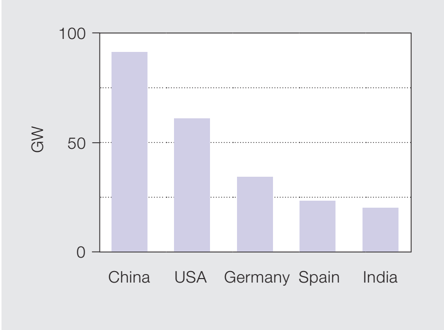
Putting it all together

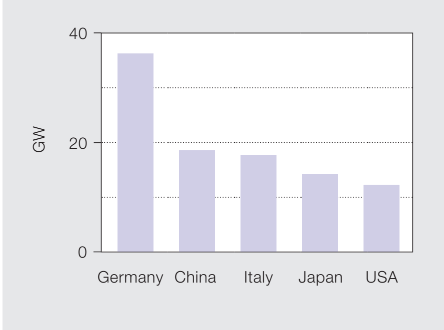
Integrating distributed renewable energies into the grid

JOCHEN KREUSEL – More than ten years ago the new renewable sources of electric energy – sun and wind – began to make their way into the electric power supply system. At that time, they were seen as two additional primary energy sources that could be connected to the existing systems without making any fundamental changes. Today, these new renewable energies have, in some countries, become the largest generation subsector. In light of the significant cost reductions of the past years further acceleration of this growth is expected. But the approach of connecting renewable energies to the existing systems is too shortsighted. Instead, electric power supply systems must be further developed to integrate new sources on a larger scale. With its high scalability, photovoltaics is the strongest driver of this change, affecting all areas of supply and utilization along the electric energy value chain. ABB's in-depth knowledge of renewable power generation technologies and comprehensive experience with grid codes and utility practices in use around the world enables it to provide the full range of products, systems, solutions, services and consultant capabilities to serve the renewable energy industry.

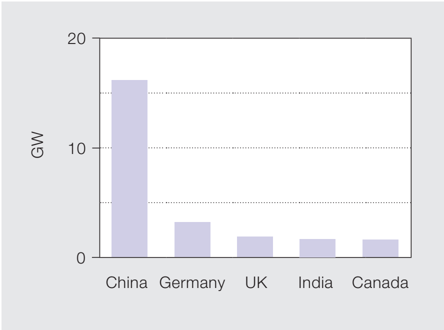
1 Wind and solar energy – top five countries in terms of installed and new capacity in 2013



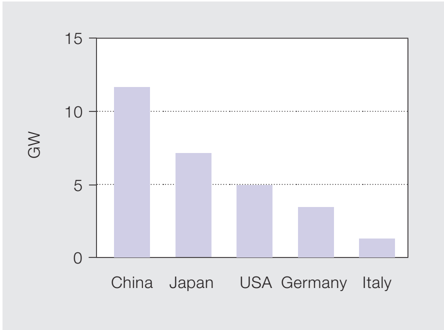
1a Wind: installed capacity, 2013



1b PV: installed capacity, 2013



1c Wind: new capacity, 2013



1d PV: new capacity, 2013

Sources: Wind: Bundesverband Windenergie e.V., Deutschland; Photovoltaics: IEA-PVPS, IDAE, PV News, BSW, IWR

Since the end of the 20th century, an increasing number of countries have been promoting the use of wind and solar energy. Denmark has been a pioneer in this field, and by 2011, was supplying more than 40 percent of its electric energy demand with renewable sources – three-quarters of which was wind energy. Germany is also being watched closely as the first large industrial country attempting to transform its electricity supply with a strict focus on new renewable sources.

➔ 1 shows the five leading countries in the world in terms of installed capacity and new wind and solar capacity in 2013. Countries from all regions are active, and some of the early pioneers – recognizable by their high installed capacities – have been overtaken by other countries. Today, the new renewable energies are a global reality, no longer dependent on the support from individual countries.

The strongest driver of this change is photovoltaics, which – after the significant cost reductions at the end of the last decade – has reached or fallen below grid parity in a number of countries. That is, photovoltaics has achieved competitive end-consumer prices in low-voltage grids. ➔ 2 shows the development of the generation costs of photovoltaic (PV) power compared with household electricity prices in Germany. Photovoltaics is an economical option for meeting the demand of individual households, provided that the grid usage fee is largely energy-based. This makes it independent from direct subsidiaries for a large scope of applications as long as it reduces the owner's own demand.

