Projektinfo **06**/2015

Detailed information on energy research

Stable grid with 100 per cent green electricity

The provision of electricity in future from just renewable energy is not a utopian vision – but it is also not going to happen automatically

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In a power grid, the energy provided must always be equal to the power demanded. Only then can frequency and voltage remain stable. Ensuring this is the task of grid operators. But when volatile — meaning not arbitrarily adjustable — energy sources are the main sources of electrical energy, grid operators face a challenge. In the combined power plant (Kombikraftwerk 2) project, researchers modelled a power supply system based on 100 per cent renewable energy, and demonstrated that the grid can function reliably even with an ample supply of photovoltaic and wind energy.

In order to balance consumption and generation, transmission system operators rely on so-called ancillary services. An important issue on the way towards a predominantly green power supply is therefore: to what extent can renewable energy support the grid and reliably provide balancing power? Project manager Kaspar Knorr from the Fraunhofer Institute for Wind Energy and Energy System Technology IWES explains that, "In the Kombikraftwerk 1 project, we already demonstrated that renewable energy sources combined with storage systems can cover the electricity demand in Germany at any time. The Kombikraftwerk 2 project now shows: they can even offer ancillary services. A scenario with one hundred percent renewable energy is therefore conceivable."

Currently, ancillary services are provided by conventional power plants almost exclusively. Energy generation based on coal and gas fired power plants is weather-independent and predictable, and the conditions for participation in the balancing power market, for example, were tailored to them in the past. In addition, the rotating masses of large synchronous generators are important for supporting the grid in the first fractions of a second after a sudden load increase or decrease, owing to their inertia. Even rapidly switchable balancing power takes some time to fully ramp up.

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Ancillary services facing change

New framework conditions are required for renewable energy sources to contribute to frequency stability control: wind and solar power have little or no rotating masses, and the grids therefore lose a part of their inertia. However, they react far more quickly to changing conditions. It is therefore necessary to adjust the market for it to meet the new demands. Currently, primary balancing power must be fully available after 30 seconds. But what does that mean?

If the grid load suddenly increases, then the frequency must initially remain stable before primary balancing power can fully support the grid. Rotating masses currently perform this task. If they were not there to support the grid, it would collapse. “In our scenario, we need new requirements to primary balancing power. The power electronics of PV systems can provide primary balancing power within milliseconds, while wind turbines need approximately five seconds,” Kaspar Knorr explains. “In this scenario, there still are rotating masses in the biomass power plants that stabilise the grid until the onset of PV systems. Technically, renewables are so fast that they are able to compensate for the lower inertia.”

Currently, power plant operators must offer their primary balancing power one week in advance. In this context, the project manager adds that, “This system is not sustainable indefinitely. If renewables are to provide ancillary services, then daily tendering will be necessary.” This means: every day, wind turbine and solar power plant operators can react to current weather conditions and then define the grid-relevant contributions they can make the following day.

Accurate modelling of energy generators

According to the researchers, the scenario of the research project Kombikraftwerk 2 offers a realistic outlook for the year 2050. The assumptions are based on detailed weather information, today‘s plant locations and grid expansion plans. Figure 1 offers an overview of various grid nodes and their performance as recorded during noon one day in February. Wind energy forms the bulk of the mix with 60 per cent (Fig. 2). The researchers assume that the designated offshore areas are fully utilised and integrated into the grid, and that additional potential is tapped onshore. For photovoltaic systems, they expect four times the current installed capacity.

Roughly speaking, wind turbines are mostly located in the north and offshore, while the sunnier south increasingly employs photovoltaic systems. A large number of decentralised, inflexible and variable individual systems can be combined to form a virtual power plant, and be considered as one unit. For grid operators, this has the advantage of having to work with a low number of generators only, similar to large-scale power plants. In virtual power plants, each individual electricity producer complements the other, which helps offset fluctuations.

Local voltage maintenance ensures stable grid

Within a given grid level, the voltage may fluctuate by a maximum of ten per cent. If it exceeds that level, insulators and components can suffer damages. The risk of short circuits increases as well. If the voltage drops too far, the system can become unstable and collapse. So an important task of grid operators is to maintain the voltage level. In contrast to frequency stability, voltage maintenance measures are carried out locally. This requires

