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PVT-Wärmepumpensysteme

Batteriespeicher
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Digitaler Zwilling
Zentraler Baustein im künftigen Energiesystem

Netzinfrastruktur
SF_6-freie gasisolierte Schaltanlagen

Messwesen
Status quo beim Smart-Meter-Rollout

Künstliche Intelligenz
Strategische Potenziale und Golden Use Cases

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The digital twin

A central component in the energy system of the future

The goals of the energy transition are unprecedented in terms of scale and speed. 500,000 PV systems and 150,000 storage units connected to the Bayernwerk Netz GmbH grid are two symbols of a decentralised generation landscape. By 2030, millions of heat pumps, wall boxes and other storage units are expected to be added. At the same time, the ramp-up of renewable energy generation is being further accelerated. This results in mass processes and complexity in grid connection, operation and billing. Bayernwerk Netz is proactively addressing these challenges and has anchored consistent automation and digitalisation in its corporate strategy. For Bayernwerk Netz, the digital twin of energy grids is a central building block in the energy system of the future.

The energy transition in the Bayernwerk Netz grids has so far been characterised by a massive increase in renewable energy plants. In 2023, for example, over 88,000 PV systems with an installed capacity of almost 2.3 GW were connected to the grid. By comparison, five years ago there were fewer than 10,000 PV systems with a capacity of only around 350 MW.

The German government plans to extend the energy transition to the heating and transport sectors, with increasing electrification expected through heat pumps and electric vehicles, as illustrated in **Figure 1.** The electricity grid will thus become the largest heating network and filling station. At the same time, the expansion of renewable generation plants continues, supplemented by storage facilities that provide the necessary balance. Renewable generation plants are increasingly being built together with storage facilities. This turns former consumers into flexumers: active elements in the energy system that produce, store and flexibly supply energy [1]. In the future, flexumers and other plants in the grid must be able to be measured live, controlled digitally and billed.

Bayernwerk Netz is proactively addressing these challenges by creatinga digital twin of its energy grids. Close cooperation with E.ON's sister companies ensuresthat the latest findings from initiatives such as the Twin EU[1] lighthouse project can be taken into account.

Merging of the real and virtual worlds

The Apollo program as the origin of the twin concept

Although the concept of the digital twin is considered a central component of digital transformation, there is no uniform understanding of it in either literature or practice. The description of a digital twin varies depending on the area of application and industry. The concept has its origins in space travel: as part of the Apollo program, the US space agency NASA developed physical twins of spacecraft that remained on Earth to test various scenarios. These twins made it possible to mirror the conditions during the mission and simulate potential courses of action for the astronauts in critical situations [2].

The term 'digital twin' was first defined by Michael Grieves in 2003 [3]. According to this definition, the digital twin is characterised by three elements:

1. a virtual representation of a physical object that is located in a
2. digital environment and
3. the information exchanged between these two elements.

Since this definition was established, the concept of the digital twin has continued to evolve, both in research and in industry. More recent definitions now also include the virtual representation of processes and systems [4].

Digitisation of reality

A general distinction is made between a digital twin, a digital shadow and a digital model, which are often used interchangeably in practice [5].

These concepts differ in the way data and information are exchanged. A digital model only allows for manual data exchange between the real object and its digital image. With a digital shadow, on the other hand, there is already a one-way automated data flow: data is collected from the real system and transferred to the digital image. A digital twin is characterised by complete automation of the data flow, enabling bidirectional data transfer between the real and digital objects. This allows the digital twin not only to reflect the current state of the real system, but also to actively influence it.

Data availability and quality are crucial

The data basis is crucial for the successful implementation of the digital twin. Only with available, high-quality data on physical networks and processes can the digital twin serve as an optimal basis for decision-making. For example, reliable network monitoring based on real-time data is necessary for dynamic network control. It is essential to equip customer installations and network operating resources with measurement and control technology in order to make live data available. Stable connectivity with the sensors ensures continuous data transmission. In addition, a robust and secure data infrastructure is required to process large amounts of data and protect sensitive information.

