VIRTUAL POWER PLANT DEMONSTRATION PLATFORM

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The Virtual Power Plant Neckar-Alb is a demonstration platform for operation, optimization and control of distributed energy resources, which are able to produce, store or consume electric energy. A heterogeneous set of distributed energy devices has been installed at the Campus of Reutlingen University by the Reutlingen Energy Centre (REZ) of the School of Engineering. The distributed energy devices have been combined to local microgrids and connected to an operative central power plant with additional participants. The demonstration platform serves students, researchers and industry experts for education and investigation of new technologies, devices and software.

In 1998, the liberalization of the German electricity market led to big changes in energy sector. Big energy companies were divided into a smaller ones and the appeared new actors got chance to enter this market. In addition to increased competition, concerns about climate change have also arisen. This, in turn, has led to increased investment in the development of renewable energy sources. Gradually, renewable energy sources (wind, water, photovoltaic, biomass and geothermal) started to replace fossil fuels (uranium, coal, lignite, natural gas and oil) in electricity production [1].

The increasing number of renewable, but weather-dependent distributed energy resources including power, heat, and cooling trigeneration brings new challenges for the electrical power grids and the energy market, such as protection against overloading of the power grids.

The energy market is also moving forward and is constantly being improved; currently in Europe is functioning three types of short-term continuous electricity trading between buyers and sellers: day ahead, intraday auction and intraday continuous. Since December 2011 electricity deliveries are usually traded in both 15-minute and hourly blocks. During quarter-hourly trading, a position can be traded up to 5 minutes before the start of delivery (Fig. 1.).

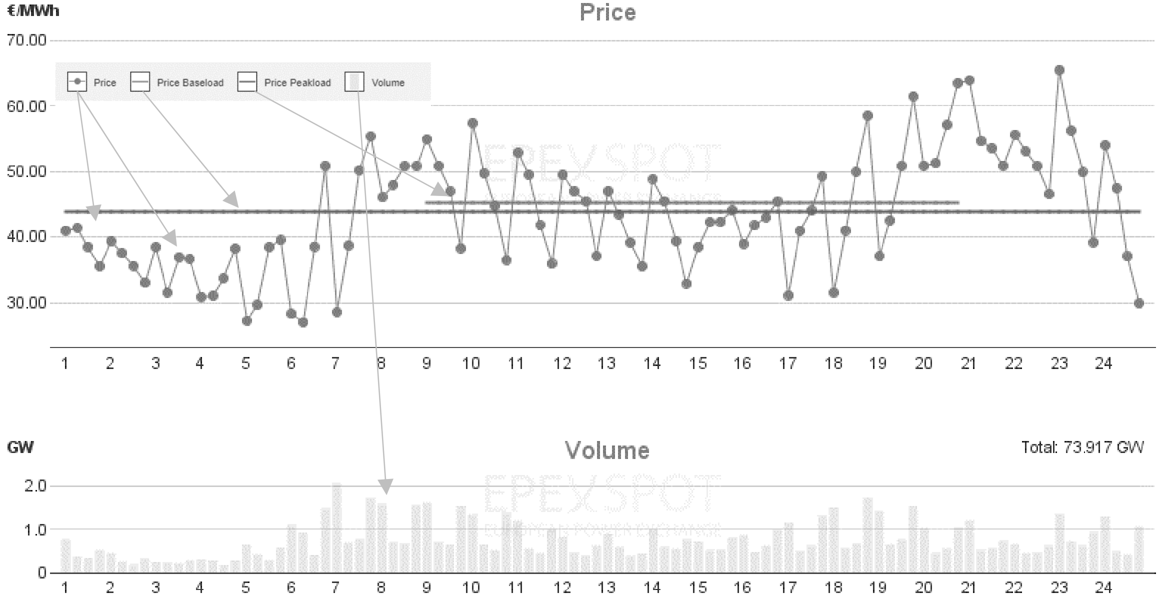

Fig. 1. Market data from EPEXSPOT: Intraday auction in Germany at 22.07.2019 [2].

In electricity trade, new concepts replace traditional centralized structures with a digital, flexible, market-oriented and environmentally sustainable electricity market of the future. Energy-efficient handling is becoming increasingly important.