Remote generation, distributed generation and volatility affect all areas of electric power supply and utilization.

New renewable energy sources and system integration

New renewable energies have three main features that fundamentally change the electric power supply system: remote generation, distributed generation and volatility.

Remote generation

The share of remote generation of renewable energy is much higher than with power plant systems in which a regional balance of generation and demand is preferred for both economic and technical reasons. This development is mainly driven by the heavily location-dependent sources of wind and water and can lead to very large generation units or clusters.

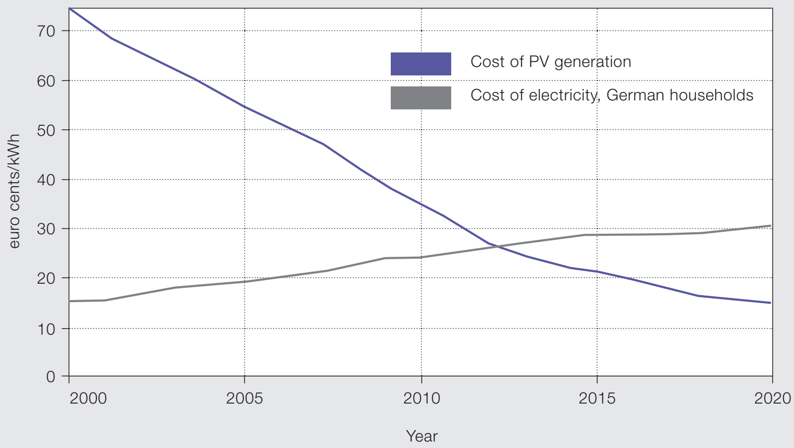
Distributed generation

The growth of distributed generation is primarily driven by photovoltaics and combined heat and power generation (CHP). For photovoltaics, this is mainly due to the relatively low economies of scale in terms of costs combined with economic performance, relative to the end-consumer prices in a low-voltage grid. CHP must be distributed in order to provide the heat close to the consumer.

Title picture

The shift to renewable power sources makes the reliable delivery of power a bigger challenge than ever before. ABB's comprehensive wind and solar power offering is helping to meet this challenge.

2 PV generation costs* compared with household consumer prices in Germany



* 1 euro is equal to about $1.05.

Source: www.solarwirtschaft.de, Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety of Germany (Leitstudie 2010), BSW Solar (PV-Roadmap)

The rising share of renewable energies is influencing the operation of conventional power plants.

Very small PV systems in particular can lead to a considerable share of the generation being covered by a very large number of smaller units feeding energy into the distribution networks.

Volatility

Volatility is mainly introduced to the electric power supply system by wind and solar energy, both of which lead to faster, larger and, especially in the case of wind energy, less predictable fluctuations than before.

Remote generation, distributed generation and volatility affect all areas of electric power supply and utilization. An overview of these areas, including the influence of new loads as drivers for change, is given in ➔ 3.

Conventional provision of electric power

The rising share of renewable energies is influencing the operation of conventional power plants. The increased frequent use of power plants originally intended as base-load plants for loads following operation with steep power output gradients poses a great technical challenge. Using Germany as an example, the effects of this change were investigated in detail in [1]. The study concluded that already in 2015 power gradients of up to 15 GW/h are expected for the conventional power generation park.

Another factor influencing the operation of conventional power plants is that, as wind and solar energy have no variable costs, they will always be placed at the lower end of the merit order in an energy-only market. This means they displace conventional generation, reducing the utilization of conventional power plants and making fixed-cost coverage more difficult.

These economic effects mean that building and operating conventional power plants is no longer attractive. But as conventional generating capacity is indispensable both as backup for periods of low renewable power output and for power system control, suitable adaptations of the market design are now being discussed. ABB is deeply involved in the discussions and is helping to shape the modern electric power supply system.

Transmission level

In transmission networks, remote generation leads to increased capacity requirements. Additionally, the volatility of the generation – particularly in combination with the low number of full-load hours of the renewable energies – increases transmission requirements. Expanding the interconnected power system represents the most cost-efficient option to match volatile generation and consumption [2].

The benefit of regional expansion for the integration of a very high share of renewable energies into the electric power supply is illustrated in ➔ 4, using the expansion of the European interconnected power system to North Africa and the Middle East as an example.

The increasing variety of operating conditions in the distribution networks increases the information requirements.

