dena Ancillary Services Study 2030.

Summary of the key results of the study

"Security and reliability of a power supply with a high percentage of renewable energy"

by the project steering group.

Project management:

Deutsche Energie-Agentur GmbH (dena) – German Energy Agency

Project partners:

50Hertz Transmission GmbH, ABB AG, Amprion GmbH, BELECTRIC Solarkraftwerke GmbH, E.DIS AG, ENERCON GmbH, EWE Netz GmbH, Mitteldeutsche Netzgesellschaft Strom mbH, N-ERGIE Netz GmbH, Netze BW GmbH, SMA Solar Technology AG, TenneT TSO GmbH, TransnetBW GmbH, Westnetz GmbH, Younicos AG

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1 dena Ancillary Services Study 2030: Background and objectives.

With the 2010 energy concept and the decision to accelerate the Energiewende (energy turnaround) in Germany in 2011, the German Federal Government committed to the objective of expanding the percentage of the gross electricity consumption supplied from renewable energy sources to at least 80 percent by 2050. This objective is part of a far-reaching strategy to establish a secure, economical and sustainable energy supply, which takes into account the requirements of climate protection and the targeted reduction of Germany's dependence on fuel imports between now and 2050. The objectives chosen brought about a major change of the power supply structure in Germany, which requires new solutions to provide ancillary services in future. These new solutions are necessary to guarantee reliable and stable operation of power supply grids.

As part of the Energiewende (energy turnaround) in Germany, the electricity grids must be modified and expanded to facilitate the changes in the electricity generation structure, and to guarantee constant supply security in the future. The electricity transmission grid must be upgraded to transport large quantities of electrical energy from the main generation areas for onshore and offshore wind energy in the north and east of Germany to the main consumption areas in the south and west of Germany, and at the same time to permit increasing international transit as part of European electricity trading. Renewable energy systems are largely connected to the distribution grid, i.e. at high, medium and low-voltage levels. The energy generated is largely fed from the distribution grids into the transmission grids, and must often be transported over long distances. As a result, there is a significant need for expansion and innovation in the transmission and distribution grids in Germany to prevent overloading of the operating equipment and the permitted voltage limits being exceeded.

Against this background, a review is needed of how secure operation of the power supply system can be organised under the new conditions. Conventional power plants, which today still largely provide the ancillary service products for stable grid operation, will be on-grid for fewer and fewer hours in future. The question as to how the scope and type of these ancillary service products must change to provide the **ancillary services frequency control, voltage control, system restoration and system control**.

Relevance of ancillary services for the power supply system.
In order to guarantee a high quality, reliability and security of electricity transmission and distribution, the system operators continuously take measures to keep the frequency, voltage and load of the operating equipment within the permitted tolerances or to return them to the normal range after faults. **These services, which are essential to keep the supply of electricity functional, are called ancillary services. The products required for this are largely provided by power generation units or other technical systems. System operators use these products and provide ancillary services by deploying them appropriately.**

Frequency control is implemented by transmission system operators by maintaining a balance between electricity generation and consumption. Transmission system operators can use the instantaneous reserve and balancing energy to do so.

Voltage control refers to the responsibility of the transmission and distribution system operators to maintain the grid voltage in a permissible range for the voltage quality. The system operators must also ensure that voltage drops are limited if a short circuit occurs.

Re-establishing the power supply is used in the event of a widespread power failure. Then the transmission system operators, with the cooperation of the distribution system operators, must be in a position to restore the supply of electricity within a very short time.

As part of **system control**, the system operators are responsible for organising secure grid operations. Therefore, they continuously monitor and control the electricity grid including generation and (to a limited extent) load for threshold violations (e.g. current flow overloads), in order to guarantee secure operation of the entire power supply system.

To ensure the provision and availability of the ancillary services required for secure and stable operation of the electricity grids, the following options are used today:

- Intrinsic system properties of electricity generators or consumers or properties required via grid connection codes or legal specifications
- Flexible use of operating equipment of the system operators as part of system control
- Services procured by system operators from third parties based on bilateral agreements or market mechanisms

Table 1 provides an overview of the main ancillary service products and their providers.

The **transmission system operators have the superordinate responsibility for system stability**, and must also coordinate with the other transmission system operators involved in the European integrated grid.

System restoration is realised based on a specified process controlled by the transmission system operators in the event of a power failure. The respective distribution system operators are responsible for local grid faults which are restricted to the distribution grid. In the event of larger-scale failures which impact grids up to the extra high voltage grid, the transmission system operators are responsible for controlling the system restoration.

System control and **voltage control** are the responsibility of the respective system operator, which must take into consideration the required specifications of the upstream system operators.

Ancillary service	Frequency control	Voltage control	System restoration	System control
Objective	▪ Maintenance of the frequency in the permitted range	▪ Maintenance of the voltage in the permitted range ▪ Restriction of the voltage drop in the event of a short circuit	▪ System restoration after faults	▪ Coordination of the grid and system operations
Products/ Measures	▪ Instantaneous reserve ▪ Balancing energy ▪ Flexible loads ▪ Frequency-dependent load shedding ▪ Active power reduction on excessive/insufficient frequency (RE and CHP plants)	▪ Provision of reactive power ▪ Voltage-related redispatch ▪ Voltage-related load shedding ▪ Provision of short circuit power ▪ Voltage regulation	▪ Switching measures to restrict the fault ▪ Coordinated commissioning of feeders and sub-grids with loads ▪ Black start capability of generators	▪ Grid analysis, monitoring ▪ Congestion management ▪ Feed-in management of RES ▪ Coordination of the provision of ancillary services across grid levels
Current providers (selection)	▪ Conventional power plants ▪ Flexible controllable loads ▪ Balancing energy pools (including RE systems and large-scale batteries)	▪ Conventional power plants ▪ Operating equipment (e.g. reactive power compensator) ▪ RE systems	▪ Network control unit ▪ Black start capable conventional power plants ▪ Pumped-storage power plants	▪ Network control units in conjunction with operating equipment and conventional power plants

Table 1 - Classification of current ancillary service products.

