The Future Role of Fossil Power Generation

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Answers for energy.

SIEMENS

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Introduction

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 optimization 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 CO_2 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 top 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 in the power supply network. However, 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 stabilization.
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 Figure 1.

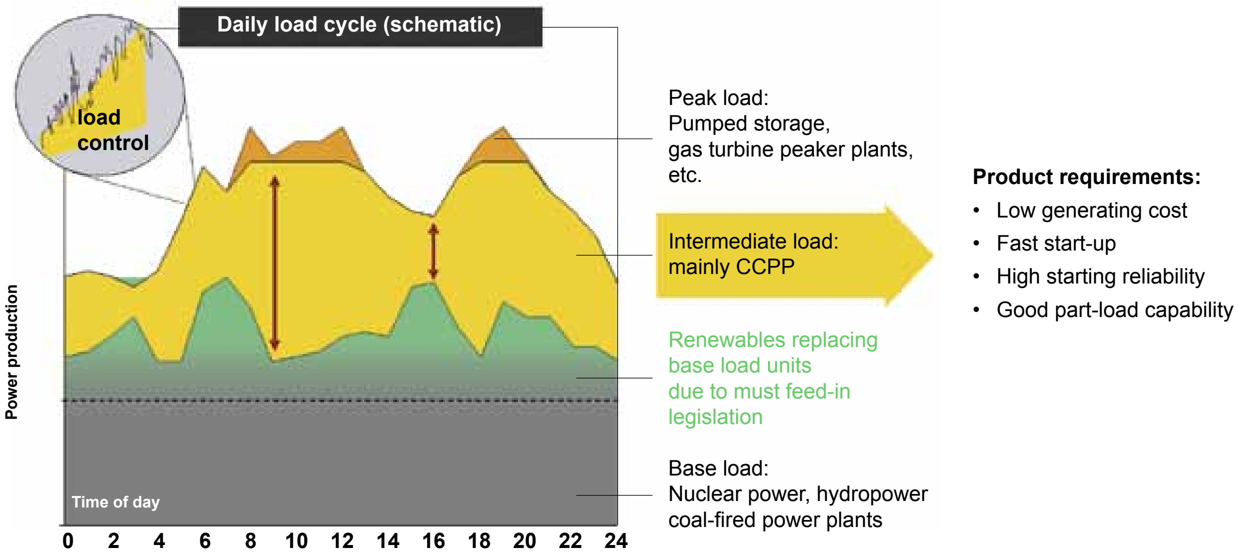


Figure 1: Daily load cycle (schematic) and its implications especially for combined cycle power plants

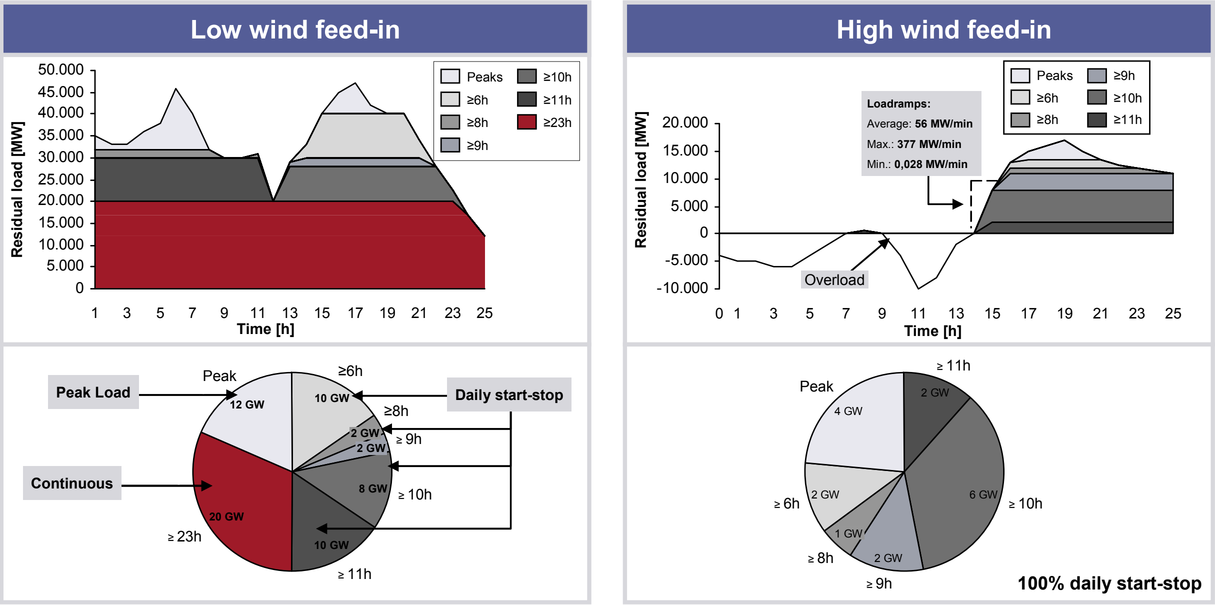
Changing demands made on fossil power plants

How is the power generation market going to develop in the future, and what will it mean for my power plant? This is a question of concern to any power producer thinking of building a new power plant today. The primary aim is to design the power plant today so that it will be capable of running profitably throughout its service life, that is to say over 20 years or more.

