The future role of fossil power generation

by Andreas Pickard and Gero Meinecke, Siemens Energy

Operational flexibility of conventional power plants is set to become more and more important in the future. This trend is already becoming apparent in the power generation market and is also reflected in the changing demands made on fossil-fired power plants by the power producers.

On the one hand, a highly versatile power plant fleet is indispensable for compensating the fluctuating availability of power from renewable energy sources and is thus an essential prerequisite for the intended large-scale expansion of renewables-based capacity. On the other, improved technologies and more sophisticated operating philosophies, such as start-up optimisation and overnight shut downs, are helping to significantly reduce the running costs of each power plant.

The increasing importance of this topic is due above all to the ongoing shift in the power generation market in Europe. Driven by the need to reduce CO₂ emissions over the long term, the share of renewable energy resources is growing at a rapid pace. Whereas at the turn of the millennium only about 2% of the electric power generated in Europe came from renewables, this figure has by now risen to over 12%. By the year 2030, the share of power generated from these technologies in Europe is even expected to exceed 30%.

Nowadays, power from renewables is given priority over electricity from other sources fed into the grid: so it serves as a kind of variable base load. Unlike the conventional providers of base load, the feed-in of renewables-based power into the grid depends strongly on the day/night cycle and on the momentary weather conditions (sunshine and wind force). The supply of wind and solar power available at any given time is not entirely predictable, so the renewables do not lend themselves to grid control and stabilisation. That means that the inevitable shortfalls (for example, when there is no wind or heavy cloud cover) still have to be made up by conventionally generated power. This correlation is shown in Fig. 1.

Changing demands on fossil power plants

As power producers plan a new plant, they must consider how the power generation market is going to develop in the future, with the primary aim being to design a power plant today that will be capable of running profitably over the next 20 years or more. The importance of understanding how the expansion of renewables will affect the reliability of power supply as a whole, makes it essential to have a long-term prognosis of anticipated renewables-based power generation within typical power demand scenarios so as to identify potential oversupply or shortfalls, which in future will need to be balanced or backed up by conventional power generation. Accordingly, a number of studies have been commissioned with the aim of forecasting the contributions of these power sources to future supply. The analyses in this paper are based on a study which predicts that 40% of the power supply in Germany will come from renewables by the year 2020.

The first analysis of the residual load (the difference between incoming renewables-based power and consumption) forecast in the study shows that during a day with a high wind power input the feed-in from renewables may at times exceed the expected consumption. This input from wind power is to be expected mainly in winter, due to the typically high wind forces.
in that season. In summer, the feed-in expected from photovoltaic installations is higher, peaking around noontime, which is also when demand is highest. This shows that the generation profile of photovoltaic plants harmonises well with the daily demand cycle.

A statistical analysis for the full year shows that conventional power generation will hardly deliver any continuous and uninterrupted base load supply any more. On-line times of more than 600 hours are required only for about 5 GW. By contrast, on-line periods of 4 – 12 hours will be more and more common.

Fig. 3 shows the distribution of operating hours and the number of expected start/stop events in the various residual load bands over a year. It is clear that even power plants whose full-load hours would qualify them as base-load units (7000 – 8760 full-load hours per year) could be run down to part load up to 230 times per year. The forecast indicates that demand for the uninterrupted operation of fossil-fired plants in base load that is the rule today will virtually disappear from the market.

As well as the on-line times, the expected load ramps will also be of crucial importance. As the time resolution of the study is greater than one hour, this leads to pronounced computational attenuation of the gradients. A statistical analysis shows that load ramps of up to 22 GWh are to be expected, which will have to be handled by a relatively small fleet of conventional power plants (on average 25 GW, equivalent to about 40 power plant units). Furthermore, local effects (shadowing of photovoltaic arrays) cannot be completely compensated via other grid participants, as the grid’s own capacity is limited. At any rate, it is clear that a declining conventional power plant fleet will have to be able to cope with much steeper load ramps.