Please note here that for supply security, irrespective of the provision of ancillary services, a sufficiently dimensioned secure generation capacity will have to be maintained in the future[1] to meet the electricity demand if there is a generation shortfall from renewable energy sources due to weather conditions.

Ancillary Services Study 2030: Objectives.

The objective of the present study is to identify the need for action to guarantee secure and reliable grid operation between now and 2030 in a power supply system with a high percentage of electricity generation from fluctuating renewable energy sources. The study focuses on the power supply system in Germany taking the European integrated grid and international electricity trading into consideration.

[1]The secure generation capacity for guideline scenario B2033 of the 2013 Network Development Plan is roughly 96,000 MW with an annual maximum load of 84,000 MW.

The following **key questions** were examined as part of the study:

- How will the requirements and the demand of ancillary services to be provided develop between now and 2030?
- What contribution can and should innovative technological solutions (in particular via renewable energy sources, inverters, grid technology, demand-side management and electricity storage units) make to the provision of ancillary services in future?
- To what extent can the minimum generation capacity from conventional power plants currently required to provide ancillary services be reduced?

Study design.
This dena Ancillary Services Study 2030 was produced by the Deutsche Energie-Agentur (dena) – the German Energy Agency in close interdisciplinary cooperation with transmission and distribution system operators, manufacturers and project developers for renewable energy and manufacturers of grid and system technology.

dena initiated and headed up the study project. The study was designed by dena and coordinated with the group of experts from the companies involved in the project steering group.

The following members were represented in the project steering group as sponsors of the study: **50Hertz Transmission GmbH, ABB AG, Amprion GmbH, BELECTRIC Solarkraftwerke GmbH, E.DIS AG, ENERCON GmbH, EWE NETZ GmbH, Mitteldeutsche Netzgesellschaft Strom mbH, N-ERGIE Netz GmbH, Netze BW GmbH, SMA Solar Technology AG, TenneT TSO GmbH, TransnetBW GmbH, Westnetz GmbH, Younicos AG**. In addition to this, RWE Deutschland AG and Statkraft Markets GmbH took part in the meetings of the project steering group as guests.

The **research partner** involved was **ef.Ruhr GmbH** under the **leadership of Prof. Dr.-Ing. Christian Rehtanz**. The ef.Ruhr GmbH performed the quantitative and qualitative analyses. The project steering group discussed and checked the methods used and the results.

2 Scenario assumptions for the power supply system in 2030.

For the investigations in this study, Scenario B from the 2013 Network Development Plan was assumed for the 2033 study year. Any time “Ancillary services in 2030” is mentioned in this study, this refers to the study year 2033.

The analyses in this study assume that the installed renewable energy capacity for electricity generation will almost triple between 2013 and 2033. Onshore wind with an installed capacity of 66.3 GW, photovoltaics with an installed capacity of 65.3 GW and offshore wind with an installed capacity of 25.3 GW are the dominant generation technologies in this scenario.

For the conventional power plant fleet, the 2013 Network Development Plan predicts that the nuclear power phase-out will be complete by 2022, and that many gas power plants will be built. Overall, an installed conventional generation capacity of approx. 76 GW is assumed for 2033.

Installed generation capacity in Germany in the study year (total: 259 GW)									
Lignite	Hard coal	Natural gas	Pumped-storage	Others	Onshore wind	Offshore wind	Photovoltaics	Hydroelectric power	Biomass and others
12 GW	20 GW	41 GW	11 GW	3 GW	66 GW	25 GW	65 GW	5 GW	11 GW

Table 2 - Installed generation capacity in the study scenario (Source: Scenario framework of the 2013 Network Development Plan).

Even if changing political stipulations result in deviating expansion and development targets, the trends and the need for action revealed will largely remain unchanged as the expansion of renewable energy progresses.

For other European countries, the assumptions of the Scenario Outlook & Adequacy Forecast (ENTSO-E 2013) published in 2013 were assumed for the composition of the electricity generation mix. This analysis predicts a moderate expansion of renewable energy sources for other European countries compared with Germany.

The renewable generation capacities were allocated to individual grid nodes or regions in the grid model based on a number of criteria. Among other factors, an increase of the installed renewable energy capacity at current locations (e.g. repowering of onshore wind) and the construction at new locations particularly suitable for generating electricity are incorporated. As part of the analyses, the power plant use is calculated with hourly precision using a market-based model.

The transmission grid model used for the analyses in the dena Ancillary Services Study 2030 incorporates the expansion of the extra high voltage grid with three-phase and alternating current connections in accordance with the 2013 Network Development Plan, and the measures in the ENTSO-E Ten-Year Network Development Plan 2012 (TYNDP) for the further grid upgrades in Europe.

As part of the Network Development Plan for the extra high voltage grids, state of the art technologies are to be implemented by the transmission system operators (e.g. reactive power compensators for voltage control) in accordance with the regulatory framework. Determining the need for expansion and modification of the electricity transmission grid in the Grid Development Plan, the need for reactive and short circuit power for static and dynamic voltage control was analysed in detail as part of grid planning.

Based on the results of the Network Development Plan, this study examines all ancillary services required for secure and stable grid operation across all grid levels, and evaluates the potential of all (i.e. even new) innovative technology solutions for their provision (e.g. provision of reactive power and emulation of instantaneous reserve with renewable energy). Accordingly, the dena Ancillary Services Study 2030 is an important and forward-looking addition to the existing Grid Development Plan. The economic forecasts made in the study permit an initial classification of the alternatives available for efficient provision of the ancillary services.

