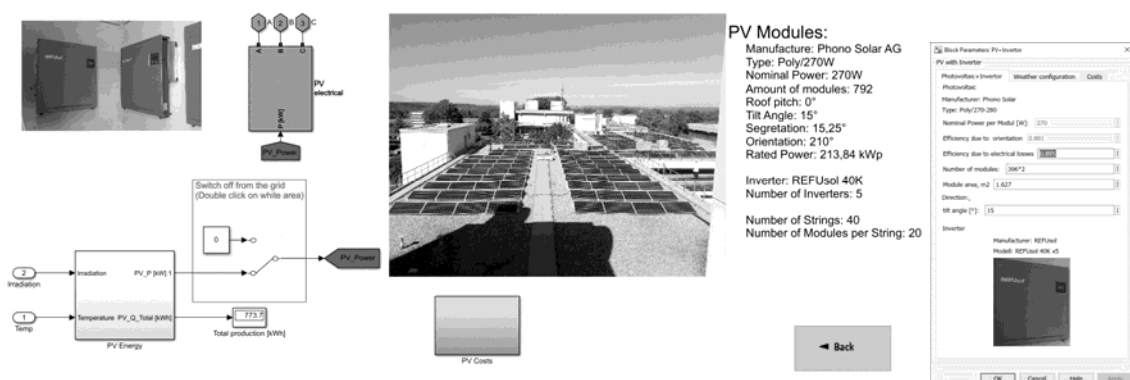

Fig. 5. Model of a photovoltaic system from the company "Phono Solar AG".

The weather input can be taken from historical time series, live data from a local weather station on the campus or from an open Weather API. Panel efficiency, shadow losses and energy conversion losses are taken into account. The difference between the simulation results and the actual values of produced power do not exceed 5%.

Some devices have an internal controller of the device, which ensures manufacturer's requirements for the use of the device. The Simulink Stateflow models, which provide logical

similarity to the internal controller of the actual devices, have been implemented to the digital twin.

For example, the internal controller of the combined heat and power plant can be controlled with an externally provided working schedule (Fig. 6).

. However, the internal controller switches off the plant whenever the return flow temperature in the circuit exceeds a given value, independent of the working schedule.
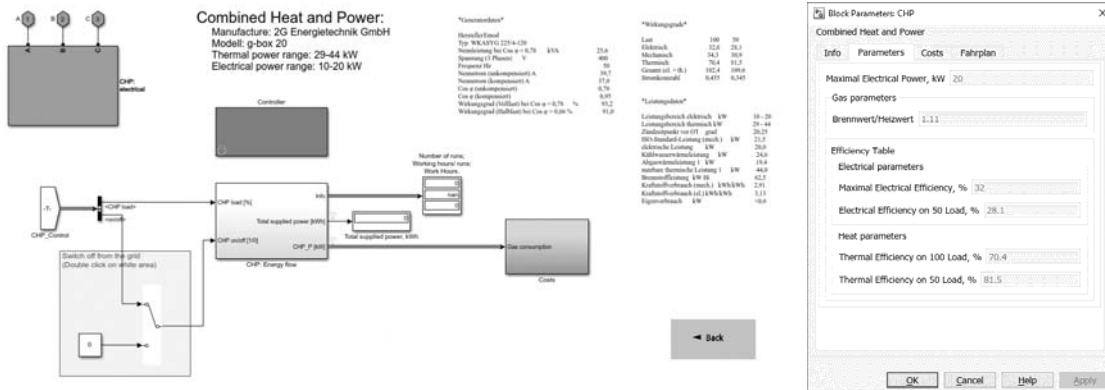

Fig. 6. Model of combined heat and power plant g-box20 from company "2G Energietechnik GmbH".

It is provided a possibility for the combined heat and power plant to receive a signal from the central system management of the virtual power plant. In absence of such an externally provided signal, the model itself creates its own working schedule. The logic of the working schedule model takes into account parameters such as the heat storage capacity, an efficient ratio of hours of operation to the number of launches, as well as the minimum allowed working time per launch (Fig. 7).
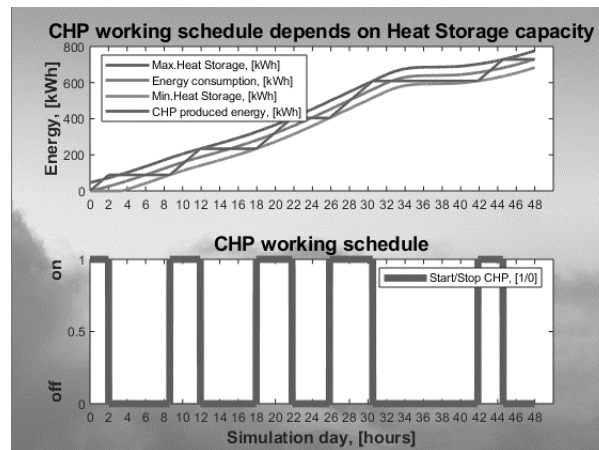

Fig. 7. Example of a two days working schedule for the combined heat and power plant.

The historical data of power consumption can be uploaded to the model. The maximum duration of created working schedule is one year.