In the coming years, we can expect even greater market flexibility and an even greater number of distributed energy sources, including electric vehicles. This makes it possible to combine the management of all sources of energy management and control system, optimize matching energy demand and supply and achieve the most efficient energy production. This way multiple small distributed energy devices are aggregated and can participate at the energy market as a larger entity called Virtual Power Plant.

Virtual Power Plants, together with technical simplicity and affordability for implementation, can create plenty of advantages for the industry such as lowering energy costs and additional income through marketing. Small and medium-sized enterprises can strengthening their competitiveness by opening up new business opportunities and optimizing components. Benefits for the energy system would be efficient renewable energy integration and thus CO2 reduction, energy balancing, reserve power and mains operations. Virtual Power Plants are therefore important components for the energy supply of the future.

Structure

The structure of a virtual power plant is shown in Fig. 2. It consists of a hierarchical tree with four levels from the Electrical market on the top to the individual technical units in the bottom. Microgrids can control one or more technical units. Virtual power plants control between one and several thousands of microgrids. The total power ranges typically from about 100kW to several GW. Electricity traders can offer the power from conventional and virtual power plants on the electricity exchange.

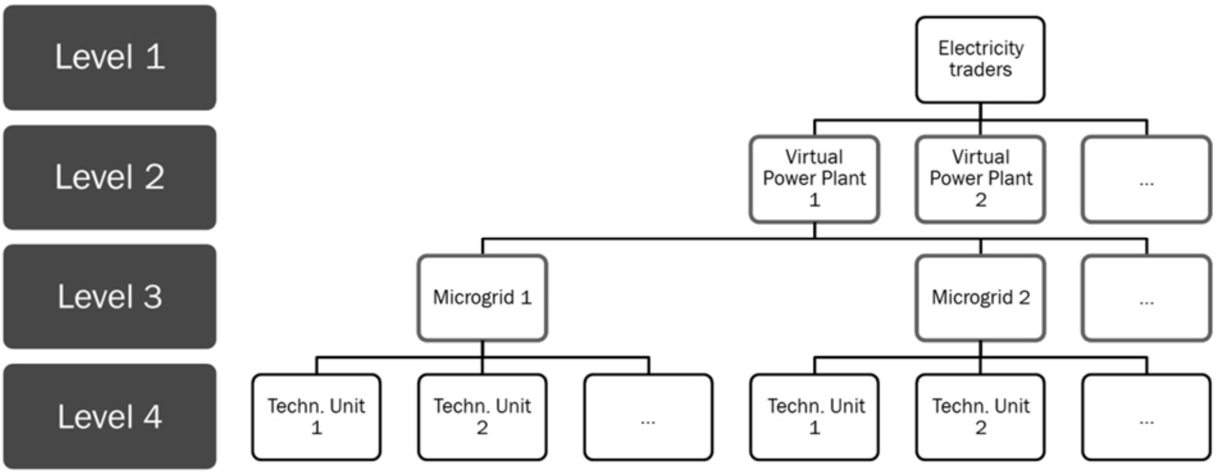

Fig. 2. The structure of virtual power plants.

The role of the different levels in a virtual power plant is summed up in Table 1. The first level represents the electricity market where the energy price establishes depending on demand and supply of energy. The main objective at this level is to profit from the purchase and sale of energy. More flexible price formation and quicker reaction of the proposed prices depending on the market conditions will allow optimizing the operation of the energy market.

The second level represents a power plant or a sum of numerous microgrids. At this level, centralized management of distributed energy sources is performed. The main task performed at this level is to enable flexible offers for the electricity exchange aggregating the flexibility options from all system participants.

The third level represents microgrids, such us industrial facilities, residential quarters or houses. Each microgrid is controlled by at least one control box installed on site. The control box collects information from all connected technical units, ensures secure communication with the central system management and directs control signals to the corresponding technical unit.

The fourth level represents technical units. They can receive a control signal from the next higher level control box or be controlled manually on site. Most technical units are equipped with an internal controller to emergency actions, when functionality or save operation of the device requires action.

Table 1: Description of different levels in a virtual power plant.