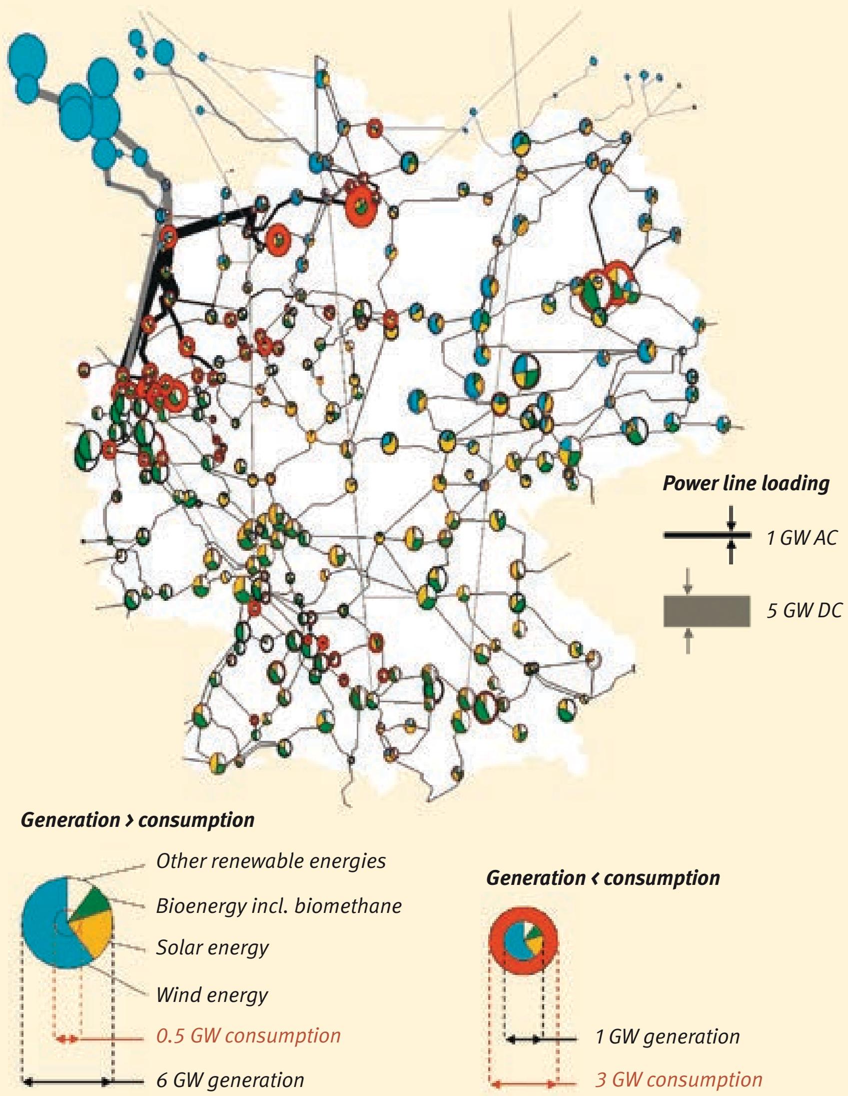


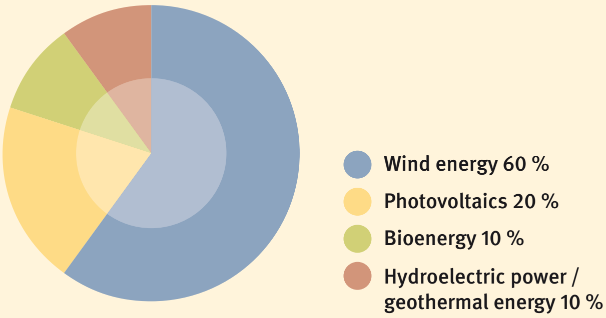
Fig. 1 *Illustration of the topological distribution of grid nodes in Germany with the corresponding ratio of offered to demanded energy.*

reactive power. While it creates a current flow, it cannot perform work. By selectively adding positive or negative reactive power, grid operators can affect the voltage.

The voltages of the individual grid nodes also influence each other. That means: for all voltage maintenance measures, adjacent nodes need to be considered in the calculations. As part of the project, the developers designed a proportional control scheme, with which it is possible to limit the voltage within the specified voltage range at all times. Only some feed-in nodes exhibited a voltage slightly in excess of the tolerance range. Overall, and as a result of the control scheme, the researchers certified that the scenario was able to keep the voltage range within the limits even when using renewable energy sources, and regardless of the season. The planned HVDC transmission lines can also help lower high reactive power during transmission.

Supply restoration from the bottom up

Currently, grid operators restore voltage after a power failure by starting at the highest voltage level and finishing at the lowest voltage level. That means: first, large power plants ensure a stable grid at the 400-kV level before the next lower grid levels are reconnected. This method will not work with a supply coming from many generators in the low and medium voltage levels. This is why the engineers looked into supply restoration from the bottom up. This is how it works: after a power failure, a number of isolated



Power generation	*Annual energy yield [TWh]*	*Installed capacity [GW]*	*Annual full-load hours [h]*	*Share of electricity generation [%]*	*Consumption*	*Annual energy consumption [TWh]*	*Installed capacity [GW]*	*Annual full-load hours [h]*	*Share of electricity consumption [%]*
Import	*11.5*	*20.0*	*325*		***Export***	*11.5*	*36.6*	*314*	
Surplus	*58.5*								
Onshore wind energy	*213.9*	*87.0*	*2,584*	*35.58*					
Offshore wind energy	*108.7*	*40.0*	*3,862*	*18.08*					
Photovoltaics	*119.7*	*133.7*	*909*	*19.91*					
Local bioenergy	*34.5*	*17.3*	*2,000*	*5.74*					
Biomethane	*26.0*			*4.33*					
Geothermal energy	*41.0*	*4.7*	*8,760*	*6.82*	***Old & new loads***	*523.6*			*87.09*
Hydroelectric power	*25.0*	*4.8*	*5,253*	*4.16*	***Grid losses***	*8.7*			*1.45*
Pumped storage power plants	*11.1*	*12.6*	*883*	*1.85*	***Pumped storage power plants***	*14.8*	*11.2*	*1,318*	*2.46*
Batteries	*2.7*	*55.0*	*49*	*0.45*	***Batteries***	*3.2*	*55.0*	*58*	*0.53*
Methane power plants	*18.5*	*53.8*	*828*	*3.08*	***Power-to-gas***	*50.9*	*13.1*	*3,869*	*8.47*
	Σ601.2			*Σ100*		*Σ601.2*			*Σ100*