It became clear at an early stage in the expansion of renewables in Germany that it is important to understand how this expansion is going to affect the reliability of power supply as a whole. It is essential to have a long-term prognosis of anticipated renewables-based power generation within typical power demand scenarios so as to identify potential over-supply 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 the VDE AT40 study (most probable scenario, current trend, 40% renewable energy), which predicts a 40% share of renewables in power supply in Germany for 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 in the year 2020 the feed-in from renewables may at times exceed the expected consumption, so that in this situation the entire power demand in Germany could be met from renewables. This high renewables input especially 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 from photovoltaic installations is higher, peaking around noontime, which is also when demand is highest. This shows that the generation profile of photovoltaic plants harmonizes well with the daily demand cycle.

Figure 2 shows the forecasts for a typical day with low versus high wind power feed-in. In the case of a high expected wind power input as shown here, no further fossil power generation is required during the night, i.e. when demand is low, as there is a residual load of zero or even over-capacity (that is to say negative residual load). This does not take into account power input from combined heat and power (CHP) plants in district heating systems, which always also generate electric power that, due to statutory feed-in and purchase obligations, must also be fed into the grid and leads to further over-capacities. By contrast, on the day with a low wind feed-in, there is a continuous demand for about 20 GW of conventional base load capacity. This base load is likewise reduced by the input from CHP plants, for which no allowance is made here. The conclusion to be drawn is that the major part of the conventional power generating capacity will probably not be continuously required.



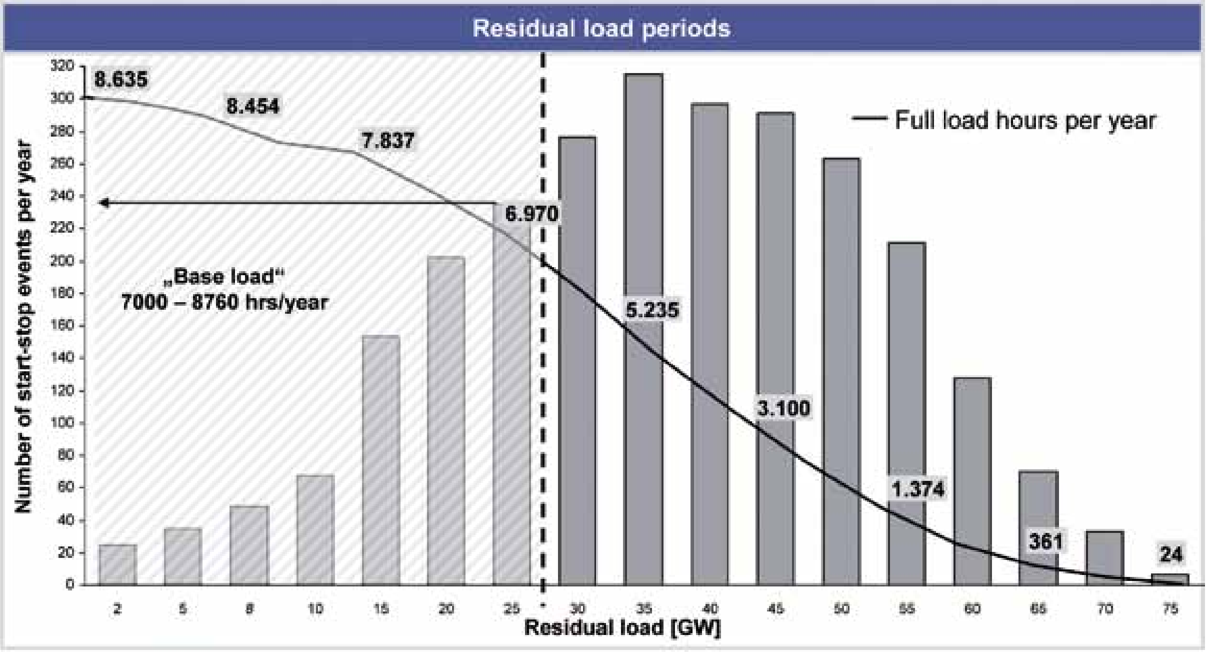
Source: joint study Siemens and VDE, AT40 scenario, March 2011

Up to 100% of the fossil fleet in daily start-stop operation
Load ramps of about 200MW/min to be covered

Figure 2: Residual load cycles in the year 2020 (examples of feed-in scenarios) for Germany

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 to 12 hours will be more and more common.

Diagram 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.