Ancillary service products (e.g. primary balancing energy for frequency control) are currently utilised jointly by the participating transmission system operators, and will continue to be in future. However, for physical reasons, there is automatic mutual support in the European integrated grid for other ancillary services (e.g. instantaneous reserve for frequency control).

As a boundary condition, the requirement for all analyses performed in this study was that the technical alternatives studied for future provision of ancillary services must be provided in a manner and volume to guarantee the current level of system stability in Germany and Europe in future, too.

All analyses of the dena Ancillary Services Study 2030 were also made under the boundary condition that Germany will continue to fulfil its share of the system responsibility in the European integrated grid at a constant level compared with the current situation, and that the system support responsibility is not to be transferred to European partners.

3 Frequency control in 2030.

For stable operation of the power supply system, the power fed must correspond with the electricity consumption in the grid at all times, taking the import/export balance into account. The balancing group managers should ideally ensure fully balanced planning and react in the event of deviations within their respective balancing group.

In the event of deviations between generation and consumption, the frequency increases or decreases. The transmission system operators must ensure that the balance is restored immediately so that the target frequency of 50 Hz is maintained again.

The instantaneous reserve and the balancing energy are particularly important and are analysed in detail in this study. To maintain the frequency, transmission system operators can use contractually agreed flexible loads, or demand further adjustments from electricity suppliers and consumers in emergencies. Frequency-dependent load shedding, i.e. automatic gradual disconnection of loads from the grid, is used as a final security measure in the event of insufficient frequency. In the event of excess frequencies, electricity feed-in is throttled.

3.1 Instantaneous reserve.

Before balancing energy is technically fully available to equalise generation and consumption due to the activation times, rapid frequency changes are attenuated in the short term due to the inertia of the rotating masses of generators in the conventional power plant fleet. The capability of counteracting frequency changes by absorbing or feeding kinetic energy is referred to as instantaneous reserve.

In order to check whether there is sufficient kinetic energy in the system as an instantaneous reserve, a load or generation step of 3,000 MW is assumed as the design case for the current European integrated grid. In such cases, the instantaneous reserves must attenuate the resulting frequency change sufficiently before primary regulation sets in, so that the permitted frequency range of 50 Hz +/- 0.8 Hz (short-term/dynamic) or 50 Hz +/- 0.2 Hz (stationary) is not exceeded.

Development of the need for instantaneous reserve until 2030.

In terms of the development of the demand for instantaneous reserve by 2030, it can be assumed that the currently standard design case for grid support with a capacity change of 3,000 MW (equivalent to the failure of a double power plant block) will remain adequate.

The introduction of more renewable energy systems with generally smaller system sizes will not reduce the design case of 3,000 MW by 2030. The design criterion applies in the entire synchronous integrated grid of ENTSO-E. In 2030, there will still be a sufficient number of large-scale power plants (which determine this design criterion) in operation – based on the assumed generation scenario for Germany and Europe. Even taking the connection of offshore wind farms, construction of HVDC lines in the integrated grid and the existence of electricity distribution grids with a high installed capacity from renewable energy sources, there will be no need to increase this design criterion. This is based on the assumption that the planning principle for grid design, i.e. that no capacity steps of over 3,000 MW can occur during failures, will be retained in future.

As the renewable energy systems which feed in via inverters cannot contribute to the instantaneous reserve without additional technical measures, Germany's contribution to system support in the integrated grid would be far lower in 2030 in situations with a high RE feed-in unless countermeasures are taken. Germany's involvement in the instantaneous reserve and the need for alternative provision of instantaneous reserve to keep the contribution constant until 2030 is summarised in Figure 1. For 2011, the model calculations in this study show a contribution of the German balancing zones to a capacity step of 3,000 MW with a braking power of 372 MW and a kinetic energy of 0.95 MWh. Without the provision of instantaneous reserves from alternative sources, this contribution would reduce to roughly one third by 2030 during certain hours of the year. Until the limit value of the maximum dynamic frequency deviation of 49.2 Hz, there remains a sufficient safety margin of 0.25 Hz. To operate the power supply system as stably as in 2011 in future, i.e. to keep Germany's contribution to the instantaneous reserve constant, in 2030 at times of high RE feed-in or low conventional generation, a capacity difference of roughly 254 MW and a kinetic energy of 0.68 MWh must be provided for the instantaneous reserve via suitable alternative technologies.

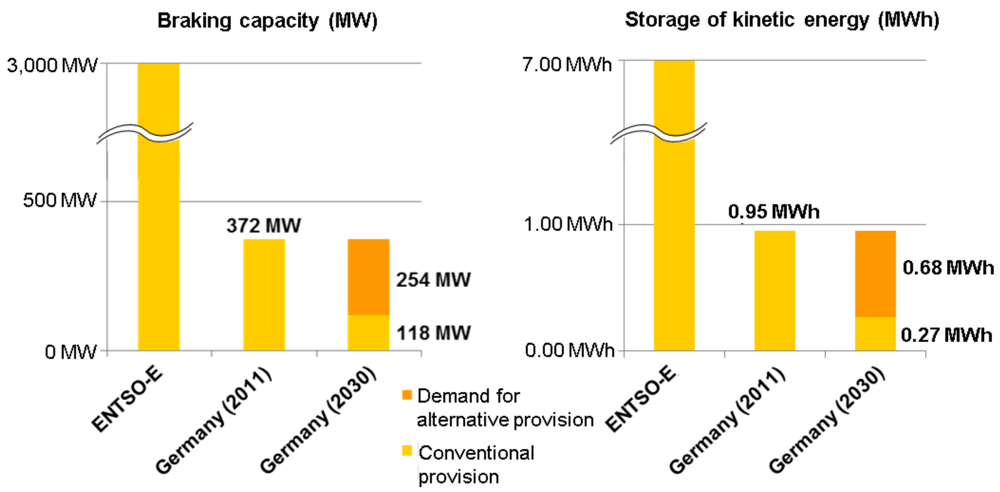

Figure 1 - Provision of the German share of instantaneous reserve.