Level	Virtual Power Plant	Controlled by	Optimizing	Responsibilities
1	**Electricity market**	**ENTSO & Prices**	**Bids**	**Trading profits**
2	**Power plant**	**System Control**	**Multi-site**	**Flexibility offers**
3	**Industrial/residential microgrids**	**Microgrid control**	**Operation**	**Securing the operations**
4	**Technical unit**	**Unit control**	**Efficiency of the technical unit**	**Function & unit safety**

Demonstration platform

Reutlingen Energy Centre (REZ) has constructed the Virtual Power Plant Neckar-Alb demonstration platform at the Reutlingen University campus (Fig. 1) [3] [4].

The platform consists of centralized and decentralized information management systems and includes several microgrids.

Figure 1: Logo of the Virtual Power Plant Neckar-Alb (left side), heating and cooling systems of the microgrids “business” and “residential” at Reutlingen University (right, top) and the photovoltaic system on the campus (right, bottom).

The microgrids “business” and “residential building” consist of controllable distributed energy devices on the campus of Reutlingen University (Fig. 3). The microgrid “weather station & building monitor” is monitoring-only system and the digital twin microgrid acts similar to microgrids with connected real energy devices. External participants provide additional monitoring-only data from their industrial facilities or residential buildings.

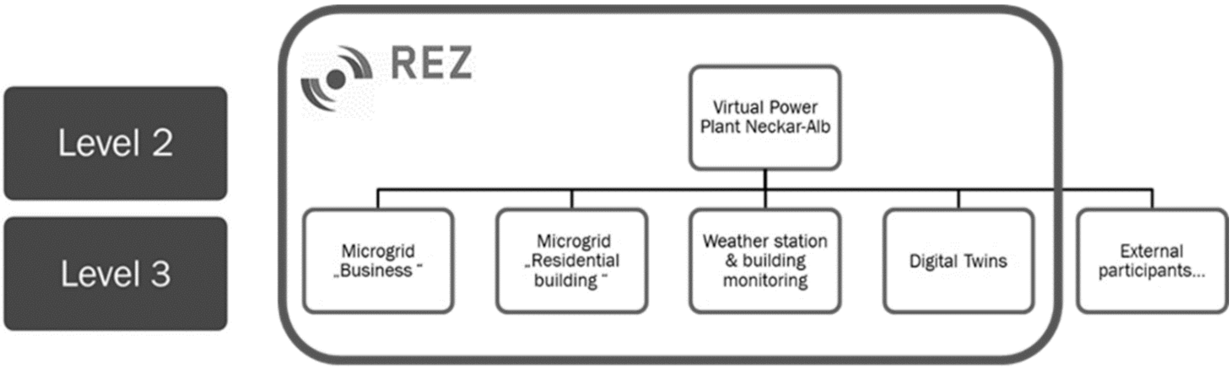

Fig. 3. Microgrids on the campus of Reutlingen University and from external participants connected to the Virtual Power Plant Neckar Alb.

The following is a more detailed description of each of the components.

Central control system

The partner company AVAT GmbH implemented the SE²DIRECTOR software for virtual power plant as the central energy management and control system. The program allows real-time monitoring and interaction with the facilities. Its main surface shows possible error messages and indicates the location of the microgrids on a map (Fig. 4).

. Details and current measurement results can be displayed for each microgrid, as shown by the inset in Fig. 4.