Fig. 2 *Overview of the distribution of energy generation, annual energy yields and installed capacity and full-load hours*

grids form without a live high-voltage grid level. Once the isolated grids are stable, they can be connected. They then connect to the transmission system.

To test this, the developers implemented an experimental setup. It consisted of a typical distribution network with a biogas plant, a wind turbine and controllable and non-controllable loads. At the beginning of the test, the plant was disconnected from the grid and gradually, the engineers were able to activate the individual elements – until the grid was finally stable and able to synchronise with the interconnected power system. The conclusion: supply restoration from the bottom up and voltage maintenance with renewable energy sources are both possible.

Storage technologies for periods without sunshine and wind

But what if there is neither wind nor sunshine? Storage technology is the answer. In addition, permanently available systems such as biomass power plants are utilised in emergency cases. Surplus energy must be stored to ensure a stable supply even under continued bad weather. The researchers focus mainly on the so-called power-to-gas process. Excess energy splits water into hydrogen and oxygen. Hydrogen can be methanised in a chemical reaction, and fed into the natural-gas grid. Under bad weather, gas-fired power plants then reconvert it.

Effective grid expansion can help support renewable energies. The necessary backbone can be created in conjunction with new energy storage systems.

Virtual power plants

The purpose of virtual power plants is to link the energy production of smaller plants, so that grid operators can treat them as one large power plant. They usually consist of a mix of photovoltaic systems and wind turbines supplemented by biomass and hydroelectric power plants. However, geothermal plants and CHPs can also contribute their output and partake in virtual power plants.

The control centre communicates with the individual plants and determines the amount of energy required by the grid. In addition, it checks to see how much power can be supplied by volatile producers at the present time. For predictions, it relies on high-resolution weather data and combines it with local data of the producers. With this information and with price forecasts for the electricity markets, a virtual power plant can then feed in electricity.

One disadvantage is the communication overhead. It requires a lot of computing power and incurs additional costs. Nevertheless, virtual power plants could maintain a secure energy supply in the future.

The researchers assume that large storage systems will be technically mature and economically feasible by 2050. In the simulation, every third photovoltaic system on a building is equipped with a battery. The already successfully employed pumped storage power plants support the new energy storage systems.

Innovations still required by 2050

The researchers see a further need for development, amongst others, in the share of grid-forming converters, voltage maintenance measures from subordinate grid levels in combination with the transmission system, in investigations into short-circuit current and further grid stability simulations. They also consider the continued coupling of power supply, transport and heating networks as key to the future energy supply. In addition, the existing electricity grid must be expanded and optimised. Ongoing research projects on these issues are being carried out, amongst others, by the Energy Storage Research Initiative and the Future-proof Power Grids initiative.

Research for modern grids

A successful energy transition is only possible with effective grid expansion. To this end, the German Federal Ministries for Economic Affairs and Energy as well as Education and Research granted the 'Future-proof Power Grids' research initiative 150 million euros. The supported projects range from basic research to specific applications and products – in distribution grids, transmission systems and offshore grid connection. The projects of the initiative include the following:

Connecting offshore networks to the grid – A major challenge of the future energy supply is, amongst others, the grid connection of offshore wind farms. While the first farms are already feeding into the grid, further research can improve the connection and allow for a network of wind farms. In the NSON project, scientists are analysing different network connectivity options of a prospective offshore power grid, including the impact on the German and European interconnected grid.

Transporting more power with a line system – The project participants of the research project DCCTL are reviewing whether or not existing power lines can be used to transport more power. Existing three-phase systems would carry up to 3,000 MVA instead of 2,000 MVA. In hybrid DC overhead line systems, pylons would carry both DC and AC. The direct-current systems would carry up to five gigawatts. Another research goal is laying underground cables – because Germany is densely populated and overhead lines cannot be installed everywhere.

Preparing Europe's electricity grid for renewable energy – Back when today's grid was being built, distributed generation and renewable energy sources were not an issue. This is why the grid is optimised for different conditions. As part of the GENESYS2 project, researchers are investigating what is necessary for an efficient grid expansion, and how it might be implemented. The boundary conditions are determined by the existing grid. Existing lines, substations and power supply voltages cannot be changed easily. The results will highlight different developmental paths and make them comparable. Scientists will be able to recommend economically viable scenarios in addition to technically viable ones.

Further research projects and information on the progress made so far is available at **http://forschung-stromnetze.info/en/**

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