Alternatives for provision of instantaneous reserve.

Renewable energy sources – especially wind turbines and large ground-mounted solar power plants – as well as battery storage capacities can already be technically equipped to contribute to the instantaneous reserve. In this case, the power electronics of the systems' feed-in inverters emulates the inertial properties of an electromechanical synchronous generator.

Inverters must be able to absorb and output energy in order to provide instantaneous reserve. The main technical solutions which could potentially be used for this are throttling wind turbines or photovoltaic systems, using battery storage capacities or the inertia of wind turbines (emulation of instantaneous reserve). As throttling fluctuating renewable energy would lead to a long-term loss of active power, and additional investments would be required to build battery storage for instantaneous reserve[2], using the inertia of wind turbines is the most efficient alternative. The studies assume that a wind turbine with an average system capacity of 2 MW can provide a braking capacity of up to 0.2 MW, and thus kinetic energy of up to 0.55 kWh by using the inertia of the wind turbine. In 93 percent of all hours studied in 2030, the instantaneous reserve provided in this way by wind turbines would be sufficient to keep Germany's contribution to the instantaneous reserve in the European integrated grid constant at the present level. In the remaining 7 percent of hours, there are sufficient power plants connected to the grid to provide the required braking capacity and kinetic energy for the stability of the electricity grids missing due to the lack of wind feed-in.

Recommended actions.

In order to enable Germany to fulfil its system responsibility in the European integrated grid reliably and fully in future, suitable alternative technological solutions are required to provide the instantaneous re-

[2] If battery storage are already available in the grid for other reasons (e.g. to provide primary balancing capacity), they can be incorporated for the instantaneous reserve.

serve in future in parallel to the further expansion of renewable energy. To implement this, the regulatory framework conditions must be adapted such that decentralised energy units can contribute to the provision of instantaneous reserve in future. In particular, in a first step, the conditions required for a provision of instantaneous reserve via large-scale wind turbines (emulation of instantaneous reserve) must be created. In the longer term, the extent to which the integration of other alternative providers (throttling decentralised energy units, battery storage) is necessary/economically viable and must be examined.

3.2 Balancing energy.

In order to compensate the excess generation or load which occurs over all balancing groups, the transmission system operators use positive or negative balancing energy. They purchase the balancing energy in the three product qualities – primary and secondary control and minute reserve[3] – via a regular market-based auction process. Potential providers on the balancing energy market are subjected to a pre-qualification process before participating to prove that the planned generation units or flexible loads have the required availability, reliability and controllability.

Development of the demand for balancing energy until 2030.
Assuming the generation scenario in the 2013 Network Development Plan, the assessment of the demand for balancing energy reveals a significant increase in the secondary balancing energy and minute reserve to be provided. In particular, the effect of generation forecasting errors which grows with the installed renewable energy capacity affects the demand for balancing energy. Assuming a constant forecast precision for RE feed-in, the demand for negative minute reserve capacity will increase approximately 70 percent and the demand for positive minute reserve capacity will increase by approximately 90 percent. The demand for secondary balancing energy will increase to a lesser extent (approx. 10 percent for negative and 40 percent for positive secondary balancing energy), however the increased occurrence of major wind flanks leads to the assumption of more frequent activation of the secondary balancing energy.

The dimensioning processes used today measures the demand for balancing energy on a quarterly basis. The increase of the average balancing energy demand required between now and 2030 can be restricted (see Figure 2) if in future an adaptive dimensioning process were used for balancing energy demand, e.g. for the previous day, and calculated based on the actual forecasts for load and feed-in of renewable energy. Note that even if the adaptive process is used, there will be individual days with high electricity feed-in from renewable energy sources with almost double the demand for minute reserve in 2030 compared with the present-day demand.

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[3] Primary control is used to stabilise the system where there is only a brief power deficit or surplus. It is provided in a way of solidarity by all synchronously connected TSOs inside the UCTE area and has to be activated within 30 seconds. The time period of availability per single incident is up to 15 minutes.
If a longer disturbance occurs, secondary control is automatically activated within 5 minutes. The time period of availability per single incident is between 30 seconds and 15 minutes.
If the power flow deviation lasts for an extended period (more than 15 minutes) secondary control gives way to minute reserve. The latter is activated by a telephonic or schedule-based request of the affected TSO at the respective suppliers. In case of a telephonic request, the minute reserve has to be activated within 15 minutes after the phone call.

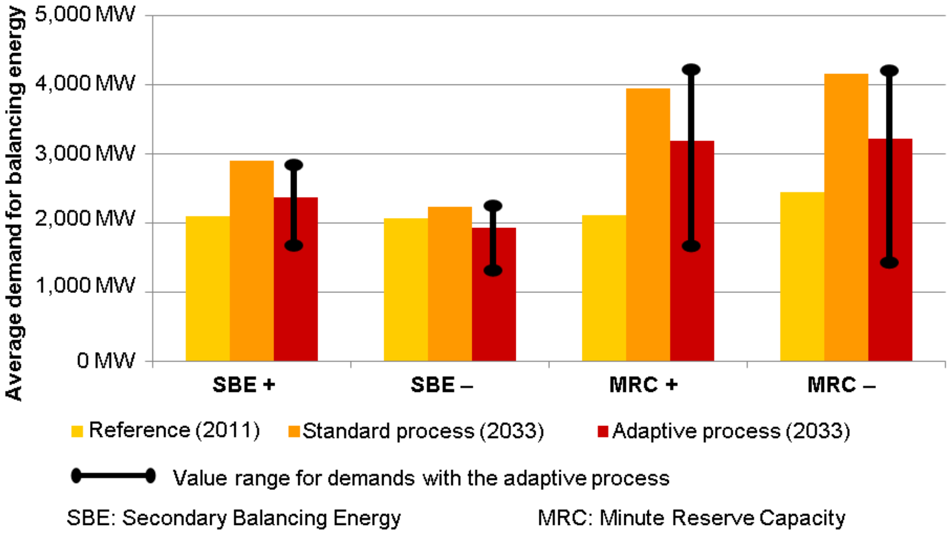

Figure 2 - Estimating the future demand for balancing energy.