Source: joint study Siemens and VDE, AT40 scenario, March 2011

Even base load units will be stopped and started up to ~230 times per year

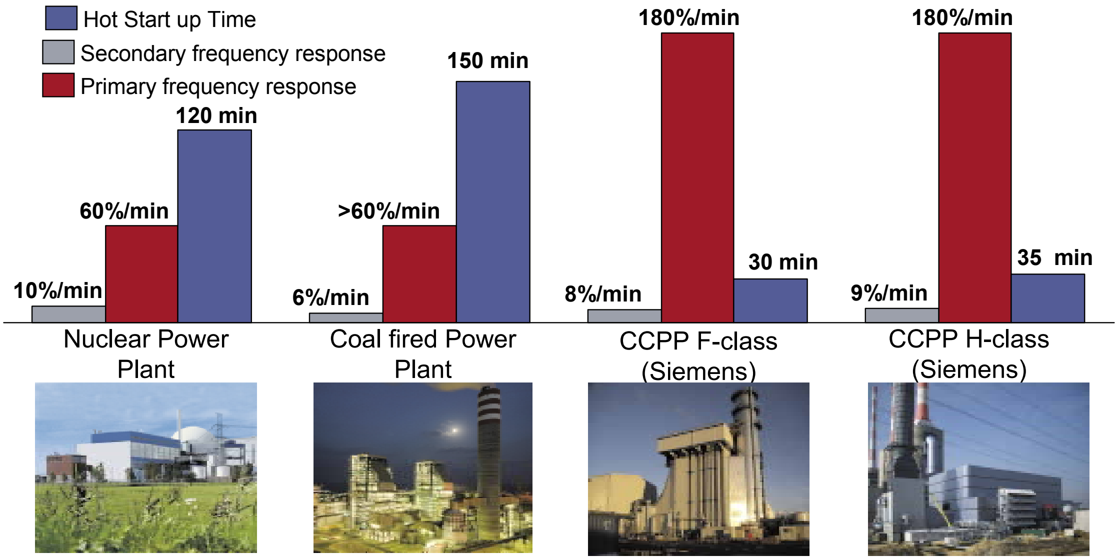
Figure 3: Distribution of operating hours and start/stop events in residual load bands, forecast for 2020, Germany

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 > 1 hour, this leads to pronounced computational attenuation of the gradients. A statistical analysis shows that load ramps of up to 22 GW/h 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 stabilization

The following discussion will examine the suitability of the available conventional power generation technologies for compensating widely fluctuating residual loads. As shown in Figure 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.



…are showing already today CCPPs are the best choice for grid stabilization

Figure 4: Comparison of the on-line dynamic response of various power plant technologies

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 (Germany) 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 optimized for maximum plant efficiency allow start-up times of only around 30 minutes.

One of the primary motives for increasing the share of renewables is the desire to minimize the CO_2 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 CO_2 emissions as possible.

In this context, nuclear power plants are in principle prime candidates as they emit almost no CO_2 at all. But since the catastrophe in Fukushima, public opinion especially in Germany, but also in many other countries, 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 favor 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 CO_2 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. But what does operational flexibility mean for a modern power plant, specifically and in detail?

The debate about operational flexibility frequently but inadmissibly reduces this general term to one narrow aspect. However, to fully appreciate the customer benefits and to take advantage of all influencing factors and drivers in the context of operational flexibility, a comprehensive approach is needed. Figure 5 gives a first impression of the complexity involved and summarizes the most important aspects including their driving forces.

