HOW IS GERMANY INTEGRATING AND BALANCING RENEWABLE ENERGY TODAY?

Educational Article January 2015
by Eric Martinot

Article link: http://www.martinot.info/renewables2050/how-is-germany-integrating-and-balancing-renewable-energy-today

Renewables now provide close to 30% of Germany's power on an average basis. And on some peak days in 2014, solar and wind supplied close to 80% of peak power demand at specific times of the day. In the future, Germany is targeting a 35% average share by 2020 and a 50% average share by 2030. Because of the feed-in tariff law (EEG), renewables have dispatch priority, meaning they are always used first, sometimes leaving very little power demand left to be supplied by coal, nuclear, and natural gas plants. So how is Germany integrating and balancing renewable energy today? What has Germany needed to do so far?

The answer is that Germany has so far managed to integrate and balance high shares of renewable energy with very modest changes to its power system. Bigger changes will be necessary in the future, certainly, including new market frameworks that are currently under active discussion. But today, Germany has managed quite well to reach close to a 30% share, for seven main reasons, which are discussed below.

The two most important reasons are: (1) the existing strength of its power grids; and (2) flexible operation of coal and nuclear plants (and to a lesser extent gas and pumped hydro). In addition, Germany has managed quite well because of: (3) better design of the balancing (ancillary) power markets, to make them more effective, faster, and open; (4) better system control software and day-ahead weather forecasting; (5) modest technical improvements to local-level distribution systems; (6) exports of power to neighboring countries; and (7) solving the "50.2 hertz" inverter problem.

(1) First, Germany's grids are already very strong, relative to typical grids found in other countries. This "grid strength" means that outages almost never occur, and that the grid has more capacity than necessary given current demand. From the beginning, when Germany started connecting renewables in the 1990s, this underlying strength has meant that few upgrades have been necessary to accommodate renewables. And this strength continues to serve Germany well, as more and more renewables are connected to the system.

Even with strong grids, Germany has needed to strengthen some transmission lines, although not too many yet. Germany has also needed to plan for further transmission capacity to accommodate higher renewables. In particular, there is a need for additional north-south transmission capacity to manage the regional imbalance of generation and demand. Since 2011, the state regulator BNetzA has been required to conduct annual transmission planning analyses that incorporate projections of where renewables will be developed over the next ten years. An additional three north-south transmission lines are being planned as part of this process. In general, "network planning with future renewables in mind" has represented a major paradigm change in Germany. In conducting this planning, BNetzA has had to conduct future scenarios for renewable energy, and also engage in greater public discussion.

(2) Second, there is a surplus of coal power capacity, and this excess coal power capacity is being used very effectively to provide sufficient balancing power to offset (or balance out) the variability of renewables. Germany built more coal power capacity than it needed over the past decade, partly because power demand has slackened in recent years due to economic conditions, and partly because the huge upsurge in renewables was not anticipated to the degree it actually happened. This surplus coal power capacity could be viewed negatively because it results in lower revenue for coal plant owners, and also results in more coal being used relative to natural gas (high gas prices have also contributed). However, on the positive side, the surplus does provide a high degree of balancing capacity.

And most of the coal power plants in Germany have been originally designed or later modified for flexible output—the ability to "ramp" on an hourly basis to much less than full output, and "cycle" on and off on a daily basis. (The lignite power plants in Germany are less flexible, but many of these have been modified in recent years to allow ramping down to 40% of their maximum output, compared to only 60% previously. And many of the combined heat-and-power plants in Germany are not so flexible either, because they must operate above a minimum level necessary to provide heat in cold seasons.)

Coal power plants can sell their power into the "ancillary" (also called "balancing") electricity markets in Germany. These markets are designed to provide minute-by-minute and hour-by-hour balancing of the difference between supply and demand. Coal power plants are not selling as much of their power into the normal day-ahead wholesale markets, because wind and solar receive priority dispatch in those markets—i.e., get purchased first. So coal plants sell into the balancing markets as an alternative source of revenue, which creates more robust balancing markets. In participating to a greater extend in the balancing markets, coal power operators have also developed better software to ramp their plants faster, and developed operational practices that reduce the stress on equipment from ramping and cycling.