Alternative providers of balancing energy.

In the present-day power supply system, balancing energy is largely provided by conventional power plants including pumped-storage plants. Alternative providers, some of which already market their capacity on the balancing energy market, include balancing energy pools comprising biogas plants, emergency electricity generators and large-scale batteries, as well as particularly energy-intensive industrial companies with flexible loads. Other alternative providers which have the fundamental capability to provide balancing energy include remote-controlled wind turbines or photovoltaic systems, and smaller generation systems (e.g. small-scale CHP plants) and loads (e.g. connection of flexible electricity loads).

In future, there will be more periods when the electricity feed-in from renewable energy sources will exceed the consumption in Germany. Then, there will be very few or no conventional thermal power plants on the German grid due to market signals. The study reveals that in 2030, market forces will dictate that during certain hours, there will not be enough conventional power plants to provide balancing energy. There are alternatives for the provision of all balancing energy products which can meet the demand, even in these hours.

Economic viability of alternative provision of balancing energy.

The study shows that there are technical options with sufficient potential. Compared with exclusive utilisation of conventional must-run capacity for balancing energy provision, using alternative providers is more economical. The study results indicate that large-scale batteries are the most economically viable alternative of those considered for primary balancing energy. There are a variety of possible alternatives for secondary balancing and minute reserve energy. The extent to which the respective alternatives can actually be developed and utilised to provide balancing energy must be derived from the supply and demand on the balancing energy market.

Recommended actions.
In order to avoid a conventional must-run capacity in order to provide balancing energy in the medium term, and thus also improve the system integration of renewable energy, the conditions for providing balancing energy from alternative sources should be improved. To do so, we must evaluate the extent to which product characteristics and pre-qualification requirements can be adapted to facilitate the market entry of new providers of balancing energy from e.g. renewable energy sources, flexible loads and electricity storage units, and meet the changing system requirements (e.g. steep flanks). In this context, a reduction of the tender periods for primary and secondary balancing energy must also be reviewed.

At the same time, technical and organisational solutions must be developed to permit coordination of increased provision of balancing energy via decentralised energy systems from the distribution grid, taking the local grid conditions into account.

In addition to this, the implementability of the adaptive assessment process must be reviewed, for example to determine and tender the probable balancing energy demand for the next day based on the previous day.

4 Voltage control in 2030.

With regard to the security and reliability of the electricity system, the stability and the level of the grid voltage must be guaranteed both in normal operation and in the event of failures. At the same time, to cope with voltage drops in the event of major failures, sufficient short circuit power must also be provided, among other things. In addition to this, stable system properties in normal operation and during failures also depend on suitable coordination of the voltage controllers in the electricity grid.

4.1 Provision of reactive power for static voltage control.

For stable grid operation and to protect people, operating equipment and end consumer devices, the voltage is kept in the permitted voltage range of +/- 10 percent of the nominal voltage at the end consumer via a variety of means. That is currently largely implemented via grid planning and operationally via provision of reactive power by conventional power plants and intentional stepping of transformers. In addition to this, reactive power compensators and voltage controllers are used in the electricity grid. Some of the redispatch measures in the transmission grid are taken for voltage control reasons.

Development of the demand until 2030.
Due to the increasing transport distances and international power transit, the demand for reactive power in the transmission grid will increase significantly by 2030. The reactive power range to be provided at the extra high voltage level, i.e. the range of reactive power demand at the respective grid nodes at different times, will increase overall.

With the increasing fluctuating feed-in of renewable energy and the increasing use of underground cables, the demand for regulating reactive power and thus voltage is growing to prevent violations of the permitted voltage range and restrict the grid expansion requirements.

Alternative provision of reactive power.
By 2030, an increasing number of alternative solutions to the current provision of reactive power in the power supply system via conventional power plants will be required. From a current perspective, the following alternatives are technical options to meet the demand for reactive power in the electricity grid:

- Installation of additional reactive power compensators (inductors, capacitors, SVCs and STATCOM[4])
- The inverter stations of the planned high voltage direct current (HVDC) transmission lines
- Reactive power provision from decentralised generation systems in the electricity distribution grids
- Modification of disused power plants for phase shift operation, equipping new power plants for decoupled phase shift operation and building standalone phase shifters

In addition to this, voltage problems can also be solved via redispatch, i.e. starting individual power plants which then regulate voltage, if the demand only arises in individual hours and corresponding generation systems are available.

The analyses show that in the studied sample electricity distribution grids, targeted controllable provision of reactive power from wind turbine and photovoltaic system inverters, which is possible irrespective of the active power feed-in, technically permits reactive power-neutral operation at all distribution grid levels. This reduces the strain on the transmission grid, which was previously used to exchange reactive power in the distribution grid. The available potential of the provision of reactive power by renewable energy sources in the high voltage grid (110 kV level) in 2030 can also be used to meet the reactive power demand of subordinate grid levels, in addition to its own demand. In addition to this, the grid regions examined in the study have the potential to provide reactive power from the high voltage grid for the superordinate extra high voltage grid.

However, results from studying individual grids cannot be extrapolated to indicate the availability and total calculated potential to provide reactive power. This must be calculated in individual cases for specific grid nodes taking the grid topology and the connected generation systems into account. A major influencing factor on the ability to provide reactive power from the electricity distribution grids for the transmission grid is the position of the grid connection points of the renewable electricity generation systems. The nearer these systems are to the transformer, the better they can be used to provide reactive power for the superordinate grid level, and the loads on the grids are reduced. For decentralised provision of reactive power, the incorporation of the tap changers from transformers to the upstream grid must be taken into account in the control concept.

