From Base to Cycling Operation - Innovative Operational Concepts for CCPPs

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Authors:
Dr. Andreas Feldmüller
Florian Roehr
Siemens AG
Power Generation Services
Power and Gas

Thomas Zimmerer
Kraftwerke Mainz-Wiesbaden AG
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1 Abstract

The increasing market share of renewable energy and high fuel prices in Europe have changed the operational profile of combined cycle power plants (CCPPs) dramatically. Faced with fewer operating hours than expected in their original business plans, CCPPs now need to deal with operational scenarios ranging from volatile and less predictable operational phases to mid-term preservation or even mothballing of plants.

With a decreasing level of generated megawatts, the utility will face the need to generate any remaining megawatts as efficiently as possible and to be available whenever the energy market is paying premium prices for generated energy or frequency control reserves. This paper will point out the optimization potential for an operating combined cycle fleet, addressing the new operational aspects with a special focus on startup and shutdown improvements. This includes hot starts after night stops as well as starts after longer offline periods and the possibility of keeping the steam cycle in a heated condition.

The paper takes the Mainz Wiesbaden CCPP KW3 as a showcase example of a plant which has recently changed from base load to a cycling mode. Operational flexibility enhancements successfully implemented in the plant as well as the results of tests for future upgrades and further aspects under consideration will be presented in the second part of the paper.

2 Introduction to the market environment for combined cycle power plants in Germany

Energy markets are rapidly changing in many countries around the world due to increases in the generation of renewable power. This trend could have a huge impact on the traditional power generation assets as has already been experienced in the case of the German Energiewende (energy changeover) and the subsequent energy market development.
Figure 1 shows German generation of wind and photovoltaic (PV) power in the year 2014, including the absolute peak of PV and wind power at around noon on March 14. Here we see more than 43 GW of volatile generation. This exceeded 50% of German power demand in the year 2014.

![Figure 1](image)

On January 9, 2015, a new record for wind generation input was set with a peak level of 31 GW. This undoubtedly underlines the continuous trend towards an increased contribution from renewable generation.

This fact has consequences for energy prices, as can be seen in Figure 2. The data clouds for the third quarter of the years 2012, 2013 and 2014 show each hour of energy prices plotted against the share of renewable power generation (PV, wind, hydro and biomass). The data taken from different sources [1a-f] shows continuously falling average quarterly power prices which reach a range of €31-32/MWh. The same is true for the other quarters of the years 2012 to 2014 as shown in the accompanying table.
This has severe consequences for the profitability of all power plants and especially for gas fired combined cycle power plants (CCPPs). These assets suffer from many annual hours of negative clean spark spreads which result from relatively high fuel costs and low power prices.

**Figure 3** visualizes this impact on CCPPs with green representing each hour of the year with a positive clean spark spread i.e. electricity price ≥, variable CCPP generation costs). Each diagram consists of 24 columns which show the hours from 01:00 AM up to midnight from left to right. January 1 is shown at the top of the vertical axis with, December 31 at the bottom of each diagram. The sample efficiency level used to evaluate the clean spark spread was taken from a typical F-class CCPP. Nevertheless, sensitivity analysis shows that not even H-class efficiencies demonstrate a strong difference in the number of hours with positive spread. The yellow cells depict a spread of between € -3/MWh and € 0/MWh, as it is assumed that some loss may be compensated for by additional payments received from the auxiliary services market, such as secondary frequency response. Comparing the years from 2010 to 2014 reveals the reason for the decreasing number of operating hours at most CCPPs in Germany and the resulting change in the operational profile of these plants.
In 2010 plants were able to operate under base load conditions, but nevertheless they were already experiencing less profitable nights as early as the second half of that year. 2011 market conditions were best dealt with by using cycling operations with a fast hot start in the morning and a stop of the plant at night to avoid the losses associated with the negative spreads of the “red hours”. Since 2012, the afternoon hours have also been negative spread hours. This has been caused by the increasing generation of PV around noon. CCPPs are facing an ever more challenging situation and many plants have been experiencing longer shut down periods. The length of these may vary by a couple of days leading to either warm or cold starts of the steam cycle. In some cases this leads to even longer stops with preservation or mothballing.

