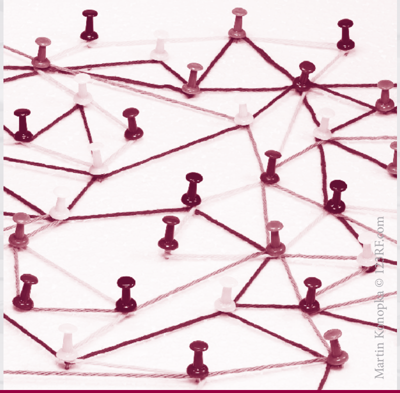
TAB
OFFICE OF TECHNOLOGY ASSESSMENT
AT THE GERMAN BUNDESTAG

MODERN POWER GRIDS AS KEY ELEMENT IN A SUSTAINABLE SUPPLY OF ENERGY



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Summary

- Currently, the German energy system is going through a transition process of historic dimensions. This means that the requirements that have to be laid down for power grids are changing dramatically.
- This results in a substantial pressure to take action with regard to grid expansion or conversion as well as to the development of new concepts of operation in order to continue ensuring a reliable and safe electricity supply.
- For the future development of power grids, there is a considerable scope for action and design both from a conceptual perspective (e. g. centralized vs. decentralized) and with regard to the technology chosen (e. g. overhead lines vs. underground cables).
- In an open social debate, preferences shall be discussed and subsequently implemented in a political approach.

What is involved

Power grids are an essential pillar of Germany's infrastructure on which largely depends the economic and social well-being as an industrialized nation. They represent the link between electricity producers and consumers. From a conceptual point of view, power grids have two priority functions. On the one hand, they have the function of transporting electricity from the producers to the consumers. On the other hand, they provide flexibility. This means that if something unexpected occurs at an individual point in the grid (e. g. the passage of a thunderstorm front causes a drop in the power generation by means of photovoltaics), this can be compensated by a quick response at a rather distant point (e. g. by quick start-up of a gas turbine). A high degree of flexibility is a major prerequisite to enable the electricity system to integrate higher shares of fluctuating supply from renewable energy sources, particularly wind and solar energy.

Currently, the German energy system is going through a transition process of historic dimensions. Until 2030, renewable energies (RE) shall cover approximately half and, until 2050, at least 80% of the demand for electricity. The generation of energy from renewable energy sources shows distinct regional focuses – wind power is generated mainly in northern and eastern Germany, energy from photovoltaics rather in southern Germany – which sometimes are several hundred kilometers away from the high-demand areas in the West and South of Germany. At the same time, the last nuclear power plant shall be decommissioned by the end of 2022. Furthermore, the successive completion of a common European single market also for the electricity sector leads to an ever closer integration and mutual interference of power systems across national borders.

Altogether, these developments partly make **completely new demands** on power grids so that currently this results in a **substantial pressure to take action** with regard to grid expansion or conversion as well as to the development of new concepts of operation in order to continue ensuring a reliable and safe electricity supply.

Required expansion and conversion of grids

The required expansion and conversion of the **distribution grids** at the local and regional level is mainly due to the fact that an increasing number of smaller decentralized power generation systems has to be connected. Besides the RE systems, cogeneration plants providing a combination of heat and power are relevant as well. For integration of the power thus generated, the distribution grids must be enabled and expanded correspondingly. If the quantity of electricity generated locally exceeds the demand, the usual direction of the current flow from the transmission grids to the distri-

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bution grids will be reversed and electricity will be fed back from the lower to the higher voltage levels. Various studies amount the investment need to approximately EUR 25 billion until 2020.

For **transmission grids**, it is of crucial importance that a further increase of RE capacities often will occur far away from the load centers. This is particularly obvious with regard to the planned use of offshore wind power. The existing transmission capacities are not sufficient to manage the occurring load flows from the generation to the centers of consumption. Beyond this demand for transportation, the necessity to ensure a supraregional equalization of geographical and temporal fluctuations in supply and demand is another powerful driving force regarding grid expansion. Since 2011, the need for expansion with regard to the transmission grids is defined uniformly throughout Germany in a new structured and formalized procedure. A broad consultation of stakeholders and the general public is an integral part of this procedure. The overall need for expansion thus determined until 2022 is 1700 km of new lines, 2800 km of new construction in existing power line routes as well as reinforcements on 1300 km. The volume of investments for these measures is approximately EUR 20 billion.