3 Effects of the main drivers for change on different parts of the electric energy supply and utilization value chain

Driver	System affected				
	Conventional generation	Transmission	Distribution	System operation	Application
Remote generation		– Long-distance transmission – FACTS[1] – Overlay grid/ HVDC		– Stabilization with FACTS[1]	
Distributed generation			– Automation – Voltage regulation	– Communication – Control – Virtual power plants	
Volatile generation	– Part-load capability – Flexibility	– Trans-regional leveling – Overlay grid/ HVDC – Bulk storage	– Distributed storage	– Load management – Virtual power plants – PMU/WAMS[2]	– Storage (in applications) – Demand response
New loads (eg, e-mobility)			– Charging infrastructure	– Demand response	

1 FACTS: flexible alternating current transmission systems
2 PMU/WAMS: phasor measurement unit/wide-area monitoring systems

→ 4 shows the costs for an additional MWh generated from renewable sources in Europe, provided that the European energy-political goals are met and that further cost reductions for the plants are used. The cost advantage is a result of significantly more ideal locations in North Africa and the Middle East compared with Europe. The costs for the additional required transmission capacity are taken into account. This cost advantage directly benefits the plant operators, and requires no special support apart from reliable framework conditions. The other cost advantage shown in → 4 is based on a better balance of renewable energy supply and demand resulting from the complementary seasonal variations of wind and consumption in Europe and the regions south of the Mediterranean Sea. This cost reduction requires suitable consideration in the market design.

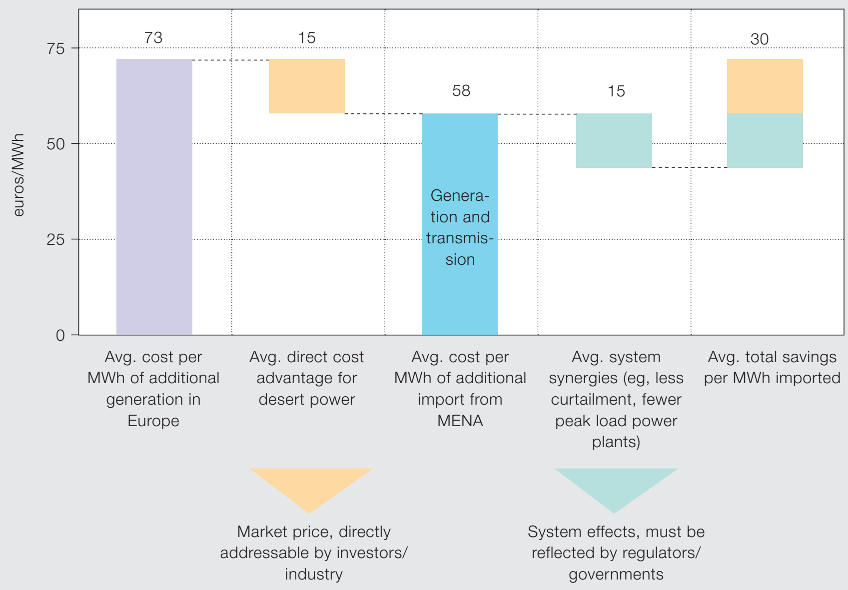
The transmission systems required under the circumstances described in → 4 will presumably be different from those of the past. Considering the large transmission distances combined with the often fundamentally changing load flow situations due to the high infeed peaks from the renewable sources, a superimposed transmission level (overlay grid) based on high-voltage direct current (HVDC) transmission technology appears sensible. A key component for this is the HVDC circuit breaker developed by ABB [4].

Distribution level

The changes occurring in the distribution networks are manifold. In many cases, an increase in distributed generation requires a reinforcement of the grids. However, especially in rural grids with relatively long transmission lines, voltage support problems occur first. As this is not caused by the one load situation the network has been designed for, but by the multitude of operating conditions between feeding and extracting power, the traditional solution of manually adapting the transformation ratio of the local distribution transformer is no longer sufficient → 5. In such cases, the often significantly more expensive grid reinforcement can be postponed or even entirely avoided by installing a voltage regulator such as a voltage-controlled distribution transformer (see, eg, [5,6]).

The increasing variety of operating conditions in the distribution networks increases the information requirements. This leads to an at least partial automation of the distribution substations, which thus far have been minimally monitored or remotely controlled. Distributed generation as well as e-mobility (due to the mobile nature of the consumers) will lead

4 Reducing the costs* for renewable energy by integrating the power supply systems of Europe, North Africa and the Middle East [3]



* 1 euro is equal to about $1.05.