Economic viability of alternative provision of voltage control
From an economic perspective, the converter stations of the planned HVDC lines are initially to be used to provide reactive power in the transmission grid. A redispatch can be implemented at grid nodes with remaining reactive power demand in individual hours only, if conventional power plants are available. For more frequent reactive power demand at grid nodes or if there is no local availability of suitable power

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[4] SVC = Static Var Compensator, STATCOM = Static Synchronous Compensator.

plants for redispatch, the most economical and currently established technology available is to build reactive power compensators.

Further provision of reactive power for the extra high voltage grid via decentralised energy units from the distribution grid can be an alternative to building reactive power compensators. For this, the corresponding requirements must be available locally (presence of sufficient capacity from decentralised energy units, grid topology and capacities). In addition, an evaluation is required in individual cases as to whether the provision of reactive power via decentralised energy units is more economical than building and operating a compensation system. The study sees considerable potential for decentral provision of reactive power which also appears economically viable. This applies in particular for large ground-mounted solar power plants and wind farms. Taking the above mentioned requirements into consideration, continuous provision of minimum generation from conventional power plants is not necessary to meet the demand for reactive power.

Recommended actions.
With the increasing shift of electricity generation to the distribution grids[5], optimisation of voltage control by providing reactive power from decentralised generation systems at all distribution grid levels must be assessed under technological and economic aspects. Where it makes sense, a reduced transfer of reactive power between the grid levels should be the goal, to relieve the strain on the overlying grid levels and in particular the electricity transmission grid. The resulting costs must be economically acceptable both for the system operators and the operators of decentralised energy units.

The provision of reactive power via the inverter stations of the planned HVDC lines, should become a fixed component of coordination of voltage control in the transmission grid.

When planning the grid, the option of providing reactive power from the high voltage grid for the extra high voltage grid from RE systems is to be assessed as an alternative to building new reactive power compensators.

4.2 Provision of short circuit power for dynamic voltage control.

The provision of sufficient short circuit power is necessary to guarantee secure response to short circuit events by the corresponding protective devices. Further, short circuit power is needed to guarantee the transient stability of electric machines and to restrict the voltage drop to an area as small as possible if a failure does occur. However, the short circuit power may not be excessively high, as otherwise operating equipment could be damaged due to excessive short circuit currents and power switches may not be able to securely deactivate the high short circuit currents in the event of a failure.

[5] In 2012, 96 percent of all electricity generation systems based on renewable energy were installed in the electricity distribution grids.

Development of the availability between now and 2030.
The analyses of the short circuit power available in future show that by 2030, the range between the minimum and maximum short circuit power will hardly change from today's levels, taking the assumptions made into account. However, significant changes can be observed at individual grid nodes compared with today. The procurement of short circuit power from other countries will not increase significantly overall in spite of the changes in the power supply between now and 2030. However, the countries of origin could change.

Systems connected via inverters contribute to the short circuit power to the amount of their operating current. The short circuit power available in 2030 is therefore subject to major weather and time-dependent fluctuations. In individual cases, a review is required to assess whether the protection concept permits this bandwidth.

Provision of short circuit power can be homogenised regionally with renewable energy plants, by enabling the provision of short circuit power from inverters even without active power feed-in. This results in a decoupling from the weather and time-dependent availability of systems for short circuit power.

Recommended actions.
With regard to the regulatory framework of grid operation, conditions must be created to allow system operators to claim short circuit power from the renewable energy electricity generation plants even in times when there is no active power feed-in.

In addition to this, an analysis is also required of the effects the short circuit power changes have on the existing protection concepts and other operating aspects of the system operators.

5 System restoration in 2030.

According to the current regulations, in the event of a full or widespread power failure in the European integrated grid, the system restoration is implemented using a central concept by starting large-scale power plants with black start capabilities in the transmission grid. At the start of the grid re-establishment process, temporary standalone grids are established around these power plants with black start capabilities. Large-scale hydroelectric power plants (especially pumped-storage) and gas turbines are current examples of black start capable power plants, which can be started with batteries or emergency power systems even in the event of a blackout. Loads are added while connecting further generation capacity. Building on that, the standalone grids are gradually synchronised and connected as part of the re-establishment.

Development of the demand until 2030.

In order to guarantee the supply security, a sufficiently dimensioned secure generation capacity will still be required. In accordance with the scenario framework for the 2013 Network Development Plan, there will still be sufficient pumped-storage and gas power plants to implement the current concept of central system restoration also in 2030.[6]

Before connecting further grid areas during the re-establishment of power supply, the extent to which electricity consumption or electricity generation are being supplemented must be known. Therefore, the weather situation and other generation-relevant forecasts must be incorporated in the power supply re-establishment concept. In addition to this, for a controlled re-establishment of the grid, the communication technology option of intentionally throttling the electricity generation from decentralised generation systems is necessary to avoid difficult to predict load changes when reconnecting grid lines or afterwards.

Alternative concepts for re-establishing the power supply.

As an alternative, the present study examines the options of decentralised concepts for re-establishing the grid. Following this concept, in the event of a widespread failure of the European integrated grid, individual electricity distribution grids autonomously permit the supply of the loads based on local generation. After elimination of the cause of the failure, the individual standalone grids are then connected and synchronised with each other in order to form the integrated grid again. As re-establishment of the grid is only needed extremely rarely, implementing a decentralised concept would mean to implement a highly complex and cost-intensive system is implemented in this case, which is only used in very rare cases. That is why a decentralised grid re-establishment concept is inefficient from a macroeconomic perspective.

Recommended actions.

Due to the extreme technical complexity and the associated investment costs, decentralised system restoration is not recommended for the future. Where corresponding options are planned by initiatives of industrial grids or individual municipal utility companies for standalone operation in subordinate grid levels, they should be incorporated in the superordinate supply re-establishment concept. Corresponding technical regulations must be issued for this.