It is not only coal plants that sell power in the balancing markets, but also nuclear, gas, and pumped hydro plants. Nuclear plants in Germany have also been designed to be flexible on a routine basis, to allow ramping their output up and down. (The German experience operating nuclear on a flexible basis is contrary to conventional thinking that nuclear cannot be flexible.) Gas turbine plants can also be flexible, although gas plants have not been able to compete very well with coal in recent years, as the price of gas has made them uncompetitive. Some gas plants are seeing service levels of only hundreds of hours per year, when they need to be used for thousands of hours to be profitable. So some gas-turbine plants are even being retired earlier than planned. Thus for economic rather than technical reasons, most of the balancing today is done with coal and nuclear, and less with gas and pumped hydro.

(3) Third, the balancing and intra-day electricity markets have been modified in ways that provide greater flexibility for renewables. Both of these markets provide additional power on short time frames (minutes and hours) to handle the imbalances between supply and demand that might occur as renewable output varies. The design and features of these markets are complex, but to put it simply, the market rules and designs have improved flexibility, opened the markets to more participants, allowed for faster balancing and ramping responses, and made it easier for demand response (see below) and storage to participate in these markets.

For example, in 2011, the German regulatory authority BNetzA designated that the intra-day market in Germany should be used for trading to handle the imbalances created by wind forecast errors. (The intra-day market existed before this, as part of the European Power

Exchange and common EU market framework, but played a less significant role.) To achieve this, the intra-day market auction period was then reduced from 1-hour auctioning to faster 15-minute auctioning to handle faster system "ramping" dynamics.

(4) Fourth, power system operators (ISOs) have greatly improved their power control and dispatch software and analytical tools. One of the impacts of high shares of renewables is that the German network has had to contend with much higher system ramp rates than in the past, for example up to 1800 MW per hour, due to swings in renewable power output. ISOs have been able to successfully modify their software to accommodate higher ramp rates. In addition, day-ahead weather forecasting was greatly improved, which is a important part of integrating and balancing renewables in several countries (see the California and Denmark cases for more on day-ahead weather forecasting). System reliability calculations (so-called "N-1" contingency events) are also greatly evolved from 15 years ago to incorporate the effect of renewables. (And reliability checking also includes Europe-wide power-system security conferences every morning, among system operators across Europe, to coordinate their reliability).

(5) Fifth, modest technical improvements have been made to local-level distribution systems. At the distribution level, power utilities in Germany have had to cope with two-way ("reverse") flows of power from solar generators. This happens when solar generation increases in a local node higher than power demand in that node. In general, power systems were never designed for reverse flows at the distribution level. Some distribution utilities have had to do grid upgrades, including substations, transformers, and power lines. But many distribution grids have not yet required upgrades. Some distribution utilities have installed special tap-changing transformers to manage reverse flows. For many distribution utilities, reverse flows are one of the main manifestations of high shares of solar, and the main challenge at the distribution level to-date.

Some distribution utilities have done pilot projects of smart-grid technologies. This includes new monitoring and data acquisition systems. In particular, some distribution utilities are starting to monitor voltages on the distribution grid, to better manage reverse flows. (One distribution expert said, "distribution utilities measuring the voltage on the network is akin to landing on the moon; who would have thought it was possible in earlier times?") But in general, utilities are at the early stages of the planning and innovation that will be required in the future. (See the California case for more on distribution system planning and innovation.)

In the future, a variety of additional measures will be required on distribution grids to handle storage, demand response, smart inverters, two-way flows, "virtual power plants" combining generation with flexible load, integration with heat supply and heat storage, and other developments yet to be encountered on distribution grids. For example, some German distribution utilities are starting to forecast local renewables output to better manage the local grid. Others are considering how to integrate local balancing and peak-shaving with local combined-heat-and-power plants and heat storage. Some utilities are experimenting with smart inverters installed on distributed solar power systems as a new way to regulate distribution system voltage and reactive power. And some utilities are thinking about long-term planning and modeling for their local networks, a practice not seen historically.