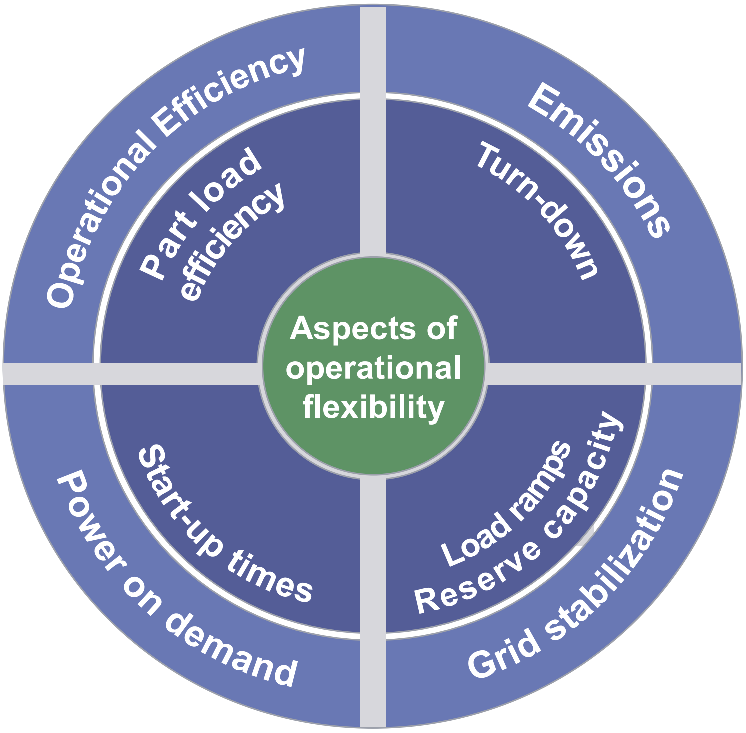


Figure 5: Operational flexibility: aspects and drivers

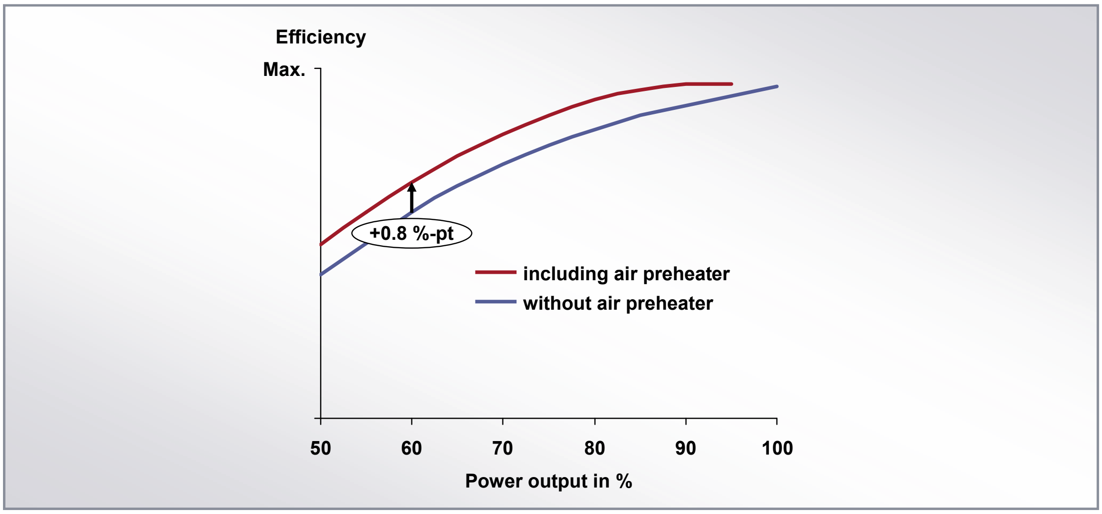
The following discussion will examine these aspects taking the example of the combined cycle power plant since, as explained earlier, these plants exhibit particularly favorable properties in this context. As an expedient power plant solution may address several of these aspects in combination, these are also dealt with together in the text.

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 CO emissions threshold as of 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 minimizing fuel consumption and CO_2 emissions. To optimize 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 further throttled, thus avoiding throttling losses. Figure 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% points.



Air inlet preheater provides up to 0.8% pt efficiency improvement @ part load

Figure 6: Improvement in part-load efficiency obtained using an air preheater

Load ramps and power reserves

In the context of stabilization 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 seconds 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.

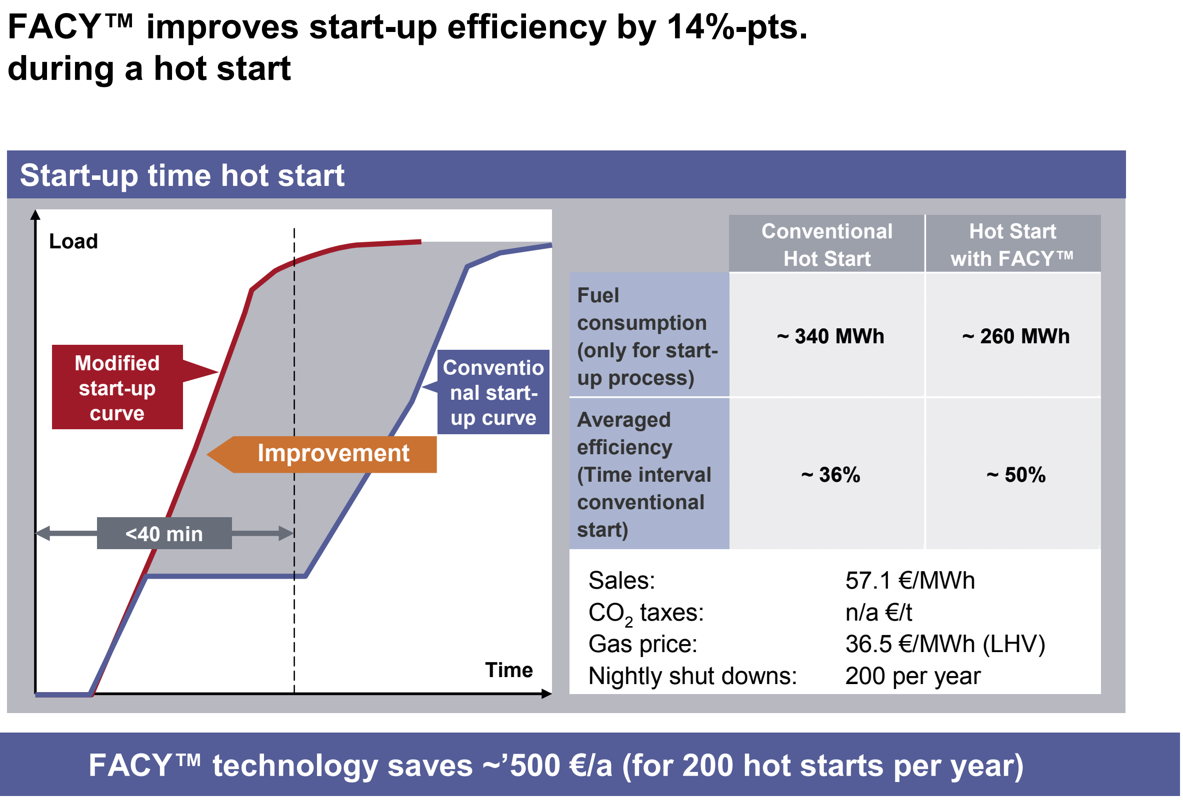
The SGT6-5000F gas turbine has been further developed for the 60-Hz market to be able to deliver up to 10% standby load over and above the full-load point. The design permits efficiency-optimized operation at the full-load point. At peak load, the guide vanes of the compressor can be opened to deliver 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. Even today 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 minutes of it being requested. The Siemens FACY^{TM} 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 FACY is available after only 15 minutes. There is already one plant in Germany that has made this option a part of its business model.