Communication

The specifics of connection and communication in the demonstration project for virtual power plants were taken into account while developing the digital twin of microgird "business". Component layers including communication layer of the demonstration platform for virtual power plants are shown on the (Fig. 8) [4] [7].

Fig. 8. Component layers within the demonstration platform for virtual power plants installed at the campus site of Reutlingen University.

Intermediate results of the simulation are packaging and sending using User Datagram Protocol (UDP) to the special program written in Python programming language. The Python program receives the intermediate results and converts them into the JSON data format, which is required for the management system. An Apache webserver provides the intermediate results together with a configuration file containing descriptions of the results to the management system. The management system interprets the configuration file and records the simulation results similar to the measurement data of the real microgrid (Fig. 9).

Communication between the MATLAB model and control signals from the central energy management and control system is secured in a virtual private network. The OpenVPN software was used to set up the virtual private network connecting microgrids and virtual twin with the central energy management and control system [5].

Fig. 9. Intermediate simulation results of the digital twin (left) and corresponding configuration file (right) in JSON format.

Sometimes the server with installed software has to be restart due to updates reasons. After restarting the server, MATLAB model, as well as Python program, OpenVPN and Apache software will autorun in autonomous mode and establish the connection to the energy management and control system.

The system management cannot distinguish between the digital twin and the real microgrid "business". Therefore, simulation results are visualized and monitored similar to the real microgrids (Fig. 10).
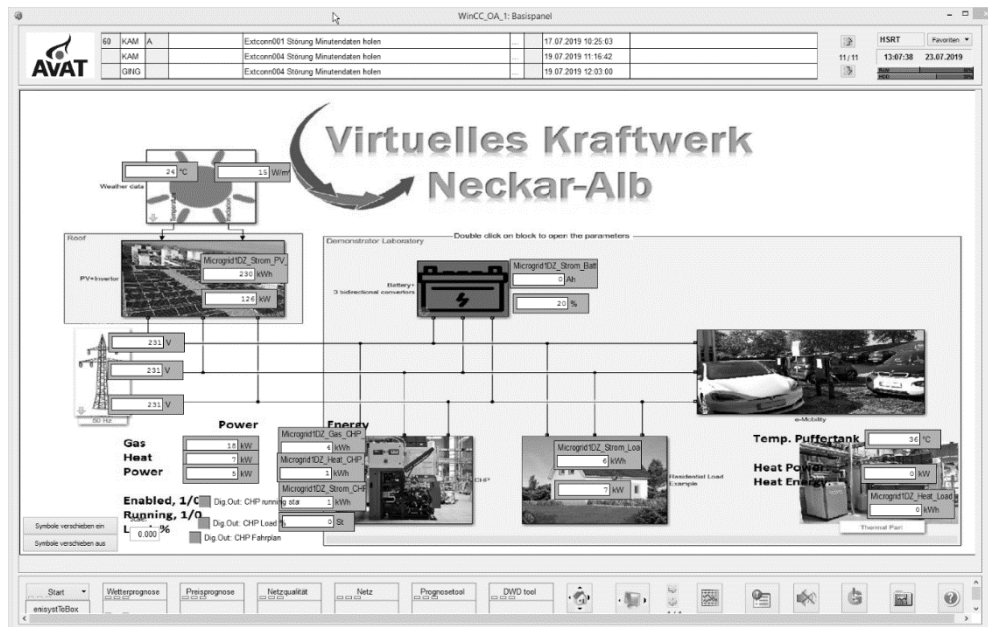

Fig. 10. Visualization of the digital twin in the central energy management and control system of the virtual power plant demonstration platform.

The optimization software SE²OPTIMIZER from the partner company AVAT GmbH includes algorithms for working schedule creation for various devices within the virtual power plant [8]. It can create working schedules and transmit them to both, the digital twin and the real existing combined heat and power plant.

Application

The connection of the digital twin to the energy management and control system of the demonstration platform plays an important role for research goals. The digital twin is used for test and research by both students and companies. In addition to the regular operation of the demonstration platform with central management of all microgrids and the digital twin, here are some examples of the usage of the digital twin for optimization purposes.

Digital twins and real microgrids can run in parallel with each digital twin and real microgrid optimizing its connected energy devices individually. This is called distributed optimization approach. Optimization and scheduling of distributed energy devices is realized by the local microgrid controllers. The central energy management and control system is responsible only for monitoring and visualization in this approach (Fig. 11).

. The results and performance of real microgrids can be compared and evaluated with their digital twins. This approach is important to validate digital twins and to evaluate new optimization algorithms for real microgrid controllers that cannot be directly implemented for testing in a productive industrial environment.
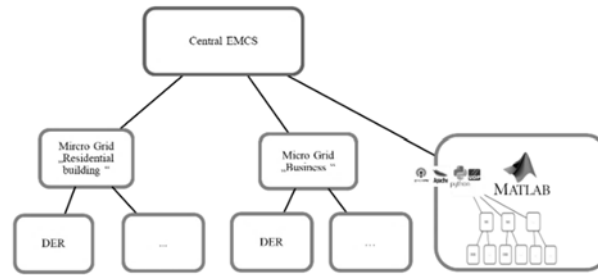
329

Fig. 11. Comparison of distributed optimization within Distributed optimization digital twin and real microgrid.