[1] www.twineu.net

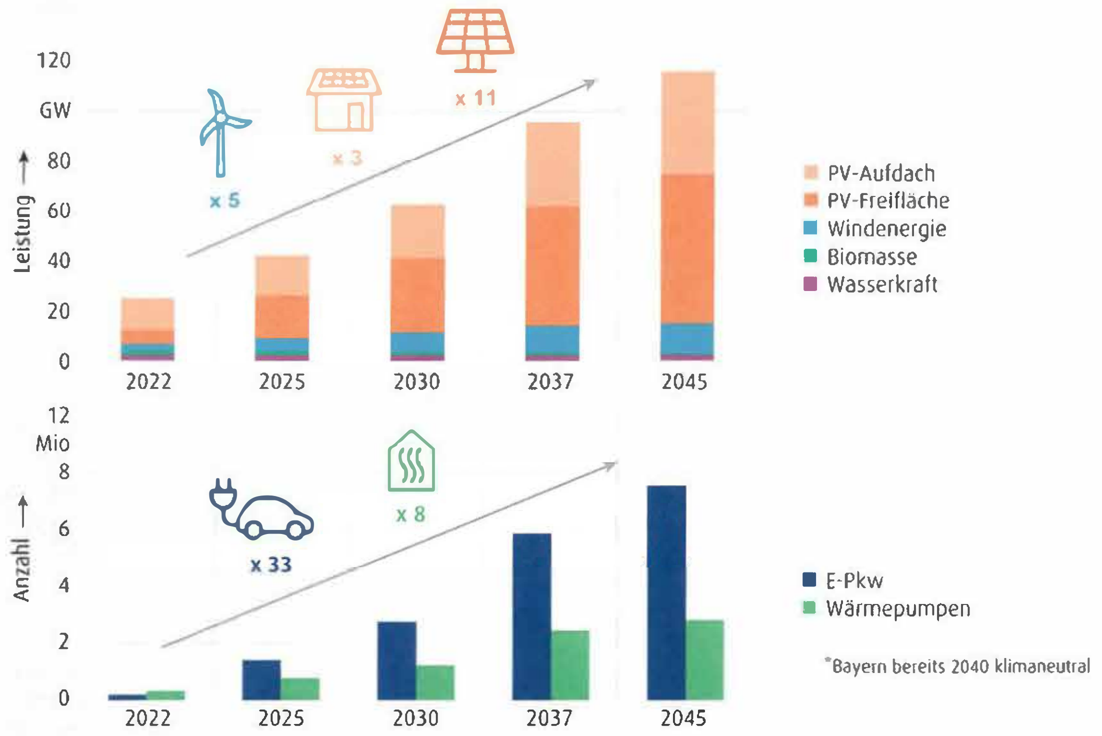

Figure 1. Ramp-up of generation and consumption in Bavaria (own calculation based on EEG and grid development plan)

Digital twins in practical use

Real-time monitoring, control and optimisation of energy networks

The digital twin at Bayernwerk Netz is a virtual representation of the electricity and gas networks and the associated processes at all voltage levels and pressure stages. This digital representation is synchronised with the physical distribution networks in real time and provides comprehensive information about the status, behaviour and performance of the network.

Bayernwerk Netz is currently implementing an automated bidirectional data flow in the digital twin of the electricity grid – from the physical object to the digital image and vice versa. This bidirectional communication makes it possible to initiate control processes and commands directly from the virtual image without the need for manual intervention on site. For example, in the event of a bottleneck, necessary control measures can be efficiently implemented from the digital image.

The data basis for the digital twin consists of the integration of static network master data and dynamic sensor data. Data analysis and modelling technologies enable comprehensive monitoring, precise simulation and targeted optimisation of the real network or process – without direct access to the physical object.

Figure 2 shows an example from the Bayernwerk Netz electricity grid. Network status assessments and calculations can be carried out using on-site measuring points, such as local network stations, as shown in **Figure 3**. The digital twin is not limited to the electricity grid. Data from the Bayernwerk Netz gas grid is also displayed. In future, other infrastructures such as those for heat, hydrogen and CO2 can be integrated. This enables a holistic view of the energy system.

The digital twin enables informed decisions to be made and problems to be identified and solved. All network data is consolidated in a single environment (single point of truth), creating an integrated and constantly available database. Linking master data with sensor data provides transparency about the network status and enables data-based optimisation of network planning. Operating resources and grid expansion are planned in a targeted manner, taking into account real-time data on the utilisation of existing operating resources.

In addition, real-time monitoring of the network is possible by mapping the network topology and the associated sensor values in the digital twin. For example, sensor data from digital local network stations is gradually being integrated so that the network status can be automatically calculated using measurements taken every minute (**Figure 4**). This data basis simplifies fault localisation and provides live information in the event of a fault.