Shorter start-up times also reduce the amount of fuel consumed during the start-up event. The new FACY^{TM} 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 CO_2 emissions costs for the power plant operator. Figure 7 shows this correlation.



FACY™ improves start-up efficiency by 14%-pts. during a hot start

Start-up time hot start

	Conventional Hot Start	Hot Start with FACY™
Fuel consumption (only for start-up process)	~ 340 MWh	~ 260 MWh
Averaged efficiency (Time interval conventional start)	~ 36%	~ 50%

Sales:	57.1 €/MWh
CO_2 taxes:	n/a €/t
Gas price:	36.5 €/MWh (LHV)
Nightly shut downs:	200 per year

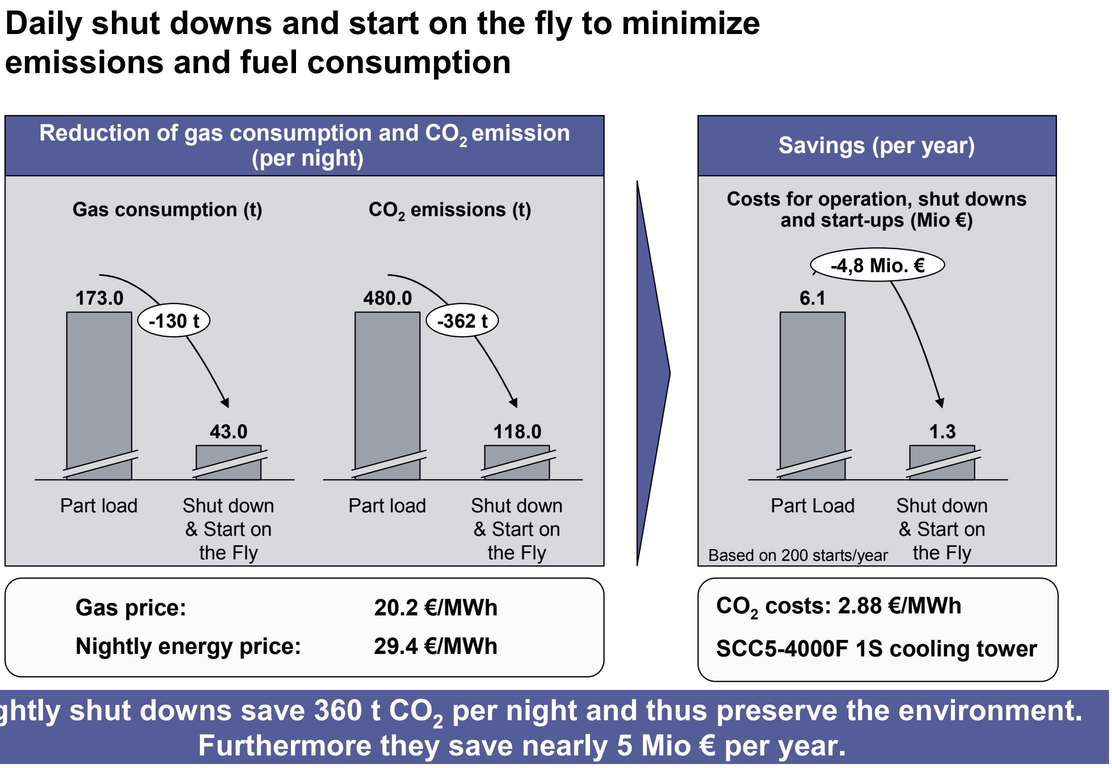
FACY™ technology saves ~'500 €/a (for 200 hot starts per year)

Figure 7: Improvement in start-up efficiency thanks to FACY™

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 utilizing 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. 100% 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, Siemens is well on the way to refuting this frequently cited argument in favor 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 tons of CO_2 per night and power plant, and wasting fuel and producing surplus power in parked load (see Figure 8).


Daily shut downs and start on the fly to minimize emissions and fuel consumption

Nightly shut downs save 360 t CO_2 per night and thus preserve the environment. Furthermore they save nearly 5 Mio € per year.

Figure 8: Advantages of shut downs over park load operation.

In the past, operators endeavored 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 FACY^{TM} start-up package developed by Siemens now minimizes 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 favor of parking plants on the grid overnight no longer applies.