In order to guarantee the supply security, it must be ensured that a sufficient amount of secured power plant capacity continues to be available in Germany. Centralised grid re-establishment should be implemented on the basis of these power plants, some of which need to be black start capable.

Technical solutions must be available to transmission and distribution system operators to control or limit decentralised energy systems after a grid collapse for a controlled re-establishment of the grid, even if public communication networks are not available at the time. Alternatively, the grid connection codes must ensure that generation units' responses after a blackout are suitable for a controlled system restoration.

[6] Note that the conventional power stations listed in the 2013 Network Development Plan are based on an exogenous assumption. Against the background of the decreasing economic viability of conventional power stations in today's electricity system, and the present uncertainty on the future energy law conditions, it is impossible to forecast the conventional power station capacities actually available in 2030.

6 System control in 2030.

As part of system control, system operators are responsible for monitoring and, where necessary, controlling the electricity grid and all connected generation units to guarantee safe operation of the overall system. The responsibilities of the transmission system operators include organising the use of balancing energy to maintain the frequency, voltage control and congestion management in the transmission grid as well as coordinate the grid re-establishment after failures. In their respective grids, the distribution system operators are responsible for voltage control, congestion management, elimination of local faults and the system restoration coordinated by the transmission system operators, and support the measures of upstream system operators.

Development of the system control requirements.

With the increasing integration of volatile renewable energy sources, primarily at the distribution grid level, the increased provision of ancillary service products in the distribution grid, the planned hybrid structure of the transmission grid comprising alternating current and direct current, and the increasingly multi-regional exchange of energy in the European electricity market, the requirements for system control of the electricity grids are growing at all voltage levels.

Due to the rising number of decentralised energy units, largely connected to the electricity distribution grids, the need for information and control in grid operation to guarantee system stability is also growing. It is expected that in future, an increasing number of innovative operating equipment (e.g. voltage regulated transformers in distribution grids or SVC in transmission grids) will be used to facilitate a cost-efficient expansion of the electricity distribution and transmission grids in Germany. There are also various technical options, e.g. overhead line monitoring and load flow control via FACTS[7], which can be used to guarantee optimised operation of the grid.

With a further dynamic expansion of the fluctuating renewable energy sources, it is expected that the need to control critical grid situations with congestion management, feed-in management of renewable electricity generators and switchable loads will increase in future. At the same time, these technical and organisational options will be implemented to an increasing extent to restrict the future grid expansion requirements, if the legal conditions are created to allow this.

Note also that the increasing shift of electricity generation into the distribution grids results in increasing need for coordination between the transmission system and distribution system operators. One example of this is the required coordination between the transmission system operators responsible for frequency control and the distribution system operators whose grid areas are to provide balancing energy for the respective balancing zone via decentralised energy units or flexible loads.

Solutions.

The analyses of this dena study show that grid stability via ancillary services in 2030 can be guaranteed on the basis of the operating equipment existing in the transmission grid or the additional operating equip-

[7] FACTS = Flexible AC Transmission Systems

ment planned in the 2013 Network Development Plan, in conjunction with utilisation of large-scale renewable generators, in particular at a high-voltage level, large-scale batteries and with larger flexible industrial loads. The conventional control technology available today is generally suitable for controlling these large units. If, in addition to this, a large number of decentralised units must be integrated at a medium and low-voltage level to provide ancillary service products for technical and organisational reasons, a broad-based standardised information and communication infrastructure must also be available. The costs and benefits of such a solution must be assessed in detail.

The increasing percentage of generation units in the electricity distribution grids and increasing provision of ancillary service products by these units require increasing coordination in system control between the transmission and distribution system operators and an expansion and standardisation of data and information transfer between the system operators involved.

Recommended actions.

Based on the fundamental need to expand the transmission and distribution grids to integrate renewable energy sources, the distribution system operators in particular must be allowed from a regulatory standpoint to make a technical and economic decision whether to invest in further grid expansion or optimise grid operation using stabilising interventions in generation and consumption.

For the necessary provision of ancillary service products from the distribution grid and the increasingly varying grid states, monitoring capabilities, in particular in the lower grid levels, must be expanded to guarantee secure and efficient system control operations management. This results in new responsibilities and tasks for data collection, evaluation, simulation and management of grid states. For this purpose, existing processes must be adapted and expanded, and new tools must be developed.

Implementation of the design and planning of the planned Energieinformationsnetz (energy information network) should be continued rapidly, to permit the transfer of information on the load, grid and generation situation between the system operators.

In order to make ancillary service products from the distribution grid useful for the transmission grid to the extent necessary and appropriate from an overall economic perspective, taking grid restrictions into account, the operative interaction between the transmission grid, distribution grid and plant operators should be developed further.

7 Summary.

The German Federal Government has decided to continue to expand renewable energy to reach 80 percent of the power supply in 2050. The path taken significantly changes the requirements and the technical and economic options available to provide ancillary services to guarantee a secure and stable operation of the electricity grids between now and 2030.

There are sufficient technical solutions for all kinds of system solutions now to guarantee the current level of system security, reliability and high quality of the power supply system in the future, too. Decentralised energy units and operating equipment can and must provide ancillary service products at a far higher level, as conventional power plants, which primarily meet our need for ancillary services today, will have far shorter operating hours in future.

With regard to the lead time to implement the solutions and the goals set for further speedy expansion of electricity generated from renewable energy sources, the requirements for using economically appropriate technical alternatives to provide ancillary service products must be created at an early stage. The need to use the alternative products presented in the study to provide ancillary services must be implemented gradually via the solutions discussed as part of the Energiewende (energy turnaround), in order to guarantee system security continuously in the electricity system.