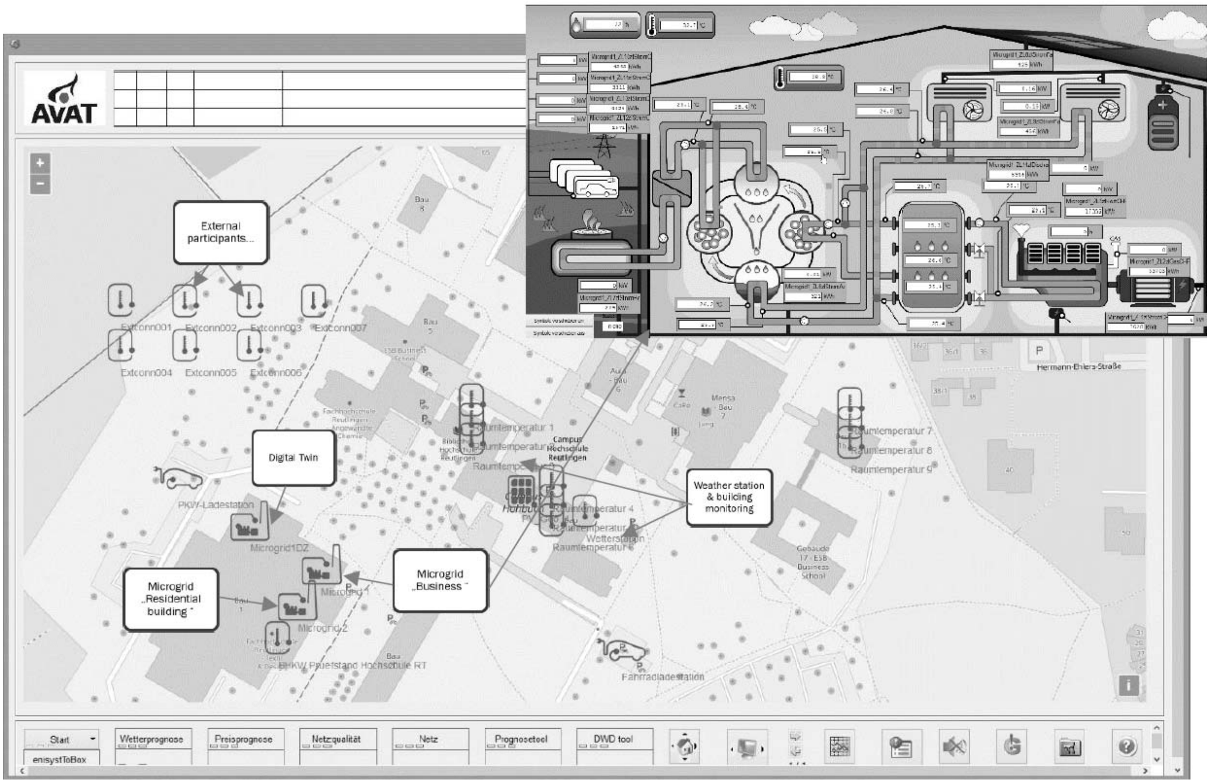

Fig. 4. Central energy management and control system interface.

All energy devices are monitored and data are archived on a regular basis of one minute. Based on this data, the following technical aspects could be investigated: identification of different solutions, creation of a complex real test environment and mapping of the entire value chain.

The central control system monitors the state of the electrical grid, generates forecasts based on artificial intelligence algorithms and communicates with an electricity trader.

Distributed microgrid optimization

The total cost of the microgrids are optimized using the SE²OPTIMIZER software with user cockpit from the partner company AVAT GmbH [5]. It allows external partners to participate in energy markets without sharing their private data with the central system of a virtual power plant. The tool includes algorithms for schedule creation for various devices, such as combined heat and power plants, different kinds of storages and consumers. It receives price forcasts from electricity traders, boundary conditions from the system and local energy demand from operator input and artificial intelligence based forecasts. .

Communication/Security

Communication between central energy management and control system and microgrid controllers is based on IP networking. Controllers are using a HTTP based interface and a JSON data format. Secure connection is provided by using virtual private network tunnels [3]. The communication protocols between the different levels of the virtual power plant are depicted in (Fig. 5).