Sloe Centrale – one of the most versatile combined cycle power plants in Europe

The Sloe Centrale combined cycle power plant (owned by: Delta Energy B.V., of the Netherlands and EDF, France) in the Netherlands was commissioned by Siemens in 2009 and has been in commercial operation since December 2009 (Figure 9).

Figure 9: Sloe Centrale, Netherlands, SCC5-4000F 1S

The plant was designed for utmost plant efficiency and supreme versatility from the start.
An important criterion in the design was that the power plant should be capable of daily start-up and shut down. In addition to its high full-load efficiency, the plant was optimized for part-load efficiency by providing an air preheater at the compressor inlet.
In view of the intended high number of start-ups the plant was equipped with a complete FACY^{TM} package which, as can be seen in Figure 10, also comprises a BENSON heat recovery steam generator.

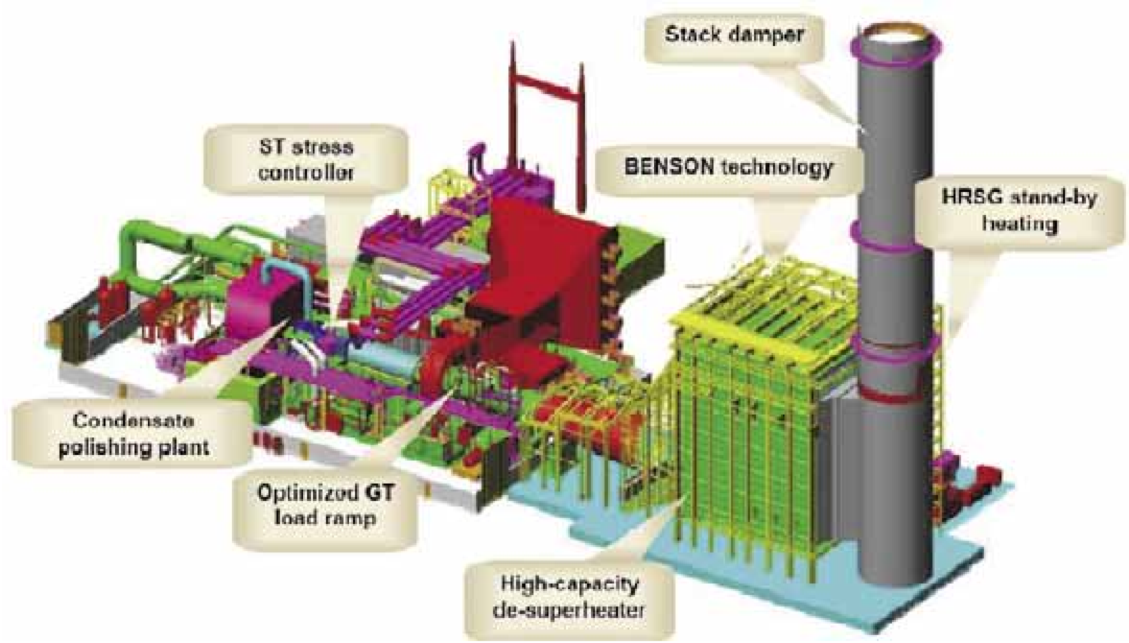


Figure 10: FACY™ start-up time optimization package

Figure 11 shows the time history of an actual start-up recorded during acceptance testing in the plant. The curve clearly shows that the time for start-up from ignition of the gas turbine to the combined cycle reaching full load is just 30 minutes. This makes the Sloe Centrale power plant one of the fastest-starting plants in Europe.