Note: cost of MENA (Middle East and North Africa) exports arriving in Europe includes cost of transmission losses
Source: Dii, Fraunhofer ISI

Expanding the interconnected power system represents the most cost-efficient option to match volatile generation and consumption.

Due to the volatile power output associated with renewable energies, the short-term demand response is gaining in importance.

to an insufficient capacity of distribution networks in some situations. This means that measurement and control will be required – and as every technical system, including measurements, can be faulty, the solution will be to transfer well-known approaches from the transmission networks, such as state estimation, to the distribution level and into the secondary distribution systems.

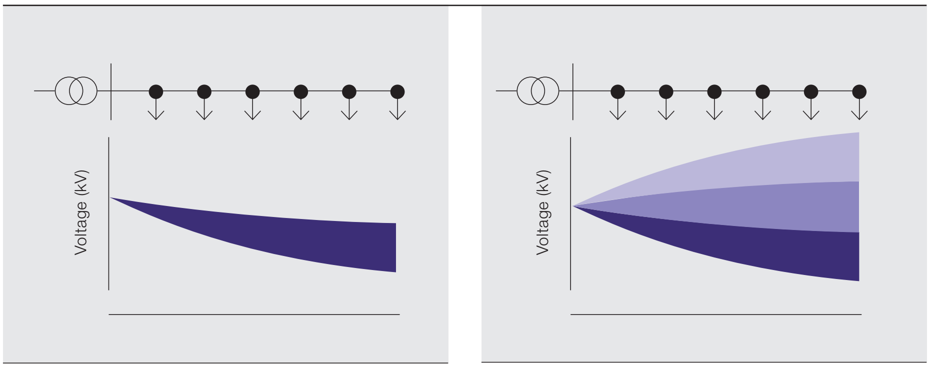
If the grid is unable to offer sufficient capacity for all situations, possible congestion must be proactively detected and resolved – a task that is not new in the electric power supply domain. In fact, it is common practice in the coordination between (large-scale) power plants and system operators. Hence, the solutions for this electric power supply area must be largely standardized and automated. An example of predictive distribution network operation, which also takes the requirements of the deregulated market into account, has been developed and successfully taken into operation within the scope of the MeRegio E-energy project in Germany [7].

Consumption

Due to the volatile power output associated with renewable energies, the short-term demand response is gaining in importance. Demand-response measures, particularly those involving loads with inherent storage, may contribute to this. The requirements associated with the balancing of loads and generation for different time domains, the solutions commonly used today and the solutions expected in the future are shown in ➔ 6. This clearly shows that demand response can make an important contribution especially in the first 15 min. This is an important period because it is sufficiently long enough to ramp up power plants with fast startup capability when generation capacity is suddenly lacking. Whether demand response can help in the very short time frame in which the rotating mass of power plants has a stabilizing

A holistic approach considering the supply of electric energy as well as of heating and cooling is essential for the utilization of demand-side flexibility options.

5 Change of the voltage support task in distribution networks with increasing distributed generation (schematically)



5a Past: Distribution; voltage is decreasing along the LV lines and voltage band can be guaranteed by a fixed setting of the distribution transformer

5b Now and in the future: Distribution and feed-in, resulting in a broader variation of voltage at the end of the line, possibly requiring on-load voltage adjustments

effect today depends on whether an autonomous reaction of the load to imbalances between generation and consumption can be achieved. After 15 min the use of demand response is only realistic for selected applications.

Demand response is particularly suitable for heating and cooling applications as thermal energy storage can in most cases be implemented at a relatively low cost. Hence, a holistic approach considering the supply of electric energy as well as of heating and cooling is essential for the utilization of demand-side flexibility options.

Future conventional generation will require plants that can be operated economically even at low loads and in frequently and fast-changing load situations. The transmission networks will have to take over more long-distance transmission tasks with strongly varying load flow situations compared with the past. To compensate for the volatility of the new renewable sources, wide-area interconnected systems such as those proposed for the region Europe-North Africa-Middle East within the scope of the Desertec concept can be an option.

Storage options

Storage is another important building block for the integration of renewable energies. But due to the variety of applications and available solutions it is a highly complex topic, which requires a separate discussion. Energy storage is explored in more detail in "A bright future" on page 27 of this edition of ABB Review.