Combined-cycle power plants – the option for eco-friendly grid stabilisation

As shown in Fig. 4, combined cycle power plants (comprising a gas turbine and a water/steam cycle with steam turbine) are among the power plant designs with the best dynamic features in the field of fossil power generation. The figure shows possible load gradients for primary and secondary control and start-up times. Nowadays, in the event of island formation (breakdown of the grid into two sections, one with a high excess supply capacity and one with a large shortfall), a modern combined cycle power plant can be run down at a rate of up to 180%/min. On the way down, the plant can halt at any load point within the allowable load range and there help to shore up the grid, i.e. participate in frequency control. By contrast, nuclear and other steam power plants meet only the requirements for primary grid control, which call for load ramps in the range of 60%/min. Test runs in the Irsching 4 power plant have shown that...
a modern combined cycle power plant can even cope with upward load ramps on a similar scale to the run-down ramps in the event of island formation. A further challenge will be how to meet the short-notice and unforeseeable demand surges caused by the sudden loss of renewables-based power generation (calm air, shadowing, etc.). In this context what counts is to be able to start up idle power plants as quickly as possible to bridge the gap in supply. Here, too, combined cycle power plants are particularly suitable. Both plants based on the established F-class gas turbine technology and plants incorporating H-class gas turbines optimised for maximum plant efficiency allow start-up times of only around 30 min.

One of the primary motives for increasing the share of renewables is the desire to minimise the CO₂ emissions associated with generating electric power from fossil fuels. In that respect, it is only logical to require that the power plants intended to provide the standby power should be based on a technology that likewise emits as low CO₂ emissions as possible.

In this context, nuclear power plants are in principle prime candidates as they emit almost no CO₂ at all. But since the catastrophe in Fukushima, public opinion has turned against this form of power generation. Apart from the risks associated with this technology, nuclear power plants cannot be readily ramped up and down. As a result, they are not suitable as standby power plants for backing up renewables.

A comparison of the various types of fossil power plant comes out squarely in favour of combined cycle power plants. Not only is the efficiency of a combined cycle power plant, at up to 60%, far superior to the 47% efficiency achievable by steam power plants today, but the ratio of carbon to hydrogen in the natural gas fuel is much better than in coal. As a result, a modern combined cycle power plant emits more steam but, at about 325 kg/MWh, significantly less of the greenhouse gas CO₂ than a steam power plant of the same rating, which at 675 kg/MWh at best emits more than double the pollutant.

Operational flexibility – the new challenge for modern power plants

Fossil power plants with a highly versatile operating response are the key to integrating renewables into the power grid and an essential prerequisite for the intended rapid growth of these energy resources. The debate about operational flexibility frequently reduces this general term to one narrow aspect. However, to fully appreciate the customer benefits and take advantage of all influencing factors and drivers in the context of operational flexibility, a comprehensive approach is needed. Fig. 5 gives a first impression of the complexity involved and summarises the most important aspects including their driving forces.

Part load and turndown

An analysis of the forecast feed-in and consumption for the year 2020 in Germany clearly shows that combined cycle power plants will in future be operated across the entire load range and not only, as in the past, limited to just a few operating points (full load, peak load, etc.). This makes it essential to design the plants for the widest possible duty range. In particular, the plants should be able to operate at as low a part load as possible. However, the lower the load factor, the higher the emissions, so the allowable minimum load is as a rule dictated by the maximum allowable emissions. Today’s gas turbines usually pass the maximum allowable CO₂ emissions threshold at around 50% load. At the same time, combined cycle plants operated at part load should also exhibit the highest possible efficiency at that load point. This is essential for minimising fuel consumption and CO₂ emissions. To optimise the minimum load as well as the part-load efficiency, modern gas turbines are fitted with variable-pitch guide vanes at the inlet to the gas turbine compressor. These guide vanes can be closed to reduce the air flow through the turbine to match it to the required combustion at the respective operating point.

Use of an air preheater heated from the water/steam cycle makes it possible to further improve the part-load efficiency and lower the minimum load down to which the plant can operate within the allowable emission limits. At part load, the air preheater heats the gas turbine inlet air. This reduces the density of the air at the inlet to the compressor. As the compressor delivers a constant volumetric flow, the lower density brings about a reduction in the mass flow of air through the gas turbine. This effect leads to a load reduction without the turbine having to be...
GENERATION

Further throttled, thus avoiding throttling losses. Fig. 6 shows the efficiency curve with and without the air preheater. In a combined cycle power plant based on an F-class gas turbine, the part-load efficiency is improved by up to 0.8%.