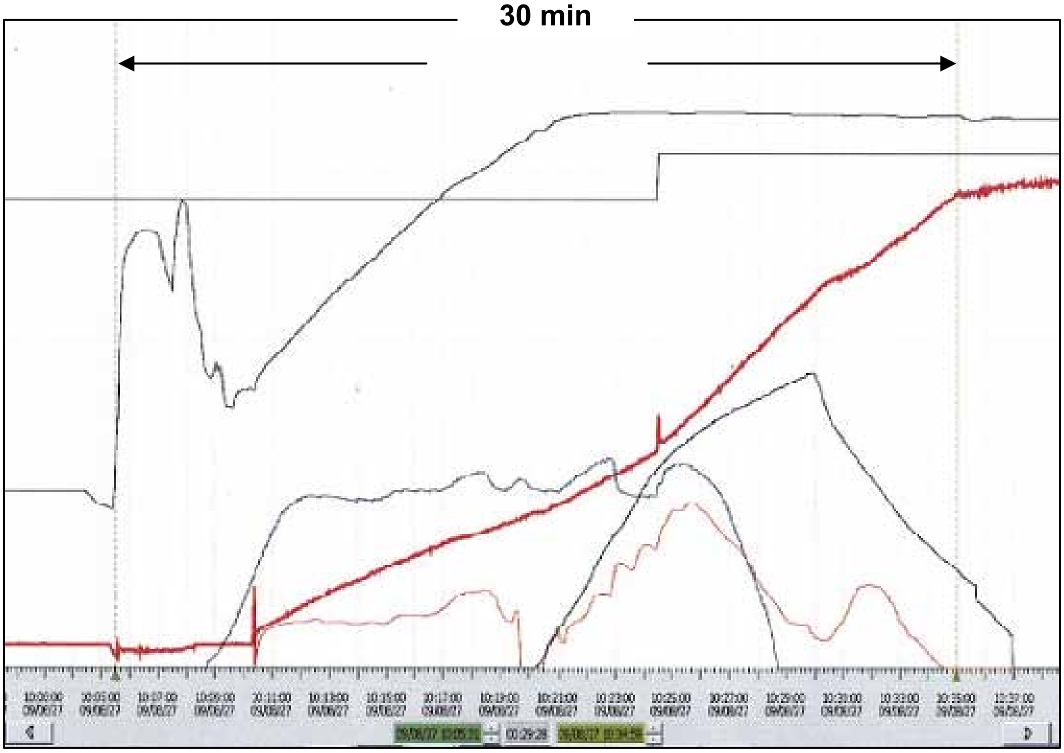


Figure 11: Time history of a hot start during acceptance testing at the Sloe Centrale power plant

A crucial consideration in shortening start-up times is how to minimize the service life expenditure of critical components, including the boiler and the steam turbine. An analysis of the turbine stress controller plots shows that the service life expenditure of the steam turbine during a FACY^{TM} start is at the same level as during a conventional start. Of course, the same also applies to the BENSON boiler.

To optimize the part-load efficiency and achieve the lowest possible minimum load while still complying with the allowable emission limits, an air preheater was installed at the inlet to the gas turbine compressor. As already described in the previous sections, this raises the part-load efficiency by up to 0.8 percentage points.

In the Sloe Centrale project, the plant was optimized in cooperation between the customer and Siemens to stay within the emission limits at part loads down to 45%. This figure is far below the target minimum load contractually agreed at the start of the project and so represents a significant improvement and added value for the customer.

Irsching 4 – The first of a new generation of combined cycle power plants

The aim of the engineering for the new H Class gas turbines was to achieve an efficiency of over 60%. As it became clear early on that customers not only expect future combined cycle power plants to deliver high efficiency at full load but also demand power plants with a highly versatile on-line response, the gas turbine was designed with air cooling of the turbine blades. Dispensing with steam cooling and a cooling air cooler makes shorter start-up times possible, as already implemented in the established F Class. The Irsching 4 combined cycle power plant, in which a gas turbine of the new H Class was used for the first time, is currently undergoing commissioning. In the context of this project, numerous tests were performed to validate the plant's on-line versatility.

For instance, the FACY^{TM} package was tested on the basis of raised steam parameters (about 170 bar, 600°C). The plots of the start-up tests (Figure 12) clearly show that, thanks to dedicated design and optimization, an H Class combined cycle power plant can also be run up within half an hour.

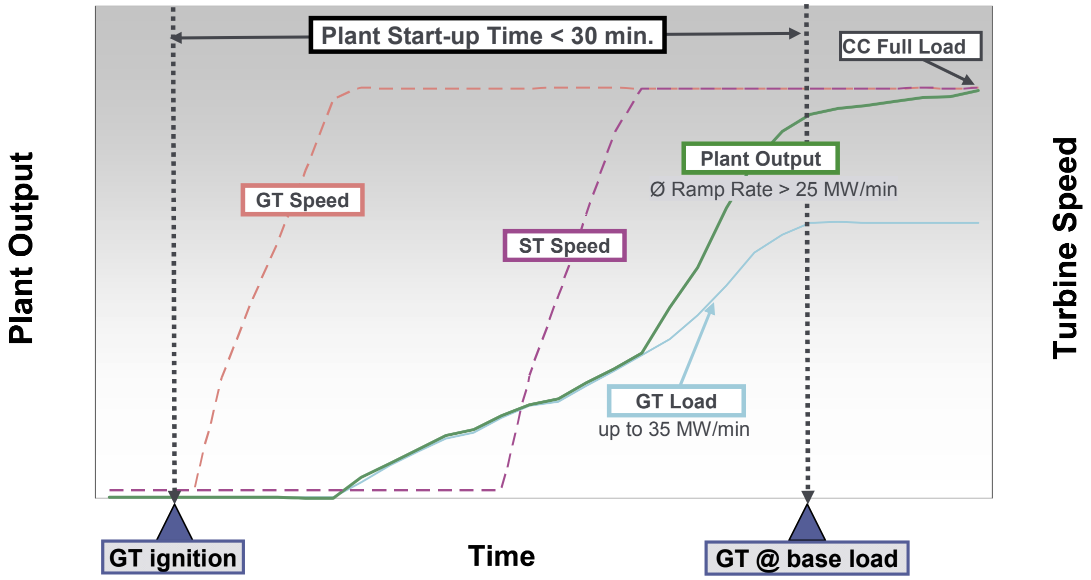
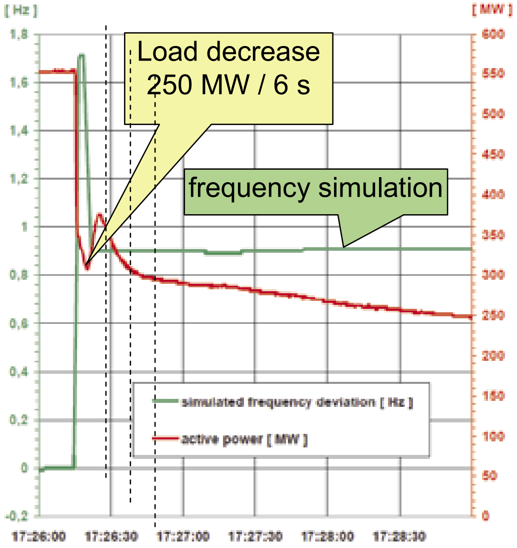