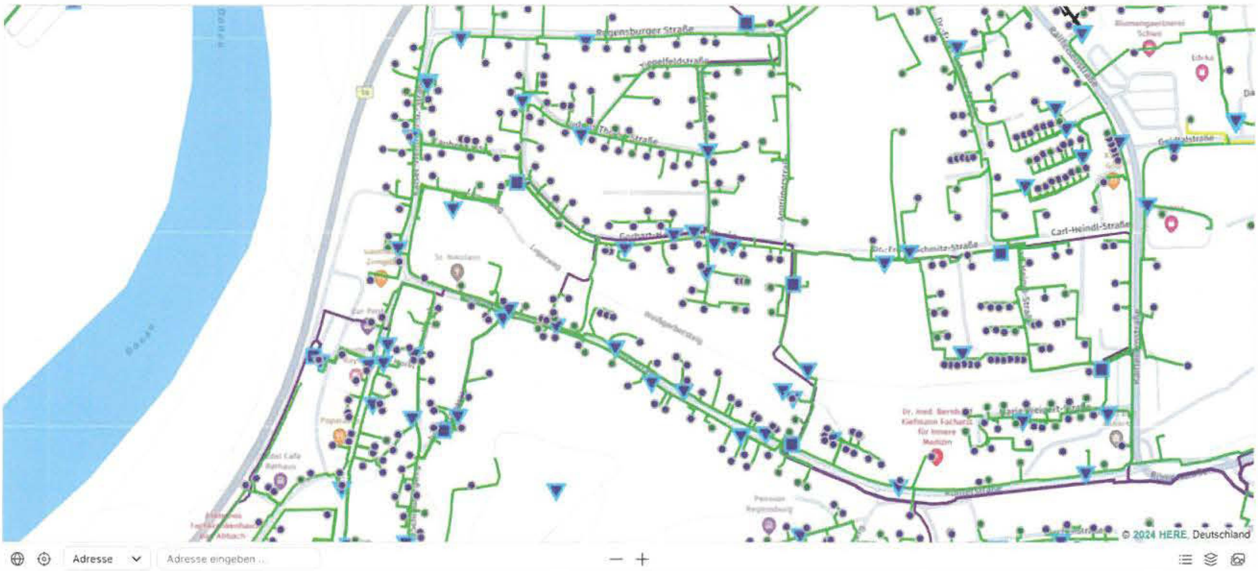

Figure 2. Example of the visualisation of a local distribution network of Bayernwerk Netz based on the digital twin.

In addition, the digital twin enables network simulations to be carried out in order to evaluate various scenarios and their effects on the network status and the utilisation of operating resources. This allows targeted decisions to be made to increase the efficiency and reliability of the distribution network.

To meet the high demands on data availability and quality, Bayernwerk Netz is investing in digital infrastructure. By 2028, for example, 8,500 additional secondary digital substations will be integrated into the gird and the rollout of smart meters will be further advanced. The implementation of data governance enables structured support to increase data quality: from identification and root cause analysis to data quality improvement.

High implementation efficiency in changing conditions

Another application of the digital twin at Bayernwerk Netz is the implementation of the legal and regulatory requirements of Section 14a of the German Energy Industry Act (EnWG), which have been in force since 1. January 2024. The aim of the National Regulatory Authority's (Bundesnetzagentur) stipulation is to accelerate the electrification of the transport and heating sectors while maintaining a high level of supply security. Distribution System Operaters have been granted the option of temporarily dimming controllable consumption units [6, 7].

This requires both the monitoring of critical networks and the ability to send control commands. The digital twin provides the basis for this and, through real-time data collection, enables network monitoring and preventive dimming in the event of impending network bottlenecks.

Furthermore, Bayernwerk Netz is implementing the legal requirements for municipal heat planning using the digital twin. With the aim of achieving greater energy efficiency and CO2 reduction in the heat supply of cities and municipalities in the long term, the legislator envisages municipal heat planning in the future [8].

Figure 3. Results view of a secondary digital substation in the digital twin

Gesamtnetzname	Netzzustand	Min. Spannung	Max. Spannung	Max. Leitungsauslastung	Max. Auslastung speisender Transformatoren	Max. Auslastung unterlagerter Transformatoren	Aktuelle State Estimation
digiONS 1		98.87 %	98.87 %	0.05 %	0.04 %	-	9. Juli 2024 13:00
digiONS 2		98.13 %	102.72 %	40.39 %	64.62 %	-	9. Juli 2024 13:00
digiONS 3		98.13 %	102.72 %	40.39 %	64.62 %	-	9. Juli 2024 13:00
digiONS 4		101.06 %	103.22 %	28.96 %	89.83 %	-	9. Juli 2024 13:00
digiONS 5		98.46 %	99.24 %	10.63 %	28.84 %	-	9. Juli 2024 13:00
digiONS 6		99.42 %	99.83 %	8.85 %	11.7 %	-	9. Juli 2024 13:00

Figure 4. Live measurements for network monitoring

The necessary data is provided by the responsible distribution system operators, among others. By using the digital twin database, municipalities will be able to make this information available automatically and with minimal effort in the future. Municipal partners can download the required data themselves at any time from the Bayemwerk Netz energy portal. This ensures that the data is provided quickly and efficiently.