In order to guarantee the same level of system stability in 2030 as today, the members of the dena Ancillary Services Study 2030 project steering group recommended the following actions:

- The regulatory framework must be adapted to ensure that future renewable energy-based electricity generation systems, especially wind turbines and ground-mounted solar power plants, as well as large-scale batteries are equipped to provide instantaneous reserves, so that Germany can fully fulfil its system responsibility in the European integrated grid at all times. The exact scope of the systems to be involved and the need to retrofit the existing systems must be reviewed.
- With regard to the characteristics of the balancing energy market, the extent to which pre-qualification requirements, tender periods and lead times between the tender and provision period can be adapted to allow new providers of balancing energy from decentralised energy units and flexible electricity loads to enter the market, must be assessed. At the same time, solutions must be developed to permit coordination of increased provision of balancing energy via decentralised energy systems from the distribution grid, taking the local grid conditions into account. Further, the determination of the demand for balancing energy should be made more dynamic to allow a daily changing dimensioning of the balancing energy demand as it is increasingly influenced by the weather-dependent electricity feed from renewable energy sources.
- The grid connection codes and the technical capabilities of the systems must be refined to allow larger decentralised energy units in particular to provide reactive power whether they are feeding active power or not. The exact scope of the systems to be involved and the need to retrofit the existing systems must be reviewed. The option of coordinated reactive power provision from decentralised energy units can be used to optimise the demand for grid expansion in the electricity distribution grids. Furthermore, the option of demand-appropriate transfer of reactive power between the high and extra high voltage grid should be reviewed as an alternative to building reactive power compensators.
- The existing grid re-establishment concepts based on black start capable conventional power plants should be retained and developed in future. Suitable instruments must be created to enable system operators to control the fluctuating generation capacity from renewable energy sources appropriately during re-establishment of the grid.
- For increased use of ancillary service products from decentralised energy units in the electricity distribution grids, coordination and suitable exchanges of information between the system operators are required. For this purpose, the existing cascade principle of passing on requirements and information between upstream and downstream system operators must be upgraded. Every system operator remains

responsible for the security, reliability, system control and voltage control in its grid area. The transmission system operators will continue to bear the superordinate system responsibility for coordinating grid operation in the European integrated grid. In future, the distribution system operators will have additional responsibilities for data processing, simulation and management.

- The implementation of future-proof solutions to provide ancillary services in an electricity supply system with a high percentage of renewable energy must already start now to identify technically and economically optimised solutions today, and ensure that they are available reliably by 2030. Note in particular that required adaptations to the grid connection codes for various elements of the power supply system must be examined and implemented if necessary, to avoid potentially cost-intensive retrofitting measures at a later stage. Sufficient transition periods for design and pilot tests must also be incorporated when introducing new systems and processes.
- The costs for maintaining and providing ancillary service products must be economically bearable both for the system operators and the operators of decentralised energy units and flexible loads. Fundamental properties of generation systems and controllability must be required and ensured as part of the further development of grid connection codes. Further provision of ancillary service products and associated expenses must be made economically viable with a suitable compensation system. Investments and ongoing operating expenditures required on the part of the system operators for secure and stable grid operation in a power supply system with an increasing proportion of renewable energy sources (e.g. grid monitoring and development of system control tools) must be incorporated suitably in the regulatory framework.

8 Appendix

The changes until 2030 described in the previous sections and the optional and alternative measures for ancillary services are summarised in the following table.

	Frequency control Instantaneous reserve	Frequency control Provision of balancing energy	Voltage control Provision of reactive power	Voltage control Provision of short circuit power	System restoration	System control
Requirements for 2030	▪ Significantly lower contribution by conventional power plants ▪ Without alternative providers, support from the European integrated grid would be required	▪ Demand for secondary balancing energy and minute reserve increases ▪ At times, conventional power plants will not be able to meet this demand	▪ The demand for reactive power in the transmission and distribution grids increases ▪ Increased demand for reactive power control in the distribution grid	▪ Bandwidth of the short circuit power available in future will hardly change ▪ Major time-dependent fluctuation at all grid levels due to decentralised energy units	▪ There are sufficient black start capable power plants to retain the central power supply re-establishment concept	▪ Increasing complexity ▪ Increased need for congestion and feed-in management ▪ Increased need for coordination between transmission and distribution system operators
Alternative providers	▪ Wind turbines ▪ Large-scale ground-mounted solar power plants ▪ Storage capacities	▪ There are alternative providers for all types of balancing energy, which can cover the future demand	▪ Reactive power compensators ▪ HVDC inverter stations ▪ Phase shifters ▪ Power plants in phase shift operation ▪ Provision from decentralised energy plants in the distribution grid	▪ Retooling the inverters in renewable energy plants to allow them to provide short circuit power even without feeding active power	▪ Decentralised system restoration is technically feasible but not macroeconomically efficient	▪ Conventional control technology is sufficient initially to utilise ancillary service potential ▪ Broad-based standardised ICT is required to utilise smaller potential Costs/benefits must be evaluated
Recommended action	▪ Use of the inertia of wind turbines ▪ Long-term: Review of the use of potential from throttling decentralised energy plants and storage facilities	▪ Adaptation of product characteristics and prequalification requirements ▪ Check implementation of adaptive demand calculation for balancing energy	▪ Develop coordinated balancing energy provision from decentralised energy plants in the distribution grid ▪ Check alternative use of reactive power from high voltage for extra high voltage in individual cases	▪ Option for distribution system operators to request short circuit power from decentralised energy plants without active power ▪ Effect on protection concepts must be evaluated in individual cases	▪ Weather and other generation-relevant forecasts must be incorporated in the future concept ▪ It must be possible to control RE systems during system restoration	▪ Esp. distribution system operators must be able to choose between grid expansion and optimised system control ▪ Rapid implementation of the “energy information network”

Table 3 – Changed requirements and options for alternative provision of ancillary services.