Figure 12: Start-up test on the SCC5-8000H 1S in Irsching (FACY^{TM}, Hot start on-the-fly)

To test the plant's grid stabilization capability, a large number of test runs were performed on the gas turbine alone and also on the combined cycle. Figure 13 shows the results of the rundown tests in response to island formation.



- Requirement :

  During island formation

  frequency control and deloading of up to 45%

  Load adjustment within few seconds needed!

- Achieved:

  Island detection in GT controller based on frequency deviation

  Followed by deloading to 55% within 6 s

  Combined response of GT and ST

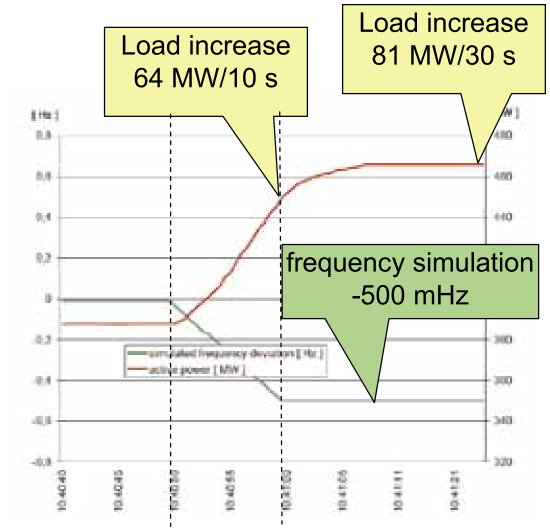
  Stable behaviour of plant systems and components

- Future ENTSO-E Network Code requirement!

Figure 13: Islanding test on the SCC5-8000H 1S in Irsching

The power plant furthermore satisfies the strictest grid code requirements in terms of primary and secondary control. The test results are shown in Figure 14.

Frequency response capability



- Requirement in UK:

Primary response:

10% of capacity within 10 s

Secondary response:

10% of capacity within 30 s

- Achieved:

  64 MW (12%) as primary response

  81 MW (15%) as secondary response

- This covers all frequency response requirements worldwide

Figure 14: Validation test – primary and secondary frequency pegging

The validation and acceptance tests at the Irsching 4 power plant have shown that the new H Class not only delivers an efficiency improvement by about 1.8 percentage points. They also demonstrated that the new generation of combined cycle power plants based on Siemens' H Class gas turbine technology features the on-line versatility required for assisting and advancing the integration of the renewable energy sources into the power grid.

Summary

Siemens was quick to realize that in future combined cycle power plants are going to play a major role as a load reserve in the power generation market. A high efficiency continues to be important as a means of achieving CO_2 savings targets. However, full-load efficiency will not remain the only assessment criterion going forward. Minimizing fuel consumption during start-ups and better part-load efficiencies are becoming more and more important.

Fossil-fired power plants will be called upon to meet demand peaks and to compensate for output reductions and non-availability of the rapidly growing renewable energy sources. Forecasts indicate a mid-term power generation market scenario for Germany in which renewables will account for on average over 30% of all power generated. There will be phases during which renewables can meet the entire power demand, while in other phases back-up power generation by fossil power plants will still be necessary. The situation is complicated by the fact that the various phases frequently give way to each other within just a short time and above all the transitions are not entirely predictable. In these forecasts, fewer and fewer fossil power plants in the grid will have to cope with ever steeper load ramps. If a power plant is seen as a system to be optimized as a whole, there are indeed solutions for meeting the future challenges of the power generation market. Modern combined cycle power plants are particularly suitable for this.

By introducing FACY^{TM} and solutions for grid stabilization, Siemens has impressively demonstrated that such solutions are not only theoretically possible. Modern combined cycle power plants such as Sloe Centrale and Irsching 4 show that there are highly efficient solutions available for delivering the versatility required for the market of the future.

As regards the question of whether park load or shut down and rapid re-start makes more sense in times of over-capacity in the grid, it has been shown that an optimized duty cycle with (overnight) shut downs and rapid start-ups while at the same time achieving a very high start-up reliability and avoiding excessive service life expenditure of the components is the economically and ecologically superior solution.

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Fossil Power Generation Division
Order No. E50001-G220-A137-X-4A00
Printed in Germany
Dispo 05400, c4bs No. 7815
TH 224-110751 | XX | 431649 SD 08113.0

Printed on elementary chlorine-free bleached paper.

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