Load ramps and power reserves

In the context of stabilisation of the grid, the aim is to respond to changes in demand as quickly as possible. The extreme case is island formation within the grid with a sudden reduction in the demand for power in the isolated network. In this case it may be necessary to run down the power plant affected by islanding from full load to the minimum load point within just a few seconds. For instance, the UK Grid Code requires a power plant to be capable of running down to at most 55% of its nominal rating within 8 s in the event of island formation. Tests have shown that today’s combined cycle plants can be run down at up to 180% (min without tripping out (e.g. due to overspeeding). What is more, the plants are again able to actively participate in frequency control after the load reduction phase.

If a power plant is already operating at full load, it can usually provide no further power reserves. In some countries, however, grid regulations call for power reserves in this case, too. For instance the UK Grid Code specifies that the load must not drop off if the grid frequency droops. Thanks to a power reserve in the gas turbine compressor and with the aid of the fast wet compression system patented by Siemens, combined cycle power plants are able to provide the required power reserves. The SG76-5000F gas turbine has been further developed for the 60 Hz market to be able to deliver up to 10% standby load over and above the full-load point. The design permits efficiency-optimised operation at the full-load point. At peak load, the guide vanes of the compressor can be opened to deliver 10% extra power. This enables power plants already in full-load operation to participate in the attractive peak load market (shaping power) and to benefit from the high prices paid in this load range.

Start-up times

Power plants with short start-up times make it possible to feed extra power into the grid on short notice. It is becoming apparent in some power generation markets with a high proportion of renewables-based power and thus an increased demand for extra power available on short notice that load dispatchers are giving preference to power plants with short start-up times.

Playing the spot market (tertiary reserve) is particularly attractive for power plant operators, as it pays high prices for last-minute power. Players on this market have to guarantee that they are able to provide the offered power within 15 min. of it being requested. The Siemens FACY solution package makes it possible to take part in this market. About 40% of the rated output of a combined cycle power plant equipped with this technology is available after only 15 min. Shorter start-up times also reduce the amount of fuel consumed during the start-up event. The new package has the added advantage of shortening the inefficient start-up sequence and thus improving the start-up efficiency. This results directly in significant savings in fuel and possibly CO2 emissions costs for the power plant operator. Fig. 7 shows this correlation.

When a conventional combined cycle plant is started up, the steam is initially discharged via the condenser until defined steam parameters are reached. The discharged steam makes no contribution to power generation. Besides, a lot of time is spent waiting for the specified steam conditions to be attained. FACY enables the first steam generated to be delivered directly to the steam turbine. The shorter start-up time and utilising the steam from the very beginning improve the start-up efficiency by 14% points.

Parked load or night shut down – a matter of philosophy?

If in future we want to manage with the smallest possible number of storage facilities for electric power (pumped storage plants, large-scale battery installations, hydrogen storage, etc.) because storage options are limited and the required technologies have yet to be developed, we will have to shut down the major part of conventional generating capacity at more or less regular intervals. Combined cycle power plants, which are designed for daily start-up and shut down and are particularly suitable for this by virtue of their versatile operating mode, should certainly not further aggravate the expected night-time overcapacities by running in parked load mode and thus feeding in even more surplus power.

One hundred percent start-up reliability is desirable for plants in predominantly start/stop operation to be sure that they can be reliably put on line again as soon as there is a demand for power that cannot be met from renewable sources. With a start-up reliability of more than 98% for its F-class gas turbine, the company is well on the way to refuting the frequently cited argument in favour of start-on-the-fly operation. The remaining minimal risk of an unsuccessful start-up can be mastered by appropriate fleet management. An intelligent operating philosophy with overnight shut down makes more economic and ecological sense than polluting the environment with more than 360 t of CO2 per night and power plant, and wasting fuel and producing surplus power in parked load (see Fig. 8).

In the past, operators endeavoured not to shut down their power plants but to keep them on the grid in order to avoid the high service life expenditure associated with each start-up sequence. The company’s start-up package minimises the service life expenditure due to start-ups such that today’s combined cycle plants can sustain up to 7500 starts over their service life of 25 years. This makes it possible to start up and shut down suitably designed combined cycle power plants every day, so that the last remaining argument in favour of parking plants on the grid overnight no longer applies.

Contact Hulisani Nemaxwi, Siemens, Tel 011 652-2167, hulisani.nemaxwi@siemens.com

energize - August 2013 - Page 22