(6) Sixth, when wind and solar reach very high levels of generation on peak days, this causes electricity market prices to decline in Germany, even go to zero or negative. This price mechanism has the effect of reducing output from other sources like coal and gas, and also

causing those other sources to export their power to neighboring countries instead of trying to sell into the German market. (This also has the effect of reducing power prices in those neighboring countries.) However, the mechanism of importing and exporting power with neighboring countries plays a very modest role in balancing renewables. This is because imports are prohibited from participating in Germany's balancing markets, and the bidding time frames for exports and imports (i.e., multiple days in advance, not day-ahead or intra-day) are too long to provide balancing functionality. (Note: imports and exports are mostly governed only by market mechanisms. However, sometimes cross-border exchanges become a technical issue, as when phase shifters were installed for transmission connections with Poland to limit flows of power into Poland. This was mostly a network stability issue.)

(7) Finally, One of the most comprehensive changes has been in response to the "50.2 hz inverter problem." An inverter is the equipment that feeds solar power into the grid, converting the power from DC to AC. The inverter can sense the state of the grid and decide to "cut off" the solar output to the grid if conditions indicate an abnormal state (like an over-frequency of 50.2 hertz). Initially, all inverters on distributed solar PV systems around the country were designed with the same "cut off" frequency. However, with the growing share of power from solar, this meant that if the grid frequency went above 50.2 hz, all the solar could go off-line at once, which became a huge threat to system stability since there was so much solar. So inverter firmware was redesigned and inverters modified to vary the cut-off frequency. (This problem arose in the first place because no one in earlier years could have imagined that solar would become such a large share of total generation in Germany.)

Further Issues for the Future

A number of issues remain for the future, and will play a role in the future, but have not yet significantly contributed to or impacted Germany's ability to integrate and balance renewables today.

Capacity market or payments. Some coal and gas plants are required by the regulatory authority to remain operating, even if they generate very little power. These plants have been determined to be necessary for covering regional bottlenecks or seasonal variations (where the plant might only be needed in winter, for example). These plants receive "capacity payments" to cover their costs of operating at zero output. However, a full "capacity market" does not exist in Germany, although many have been debating the merits of one.

Demand response. There has been some movement towards demand response in Germany, but this is still small relative to the potential for providing flexibility and balancing. Some large power generators are selling this flexible demand into the balancing markets. Some generators are integrating demand response with their coal plants to give them economic flexibility for selling into the balancing market. Some system operators (ISOs) have also been contracting directly with large demand response providers on a pilot basis. However, the regulator does not explicitly include demand response in its planning, or set rules specifically for demand response. (See the California and Denmark cases for more on demand response.)

Curtailment of wind power output. Germany still enjoys very low curtailment. Curtailment is when wind power output must be shut-down to balance the grid, resulting in economic losses. In 2013, only 0.3% of wind turbine output was curtailed. Strict curtailment rules have been instituted for ISOs, which have to curtail wind power output if transmission bottlenecks appear. Curtailment may become a bigger issue in the future, depending on progress with transmission upgrades and planning. (See the California and Denmark cases for more on curtailment.)

Storage. Energy storage has played almost no role in Germany's integrating and balancing renewables so far. And many in Germany do not expect storage to play a role in the coming decade, or at least until the share of renewables goes above 40%. Among many experts interviewed, no one pointed to a company that had plans to invest in storage in Germany. Only a few pilot projects exist. And of course, there is interest in household-level storage in conjunction with the "self-consumption" economic model for distributed solar PV. (Note: from 2009-2013, the German government created a "small residential storage" program that provided incentives for distributed customer-side storage (on the customer side of the electric meter), with the aim of fostering self-consumption of distributed solar. However, this program was stopped. (See also the California and Denmark cases for more on storage.)