Figure 5. Result of a quick network connection test

SNAP: The fastest way to connect to the grid

One application that uses the digital twin as a data basis is the 'fast grid connection check' (SNAP). SNAP provides connection seekers with immediate online information about the nearest grid connection point. Customers enter the location, the type of plant (wind energy, photovoltaic or CHP plant) and the desired feed-in capacity and immediately receive non-binding grid connection information. If the check is successful, a binding grid connection check can be initiated directly online. The SNAP tool has been in use at Bayernwerk Netz since April 2023. Within one year, an average of 10,000 grid connection points per month were calculated. An example calculation using the SNAP tool is shown in **Figure 5**.

Data on network topology, equipment, consumption, generation and sensor values are collated in the digital twin to form an integrated database. This enables automated network calculations, which provide information about available network capacities at the requested location when a query is made. In the next step, possible network connection points are checked and displayed to the network connection seeker in the online tool.

The interaction between SNAP and the digital twin as a data basis is one example of how to meet increasing customer needs. Customers quickly receive a non-binding indication of their connection project and can then continue with their projects. Network planners can concentrate on requests that are at a certain stage of planning maturity and have a high probability of implementation. The positive effects are greater transparency, speed and efficiency for customers and network operators.

Step by step towards the target image

The static network master data, the integration of intelligent technologies into the energy networks and real-time data collection form the basis of Bayernwerk Netz's digital twin. This means that the core use cases of network monitoring and calculation, comprehensive planning and rapid fault detection can already be carried out today.

The digital twin is a key component of the vision for the future of the Bavarian energy system at Bayernwerk Netz. The energy system, which is characterised by volatile, renewable generation and flexible consumption, must remain secure and affordable. With these guidelines from the energy policy triangle, the company is setting priorities for the further development of the digital twin.

Application: Data analysis and modelling technologies, as well as the application of artificial intelligence, can predict future malfunctions or maintenance issues (predictive maintenance). This enables proactive and needs-based planning of maintenance measures. This minimises unplanned downtime and optimises maintenance costs.

Control: The virtual image of the grids enables better decisions to be made regarding the use and control of flexibility. Real-time data on generation, consumption and the grid situation – both regionally and supraregionally – form the basis for maximum supply reliability and efficiency in the energy system.

Expansion: The digital twin can be flexibly expanded to meet the challenges of the energy transition. The infrastructures for electricity, gas, hydrogen, heat and, in the future, CO2 can be integrated as needed. This enables holistic planning across energy sectors. In addition to further infrastructure, new data domains can be integrated into the digital twin. Multimedia data, commercial data or even the procedural history of the networks can expand the application area of the digital twin:

- **Multimedia data**, such as satellite or drone images and objects from AR/VR, can be used for virtual tours and training, for example.
- Linking the database with **commercial data** can improve the basis for decision-making, for example when making decisions in network planning.
- With **data on process history**, the digital twin can be improved, especially for applications such as predictive maintenance. Process data on maintenance, inspections and repairs that have already been carried out can be used, for example, by means of artificial intelligence to make more accurate predictions of future maintenance measures that will be necessary.

With these priorities in mind, Bayernwerk Netz is consistently driving forward the further development of its digital twin of energy networks in order to lead energy customers to success.

Summary

A massive surge in renewable energy systems, heat pumps, storage systems and wall boxes is predicted by 2030. This will increase the demands on connection processes, grid operation and billing. New regulations such as Section 14a of the German Energy Industry Act (EnWG) for controllable consumption devices and municipal heat planning require innovative solutions.

The static network master data, the integration of intelligent technologies into the energy networks and real-time data collection form the basis of Bayernwerk Netz's digital twin. This already enables core use cases such as network monitoring and calculation, comprehensive planning and rapid fault detection to be carried out. The current focus is on the company's electricity and gas networks.

One example of how the digital twin is used is the rapid grid connection check (SNAP). This lets customers get online info about available grid connection points anytime. In network planning, integrated data helps with the efficient development of energy networks. In operational network operation, real-time data enables rapid fault detection and rectification in the event of a malfunction, as well as an increase in supply quality. For controllable consumption devices, dimming in accordance with Section 14a of the German Energy Industry Act (EnWG) is possible. Within the framework of municipal heat planning, data can be made available to municipal partners quickly and efficiently.

The target vision for Bayernwerk Netz's digital twin encompasses a holistic view of the energy system. Depending on requirements, data on hydrogen, heat and CO2 networks can be integrated in addition to electricity and gas networks. Multimedia, commercial and process data on history expand the fields of application of the digital twin. The advantages are increased efficiency, improved supply quality, greater transparency and faster decision-making processes.

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