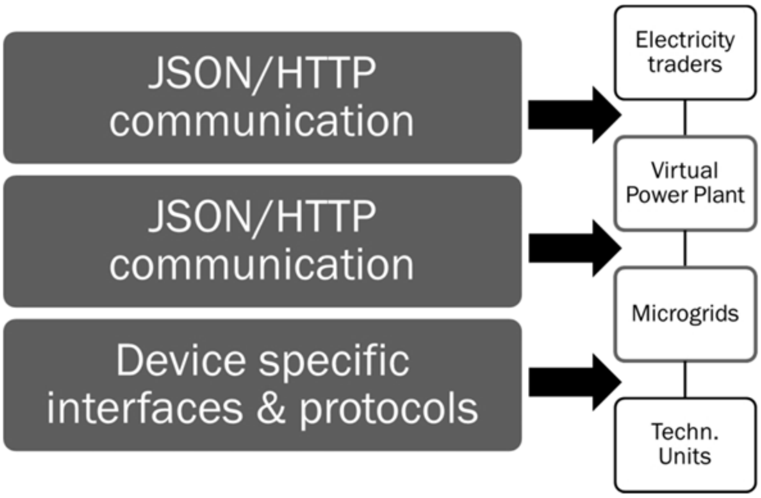

Fig. 5: Communication between the different levels of the virtual power plant.

Microgrids

Distributed energy devices were installed on the campus and combined in microgrids. For example, a Combined Heat and Power plant with maximum 20 kW electrical power production connected with almost 2,000 liters of heat storage, an adsorption chiller, several fan coils, four electric cars chargers 22 kW capacity each and a 212 kW peak power photovoltaic system form together the microgrid “business”- the equivalent of a medium sized company [4].

Another microgrid consists of a cogenerative solar system combining photovoltaics and thermal panels, a heat pump with thermal energy storage for heating and domestic hot water, radiator and heater. This microgrid is the representation of components from a single-family home.

These two microgrids can be controlled in a decentralized way via the web servers of the microgrid controllers of the partner company enisyst GmbH [6]. The microgrid controllers provide component connection and communication with the control system, as well as well as timetable execution or self-sufficient operation at the location and control of the plants via device-specific interfaces (Fig. 6).

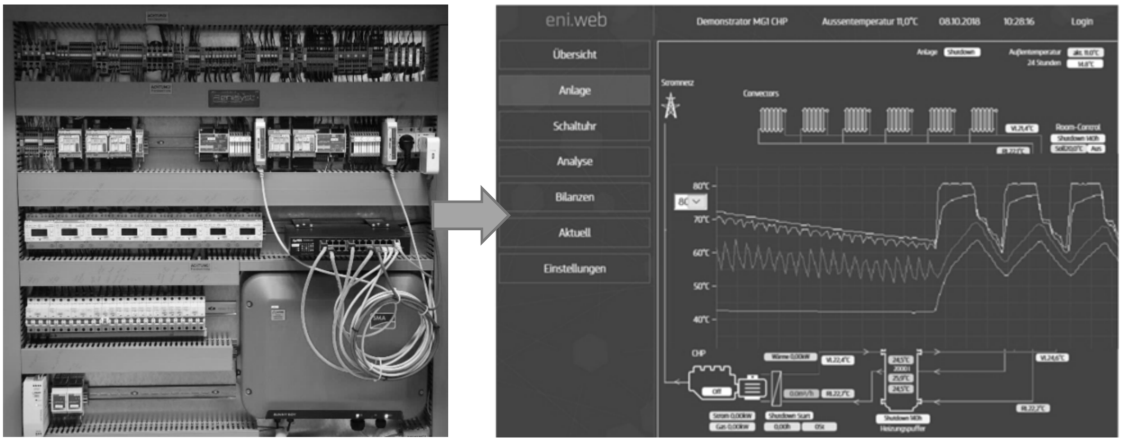

Fig. 6. Electric cabinet with microgrid controllers and photovoltaik inverter (left) and web server interface (right).

Weather Station

Certain indoor temperatures in classrooms, laboratories, computer rooms and a library are continuously monitored. In addition, an installed weather station collects data information using, for example, pyranometers, temperature and humidity sensors, etc. All this information is collected and transmitted to the central management system for analysis, forecasting and optimization of the components within the virtual power plant.

Digital Twin

Based on the technical data of the real components, a digital twin microgrid "business" was implemented in the MATLAB-Simulink software environment. Simulation of the microgrid is running in real time on a separate server and communicating with the energy management and control system. This Hardware-in-the-Loop system provides flexibility for smart grid energy management and broadens the horizons for studying and developing new optimization solutions.

Different power consumption profiles can be chosen within the model and the power of the devices can be increased or decreased for the purpose of testing optimization technologies and giving flexibility for device control and work-time scheduling (Fig. 7).