Organization of power grids

The power grids for public power supply usually are divided into subgrids by means of their operating voltage: The **transmission grids** with a voltage of 220 kV or 380 kV are intended for long-distance transmission of larger quantities of electricity and for supraregional interchange. Conventional large-scale power plants, but also large offshore wind farms are connected to them. For **distribution grids**, three voltage levels can be distinguished: **high-voltage** (60 to 110 kV), **medium-voltage** (6 to 30 kV) and **low-voltage level** (230 to 440 V). At the high-voltage level, medium-sized power plants (conventional ones, but also e. g. large onshore wind farms) are connected as well as certain large consumers (e. g. electricity-intensive industrial plants) on the demand side. The medium-voltage level is intended for the connection of smaller power generation facilities and industrial consumers. At the low-voltage level, all household customers and the typical commercial customers (crafts, trade, services) as well as small decentralized producers, e. g. cogeneration plants or PV roof systems are connected.

Future szenarios regarding the power grid

For the future development of power grids, there is a considerable **scope for action and design**. Preferences to be defined at a social level should provide guidance with regard to the design. Examples for this are questions such as: Would it be adequate always to prefer the economically most efficient solution, or is it important to provide a variety of approaches and stakeholders? Is there a focus on autonomy (e. g. self-sufficiency, reduction of dependency on imports) or on cooperation and on making use of synergetic effects?

An essential option for design playing a significant role in the public debate as well is the question on which geographical unit the grid will be based or – in concrete terms – the contrast between »**centralized**« and »**decentralized**«. Here, the scope of approaches is ranging from an exclusive use of locally available resources to a trans-European interconnection using the most productive locations for renewable energies (e. g. Norwegian hydro-electric power and solar power from southern Europe or even from the Sahara).

Local self-sufficiency: A quite radical approach is to ensure supply exclusively by means of local resources. Strictly speaking, this local self-sufficiency would mean a stand-alone (»island«) power supply e. g. of municipalities or urban districts which is decoupled from the transmission grid. Here, storage systems inevitably take center stage as an indispensable component to ensure a secure power supply at any time. Even under favourable assumptions, the storage size required is so large that it is hardly feasible from an economic point of view. Furthermore, the generation facilities have to be substantially overdimensioned to ensure supply so that considerable amounts of electricity – depending on concrete assumptions up to 50% and more – have to be discarded and remain unused. In individual cases, local self-sufficiency might be implemented, e. g. in rural municipalities where sufficient hydro-electric power is available. In cities and regions where energy-intensive companies are located, however, this is completely unthinkable. In contrast, it is significantly easier to achieve the so-called »calculated self-sufficiency« which means that – on a timely weighted average – the quantity of electricity locally generated equals at least the quantity used. Stability and security of supply still are ensured by the grid functioning as a storage system and ensuring the compensation of fluctuations as well as the provision of reserves. However, as a matter of principle, »calculated self-sufficiency« is a purely commercial approach and does not have any influence on the electrical energy flows and thus on the need for expansion of the grids without further measures to be taken such as e. g. synchronization of consumption and generation of electricity.

Regional interconnection: The basic idea here is to organize power supply at a regional level to a large extent using the regional potentials of renewable energy sources. In order to balance supply and demand, a nationwide exchange of electricity shall take place. This approach is based on the observation that a well-developed power grid is finally indispensable for mutual provision of reserve power among regions and for the development of regions with high power generation potentials (e. g. geothermal energy, offshore wind). A strategy with a regional basis would have the advantage that a multitude of different stakeholders (municipalities, electric utility companies, small and medium-sized enterprises, individual citizens and citizens' initiatives) would be mobilized and, thus, regions and municipalities would develop to become a new creative factor for the national energy system. Regarding the question on to what extent the need for expansion of power grids could be reduced, there still is a substantial need for investigation. Currently, however, experts assume that the possible reduction of the need for expansion will be limited.

Pan-European interconnection: Due to the fact that geographical compensation effects can be used even more efficiently, if the geographical extension of the network is very large, the potentials of renewable energy sources (which are easy to develop on a large technical scale) in Germany, Europe and beyond (e. g. solar energy in North Africa) are used in this scenario. For this, a well-developed intercontinental transmission grid (supergrid) is a prerequisite. A reduction of the demand for energy storage capacities is considered to be the main advantage. However, a major disadvantage is the higher degree of complexity (at a technological, financial, political-administrative level) of a coordinated construction of power generation facilities abroad and of the associated cross-border infrastructure.

Design of the future power system

The three drafts for the future with regard to the power grid shall demonstrate the possibilities offered for design. However, they should not be understood as three mutually exclusive alternatives. For a future supply system, elements from all three scenarios certainly could exist side by side. However, social and political options for design are available not only at this **conceptual level**. Also for the question on which **technologies** shall be applied specifically, there are options of high social relevance, not least because the construction of a grid infrastructure normally involves interventions in the living environment of people and/or in the environment. One example for this is the transmission or the protection of sensitive personal data for the use of »intelligent« electricity meters, so-called smart meters. Another example are the alternatives »overhead lines« or »underground cables« which in the following will be compared to each other with regard to their impacts on the environment.

