The world behind the socket

How does our power supply work?

by Denise Nüssle

Plug it in and off you go – the power socket has been around in its current form for about a hundred years, electrifying our everyday lives. Things get tricky when no power comes out of it for an extended period. At this point, we become aware that behind that small holey rectangular box in the wall lies a complex system involving many players, high-tech components and challenges. Together with Patrick Jochem from the DLR Institute of Networked Energy Systems, DLRmagazine has compiled answers to some of the most fundamental questions about power systems – and takes a look at DLR's research into the electricity systems of tomorrow.

What is an electricity system and what is it made up of?

An electricity system has the task of generating electrical energy, storing it and transporting it to where it is needed. In Germany, there are almost two million kilometres of power lines with different voltage levels, both overhead and underground. For long distances, the transmission grid comprises high- and extra-high-voltage lines – important to minimising losses during transport. Even so, approximately five percent of electricity is lost when moving power from northern to southern Germany. For regional distribution, medium-voltage grids are used, which also connect many larger generation plants – such as solar and wind farms, as well as companies with high consumption. The low-voltage grid then supplies electricity to individual homes and smaller businesses.

Substations are important nodes between the different voltage levels and can also help regulate the electricity system. Other components include energy storage facilities – typically battery storage systems or pumped storage power stations, which store electricity by pumping water into a higher reservoir and releasing it when needed to generate electricity via turbines.

Germany's transmission network is divided among four players. At the local and regional level, however, there are more than 800 electricity grid operators. These companies are market-based but partly with a public ownership structure, and all are strictly regulated by the Federal Network Agency (the Bundesnetzagentur or BNetzA). Much of their infrastructure is considered critical and must be protected against failures and unauthorised interference.

Images: Freepik (p. 18), DLR (p. 19)

Power always on tap?

Approximately 40 gigawatts – that's the minimum electrical output the power system needs to supply around the clock, known as the 'baseload'. Twenty years ago, this came mainly from nuclear and coal-fired power stations running continuously. When more electricity was needed, additional power stations that could be controlled more flexibly – such as hard coal, gas or oil-fired stations – were gradually brought online. Peak load refers to the maximum electricity demand, which in Germany is approximately 80 gigawatts, and only occurs a few times a year for a few hours. It has always been expensive to provide peak load capacity and expand the grid to handle it.

A special feature of the electricity system is that it must be in balance every second – that is, supply must always match demand. In the past, when fossil fuels were the main source of energy, this was relatively straightforward. Because utility companies had a good idea of how high electricity consumption would be over the course of a day or a year, they could schedule accordingly.

The more electricity is generated from renewable resources, the more flexible the electricity system and its components need to be. Sunlight and wind are available free of charge, but are fluctuating sources – that is, they cannot be scheduled reliably or over the long term. As such, the electricity supply depends on the weather and seasons and is delivered by a growing number of smaller players. At the same time, more storage, reserves and other flexibility options are needed.

How does the electricity market work?

To generate electricity as efficiently and cheaply as possible, trading in Germany – and many other countries – is organised according to market principles. These markets can be thought of as wholesale electricity markets for traders. Prices set there are, however, not the final prices for individual end consumers. The electricity market has several sub-markets, which differ in terms of how far in advance electricity is traded. For example, electricity can be purchased a year in advance and resold. The closer the delivery date gets, the easier it is to determine how high supply and demand will actually be – which determines the price. In the 'day-ahead market', electricity is traded for the next day. If an electricity supplier realises it has too much electricity available for the same day, it can try to sell it on the 'intraday market'. If it has too little, it can buy more there at short notice.

There is also the 'balancing energy market', where electricity is made available in real time for emergencies – for example, in the event of bottlenecks caused by a power station failure. The balancing energy market stabilises the system in real time, providing electricity at very short notice if required. The supplier is paid simply for making the electricity available, regardless of whether or not it is consumed.

All of these markets have digital platforms, and participants must qualify before they can trade there. In the past, electricity markets were

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Last power outage: About two years ago while working from home. It lasted about 15 minutes and, fortunately, was very localised – so mobile networks still worked. I could continue work on my laptop with internet access via mobile data – even the freezer coped well with the brief interruption.

What he finds most exciting: Implementing the energy transition amid geopolitical challenges: expanding infrastructure, resilience and security, securing resources and the further development of electricity markets.

With the DLR_NESTEC (Networked Energy Systems Emulation Centre) laboratory, DLR is investigating the behaviour of real distribution grids and testing components in a realistic environment.

predominantly organised on a national basis, but Europe is now working to integrate these markets and make them more efficient and economical. On the day-ahead market, most European countries already cooperate and interconnections between national electricity grids are increasingly used for cross-border electricity trading.