Digital twins and microgrids can be controlled centrally either by the energy management and control system or by using the MATLAB Optimization Toolbox. Each digital twin or microgrid can be controlled only by one of the central control systems at the same time. The results and performance of different central control systems can be compared in real time if the digital twin and the real microgrid show similar behavior as far as necessary for the given comparison. This way, the central energy management and control system and the MATLAB model including Optimization Toolbox can both independently manage and optimize a subset of the distributed energy devices using the same boundary and real time conditions of other devices and the environment (Fig. 12).

. This approach is important to compare and test new control algorithms for central controllers that need to be tested and validated before the final implementation in a productive industrial environment.
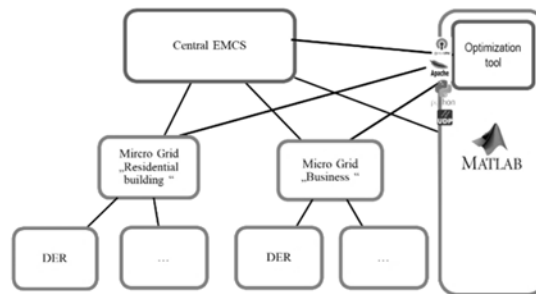

Fig. 12. Comparison and test of central optimization for digital twin and real microgrid.

Distributed control strategies for the trade of energy between multiple actors within microgrids can be tested using digital twins (Fig. 13).

. The MATLAB model allows to increase the amount and capacity of the simulated devices. A node identifier is assigned to each simulated device and nodes are interconnected in a peer-to-peer network. After starting the simulation, the nodes closes smart contracts directly with each other. Such an implementation of distributed ledger technology with digital twins allows to test the behavior of large decentralized systems, without the implementation of actual devices.

Digital twins used for distributed ledger demonstration are a promising tool. They can be used for the design of business cases and the implementation of concepts using smart contracts within a private Blockchain network.
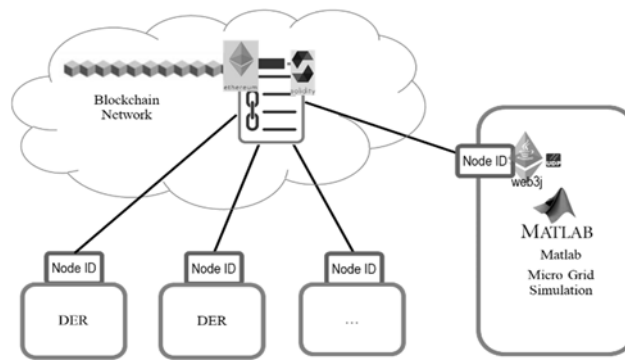
Fig. 13. Test of distributed control strategies.

Conclusion

Digital twins of distributed energy devices provide various options for research, optimization and testing of control algorithms for distributed energy devices within microgrids and virtual power plants. Digital twins are especially worthwhile for the development of new control schemes in productive industrial environments, where real-time tests using the actual devices are not feasible. Building digital twins and hardware-in-the-loop systems provides flexibility and broadens the horizon for the development of energy management and control systems.

Communication interfaces and the operation model of the energy device must be implemented accurately in the digital twin. To obtain viable results, the operation and response of the digital twin must be verified and validated with the utmost care. The digital twin of the microgrid "business" within the demonstration platform Virtual Power Plant Neckar-Alb is currently in the state of verification.

Acknowledgment

References

A. Parrott and L. Warshaw, "Industry 4.0 and the digital twin," [Online]. Available: https://www2.deloitte.com/insights/us/en/focus/industry-4-0/digital-twin-technology-smart-factory.html. [Accessed July 2019].

R. Mümmler, Industrial IoT and Digital Twins, Munich: MATLAB EXPO Germany, 2019.

P. Tugarinov, F. Truckenmüller and B. Nold, "Virtual Power Plant Demonstration Platform," Forum of Mining Engineers, Dniepro, 2019.

Reutlinger Energiezentrum, „Virtuelles Kraftwerk Neckar-Alb," 22 07 2019. [Online]. Available: http://www.virtuelles-kraftwerk-neckaralb.de/demonstrator/.

F. Heimgärtner, E. Schur, F. Truckenmüller and M. Menth, "A Virtual Power Plant Demonstration Platform for Multiple Optimization an Control Systems," in International ETG Congress, Bonn, Germany, 2017.

MathWorks, "Choose a Solver," [Online]. Available: https://de.mathworks.com/help/simulink/ug/types-of-solvers.html. [Accessed July 2019].

P. Tugarinov, B. Nold, A. Notholt and F. Truckenmüller, Smart Grid modeling in MATLAB-Simulink, Munich: MATLAB EXPO Germany, 2019.

AVAT GmbH, "SE²OPTIMIZER: AI forecast-based plant optimization on site," AVAT GmbH, [Online]. Available: https://www.avat.de/en/solutions/virtual-grids/plant-optimization/. [Accessed 29 07 2019].