Environmental impacts: overhead lines vs. underground cables

So far, in Germany, **380 kV transmission lines** are implemented almost exclusively as **overhead lines**. Recently, the **use of underground cables** is discussed increasingly as an alternative, particularly because affected residents expect those ca-bles to involve less impairment. The construction of power lines as well as their later operation have an effect on the environment. These effects must be differentiated according to the respective natural resources to be protected (fauna, flora, soil, water or countryside). Here, overhead lines and underground cables differ in many respects.

As a general rule, the environmental impacts involved in the **construction of power line routes** are more severe in the case of underground cables than in that of overhead lines. Usually, underground cables are laid in a depth of 1.5 to 2 m by means of classical civil and underground engineering processes. During the construction phase, a strip with a minimum width of 25 m is required over the entire length of the route (for four parallel cable systems). With the construction of overhead lines, the interventions are limited to the direct pylon locations. Between the pylons, the distance of which typically is 200 to 500 m, the soil remains unaffected to a large extent.

For underground cables, impacts on the soil structure due to construction and to the installation can have a negative effect on the natural **soil functions** (porosity as well as control, storage and retention function for the hydrological balance etc.). Particularly in humid biotopes (moors, marshes, alluvial meadows), this might cause a lowering of the groundwater

Power grid operation in »regional cells«

In the established pan-European synchronous interconnected network of transmission grids, fault events (e. g. the failure of a power plant or of a power line) in one region will be absorbed and compensated for by the neighbouring regions so that electricity supply generally will remain unimpaired. However, if the extent of the fault is so large that this can not be ensured anymore, the fault might spread cascadingly and – in the worst case – provoke a blackout in large areas. On 4th November 2006, for example, the failure of a single power supply line provoked a major failure during which approximately 15 million households in Europe were hit by power failures.

An innovative approach to strengthen the resilience of the power system is that in case of such a major failure smaller units (so-called regional cells) could disconnect from the faulted transmission grid and maintain a stand-alone power supply until the failure is remedied.

The controlled transition of a network part from interconnected operation to stand-alone (island) operation represents a demanding technological challenge. At the same time, this also means a renunciation of conventional operating strategies applied so far for which the formation of isolated networks is deliberately excluded to a large extent.

Altogether, however, it does not seem to be implausible that the technical and operation-related challenges can be solved and that regional cells thus could contribute to provide resilience and stability of the electricity supply and to limit major failure scenarios. Demonstration projects would be adequate to clarify questions involved and to gather practical operating experience.

Overhead line

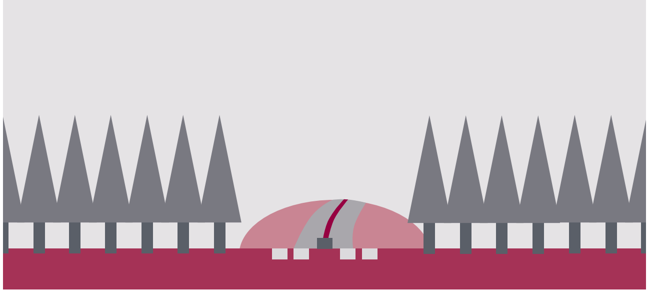
level and affect parts of the biotopes temporarily or possibly even permanently.

The thermal losses occurring during electricity transmission involve **soil heating** which might affect soil functions, the hydrological balance and vegetation. Again and again, farmers express their fears that yield losses might occur for agricultural crop land under which underground cables are running. For this, however, no reliable data exist so far.

In order to make sure that the cable bed is not damaged by roots, a strip must be kept free from deeply rooting plants during the operating phase. In forest areas, this results in a **clearance with a width of** 12 to 18 m. Compared to this, overhead lines require a substantially larger protective strip of up to 80 m to be kept free from high-growing plants. This has manifold and partly dramatic impacts on indigenous animal and plant species. In open terrain, the impacts on habitats of wild fauna and flora are less severe than in forest areas.

As overhead lines are visible even from far away, they represent a visual impact on the **countryside**. Underground

Underground cable



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Moderne Stromnetze als Schlüsselelement einer nachhaltigen Stromversorgung

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cables, how-ever, are hardly visible from a distance. Moreover, in contrast to overhead lines, underground cables do not represent any hazard for **birds** (collision with conductors, electrocution).

Thus, it is obvious that the statement about grid expansion heard again and again in the public debate saying that **»underground cables are more environmentally friendly than overhead lines« cannot be** generally **maintained**. The assessment of the environmental impacts involved significantly depends rather on the local conditions regarding location and use. Overhead lines can be the better solution, for example, if it is necessary to cross sensitive wetlands, whereas underground cables are rather considered for transit and resting areas of birds or for landscapes with a very special countryside which is particularly worth to be protected. Very often, however, difficult considerations have to be made with regard to different goods to be protected: Does the impairment of the countryside due to overhead lines, for example, outweigh the soil heating due to underground cables?

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