The transition from an electricity supply based on thermal power plants to a supply using new renewable energies as its main source will lead to a fundamental redesign of power systems.

The road ahead

The transition from an electricity supply based on thermal power plants to a supply using new renewable energies as its main source has technical implications in all areas of electric power supply and utilization and will lead to a fundamental redesign of power systems.

The consequences of the integration of distributed generation into the distribution networks will be particularly far-reaching, both quantitatively and qualitatively. First of all, an increase of grid capacity will be inevitable in many cases. As the combination of extracting power from and feeding power into the grid leads to a larger range of operating conditions, additional voltage monitoring and regulation will often be required. And finally it will no longer be sensible to design the distribution networks

6 Requirements for balancing generation and demand in different time domains and possible solutions today and in the future

Time domain	Task	Traditional solutions	New solutions for the future
<30 s	Instantaneous reserve, balancing of short-term variations	– Rotating mass of the power plants	– Battery storage – Renewable energy resources and load management may also contribute
<15 min	Minute reserve, balancing of short-term variations	– Hydropower plants – Power plants on the grid – Fast start-up power plants	– Load management – Battery storage
1-3 d	Balancing of diurnal variations of the residual load	– Pumped storage – Power plants (fuel storage)	– Pumped storage – Load management (selected applications)
Weeks to months	Balancing of annual variations of the residual load	– Power plants (fuel storage) – Water reservoir (natural inflow)	– Water reservoir (natural inflow) – Expansion of interconnected power system

One of the most significant changes in the system management will be the integration of a very large number of distributed units, both on the generation and the consumption side.

for rare extreme situations – this is mainly due to the low number of full-load hours associated with solar energy and because of e-mobility. Thus monitoring and control down to the secondary distribution level will be necessary.

Balancing loads and generation will become more difficult in systems with a strongly varying primary energy supply that is not storable. Besides the proven, but landscape-profile-dependent pumped storage plants, battery storage facilities can contribute in the short term, eg, for frequency stabilization and peak shaving. In the long term, ie, mainly for the compensation of seasonal variations, the system boundaries will likely be expanded by extending the interconnected systems or interconnecting other systems such as heat and gas supply.

The most significant changes in the system management will be the integration of a very large number of distributed units on both the generation and the consumption side, as well as achieving frequency control with a decreasing number of rotating masses acting as stabilizing elements.

The greatest challenges in the necessary further development of the systems are – from a more organizational perspective – the coordination of the required measures in all system areas and – from a technical perspective – the development of suitable storage, the operation of the system without rotating masses and the integration of large numbers of distributed units into the system management. With its commitment to innovation, ABB continues to drive the growth of renewables, paving the way for the new electric power supply system.

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References

[1] VDE/ETG, “Erneuerbare Energie braucht flexible Kraftwerke,” The Power Engineering Society (ETG) in the Association for Electrical, Electronic & Information Technologies (VDE), VDE-Verlag, Frankfurt/Main, Germany, 2012.
[2] VDE/ETG, “Energiespeicher in Stromversorgungssystemen mit hohem Anteil erneuerbarer Energieträger,” The Power Engineering Society (ETG) in the Association for Electrical, Electronic & Information Technologies (VDE), VDE-Verlag, Frankfurt/Main, Germany, 2008.
[3] F. Zickfeld, A. Wieland, “Desert Power 2050,” Dii GmbH, Munich, Germany, 2012.
[4] J. Häfner, B. Jacobson, “Proactive hybrid HVDC breakers – a key innovation for reliable HVDC grids,” presented at the CIGRE International Symposium on the Electric Power System of the Future, Bologna, Italy, 2011.
[5] ABB Ltd. (2013). *Smart-R-Trafo Voltage Regulation Solution for Distribution Transformers*. Available: https://library.e.abb.com/public/0803e28840f64334802c7c7c686b730a/Smart-R-Trafo_leaflet_EN.pdf?filename=Smart-R-Trafo_leaflet_EN.pdf
[6] T. Hammerschmidt, *et al.*, “Innovative concepts for efficient electrical distribution grids,” presented at CIRED 2011, paper 0447, Frankfurt/Main, Germany, 2011.
[7] C. Franke, *et al.*, “On the necessary information ex¬change and coordination in distribution smart grids experience from the MeRegio pilot,” Proceedings of the CIGRE International Symposium on the Electric Power System of the Future, Bologna, 2011.