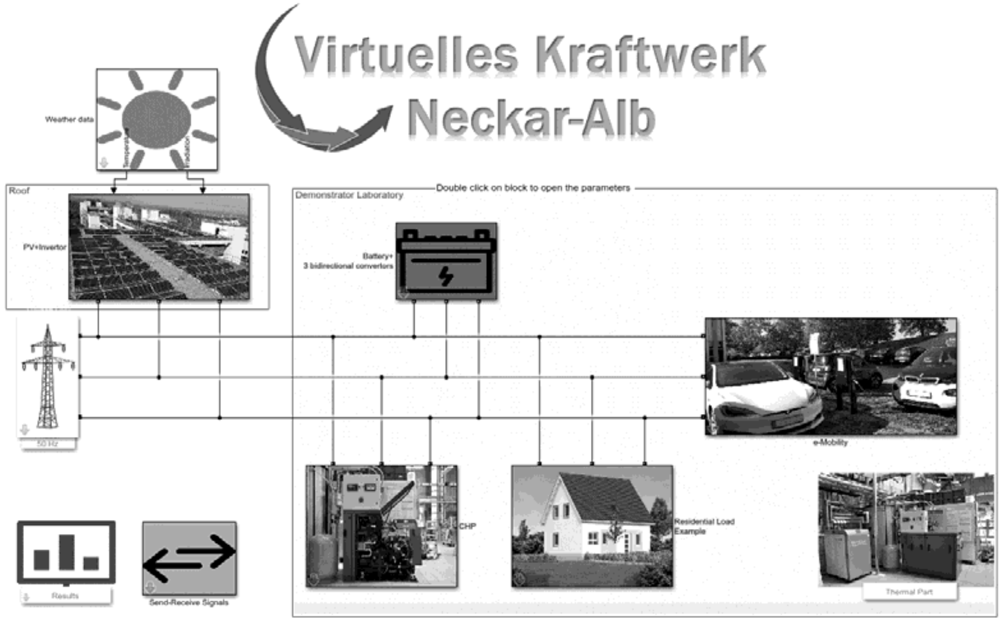

Fig. 7. Digital Twin of the microgrid „Business“ with electrical and thermal models.

In future, digital twins of partner companies will be developed to analyze and modify device behavior and plan actions to optimize electricity and heat generation and consumption in production to reduce total costs.

More information about this project can be found in [7]

External participants

Similar control systems as on the campus were installed at industrial and residential sites in the Neckar-Alb region. These remote sites are also connected to the central energy management and control system and called “external participants”. Such remote microgrids can be connected to the Virtual Power Plant Neckar-Alb. This is possible because of innovative digital technologies and secure digital connections. Encrypted measurement data is delivered to the central energy management and control system. Based on this data and information about usage, consumption, price and weather forecasts, the SE^{2}OPTIMIZER [5] can calculate efficient and economical runtime schedules and proposes it to the respective energy device. The decision to accept or reject such proposals, e.g. for manufacturing company, is always up to the external participant. This ensures that no process is interrupted or disrupted by the system and that efficiency potentials can be identified and, as far as possible, taken into account at the same time.

In addition to monitoring operations and ensuring confidentiality, when connecting external participants, the main goals are to analyze and optimize the work of existing energy devices, e.g. identifying and further reducing the peak and base loads, optimizing local management systems and increasing the self-consumption from photovoltaic systems and combined heat and power devices

Flexibility in energy production, energy consumption and storage is also identified and evaluated. The use and expansion of flexibility can be achieved through prioritization of production processes, participation in the electricity market, as well as the installation of additional flexible devices.

Conclusion

The Virtual Power Plant Neckar-Alb connects energy devices and buildings on the Reutlingen university campus and regional companies with electricity exchange price information. It provides a demonstration and research platform for interested parties, experts and students. It opens up the possibility to learn about energy monitoring, operation optimization, control of energy devices and communication. Connected industry can learn how to reduce peak loads and commercialize their flexibility at the energy market. Different technologies and business models can be tested, different scenarios played through and risks and securities checked. All relevant aspects - ecological, economic, technical and social - are taken into account.

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