How is the electricity price for consumers calculated?

The electricity price has many components. Roughly speaking, 40 percent comes from electricity generation itself, 30 percent is attributable to grid fees and another 30 percent to other levies and taxes such as VAT. Grid fees per kilowatt-hour will likely rise further in the medium term because as renewable electricity generation grows, the grid's infrastructure will need to become more flexible and complex, with greater storage capacity. Although the overall electricity demand is likely to rise due to the electrification of vehicles and heating, the amount of energy moved through the grid may fall: while companies and private households will continue to be connected to the grid, they will increasingly generate and use their own electricity. Those without solar panels and batteries will end up paying higher grid fees for every kilowatt-hour of electricity they consume.

How likely is a blackout?

A blackout is a large-scale power failure that lasts for an extended period. In Germany, the probability of this happening is extremely low thanks to heavy investments in grid infrastructure. Statistically speaking, every person in Germany experiences a power outage of just under 13 minutes on average per year, which is usually local. Globally, blackouts are often caused by the inadequate response of industry players, such as grid operators and energy suppliers, to increased fluctuations in the voltage or frequency of the power system. The balance between supply and demand is then disrupted and can spread very quickly in a closely interconnected power system.

Are solar inverters a risk for the grid?

Inverters have an important function: they convert the direct current (DC) generated by solar panels into alternating current. This 'AC' can then be used directly or fed into the public power grid. Inverters usually also have simple functions for monitoring and controlling grid quality. For example, if there's an imbalance in the grid, inverters regulate the feed-in. However, if all inverters do this simultaneously when too much solar power is available, the imbalance can worsen. This is why development is moving toward smart inverters and local network transformers, which can be controlled externally to better regulate the grid in much smaller increments. The smarter these components become, the more important it is to protect them against unauthorised access.

Image: DLR

What is DLR researching when it comes to electricity systems?

DLR is studying the power supply as a system of technologies, exploring how it can be made fit for future challenges. An important aspect of this work is 'sector coupling' – linking the electricity, transport, heating and industrial sectors so they can be considered and optimised together. From an economic perspective, DLR is examining the design of electricity markets and prices, as well as the development of electricity systems. The focus here is on how to ensure a resilient, secure, renewable and affordable energy supply for all.

DLR researchers are also modelling electricity markets using their open-source AMIRIS software developed in-house. AMIRIS takes into account the strategies and motives of different market players – from entrepreneurial self-interest to incomplete information. This makes it possible to analyse the effects of current or future market designs as realistically as possible – for example, how regulatory frameworks affect the grid. This knowledge can support decision-making in politics, administration and business. Companies in the electricity market can also use DLR's scenarios to refine their strategies or make smarter, more flexible tariffs for end customers.

In terms of technology for electricity grids, DLR is investigating the technical challenges posed by renewable energies – what is the impact of increased variability and many more, predominantly decentralised, players? The focus is on new grid technologies and architectures, regulations for smart grids and measures to prevent or quickly rectify faults and disruptions. Artificial intelligence may also play a role here.

Denise Nüssle is a press editor at DLR, mainly covering research in energy and transport. She used this article as an excuse to visit her local power infrastructure near Stuttgart – of course, keeping a safe distance.

INSIDER TERMS: ELECTRICITY

Current: The flow of electric charge (electrons) through a conductor per second, measured in amperes; analogous to the amount of water flowing through a pipe.

Voltage: The force that drives current through a conductor, measured in volts; analogous to water pressure in a pipe.

Power: How much energy is generated or consumed at a given time; a product of current and voltage, and measured in watts.

Grid frequency: How often an alternating current changes direction per second, measured in hertz. Fluctuations indicate whether supply and demand are in balance, making frequency a decisive factor in the stability of the grid. Grid operators must tightly control frequency, keeping it within narrow limits, otherwise technical equipment can be damaged.

Redispatch: The management of regional grid bottlenecks after trading on the electricity markets is complete. Grid operators adjust electricity feed-in to prevent or clear bottlenecks and ensure the stability of the grid. Renewable energies are also increasingly being incorporated.

Brownout: A controlled, local voltage reduction of 10–25 percent in the electricity grid, by grid operators. This is a last resort to prevent a blackout during shortages or impending overload. In Germany, it may not exceed four hours as a rule.

Capacity market: A shift from the previous market principle, not only is the amount of electricity delivered paid for, but also its guaranteed availability – regardless of whether or not the electricity is consumed. This ensures a secure supply, especially as renewable energies grow. Capacity markets already exist in Belgium, the UK and Italy.