**Figure 4** demonstrates the described changes by comparing the MWh generated of a typical CCPP in the month of September in 2008, 2011 and 2012. The most important technical capabilities and the related plant modernizations and improvements needed are changing according to these changing operational requirements of the plants.
As for base load plants, additional power and higher efficiency pay off quickly. A typical modernization measure is an upgrade to a more advanced version of gas turbine during an outage of sufficient length. Plants operating on a cycling basis have benefitted more than any others from optimized hot starts or fast shut downs. Increased load gradients are also typically desired by operators.

The changing operational profiles do not just consist of fewer operating days and more starts, as outlined in Figure 4. Today’s cycling operations often lead to less and different MWh/day figures as the power levels vary quickly and often between base load and minimum load, see Figure 5 [2].

**Figure 4** Example of the load regime change at a glance
What are the consequences of all this and the ongoing installation of new, additional renewable power generators? Will most fossil fuel plants shut down in future (along with the nuclear ones which are set to disappear from Germany’s generation portfolio by 2022) with new equipment simply taking over the generation task?

The answer is a definitive “no”. As can be seen in Figure 6, the minimum renewable supply was able to meet less than 1% of German demand only during low wind and no sun hours in all years despite the strong increase in renewable installations in Germany – already reaching a total capacity of 76.5 GW (wind 38.1 GW & PV 38.4 GW [3a-b]) by the end of 2014.
A reliable power plant fleet is needed not only as a backup for low wind and no sun hours, but also as an important contributor towards grid stability through the use of rotation inertia, frequency response, fast power increase or start up (Figure 7).

*Figure 7 Contribution of thermal power plants to grid stability and security of supply*

To support plant owners and operators in this period of change, Flex-Power Services™ is an undertaking by Siemens Power Generation Services which targets all aspects of plant operation with an integrated approach and offers solutions for modernizing plants with respect to their new operational requirements (Figure 8). This paper now turns to the subject of measures to optimize start-stop performance for cold, warm and hot starts. The important
aspect of faster load changes during operation for frequency response has already been addressed in depth in other papers [2, 4, 5].

Figure 8 Aspects of Siemens Flex-Power Services™

3 From base to cycling operation – innovative operational concepts

The Mainz Wiesbaden CCPP shown in Figure 9 was a base load plant for many years. The owner Kraftwerke Mainz Wiesbaden AG (KMW AG) has taken many opportunities to upgrade the plant since first fire in 2000. Together with OEM Siemens, KMW AG has often been a pioneer of modernization, ready to install the latest technology in the plant as first time application. In 2004, the original SGT5-4000F configuration was upgraded with service pack 4 and as recently as June 2014 service pack 7 was successfully implemented [6, 7]. The plant is equipped with a SGT5-4000F gas turbine in a multi-shaft configuration. This feeds three pressure stage drum boiler which supplies steam to a SST5-6000 steam turbine with steam extraction to supply process steam and district heating.
With a view to the changing market environment described above, the change from base load to cycling operation had already been discussed between KMW AG and Siemens years before it finally took place in 2014. A variety of improvement measures were implemented or discussed and tested for potential future implementation, depending on emerging market needs.

The Flex-Power Services™ improvements which were considered to optimize the start-stop operations in Mainz Wiesbaden are described in greater detail below.

3.1 Start-up improvements for starts after stops of several days

Even though the plant has just made the changeover from base load to cycling operation and stops for several days are currently rare, research is already ongoing to deal with these potential future needs as well.

The degassed conductivity measurement is under consideration by KMW AG as this may shorten the start-up time of a combined cycle power plant – especially for cold starts – as the waiting time for steam purity can be significantly reduced, as outlined in Figure 10.
This method controls the steam purity and distinguishes between the corrosive contaminants and less harmful carbon dioxide by measuring the Degassed Conductivity analyzer. The analyzer re-boils the sample downstream from the cation column to remove carbon dioxide [8].

As can be seen in the next paragraph, fast and reliable starts are possible by utilizing highly integrated start-up concepts like the steam turbine Hot Start on the Fly (HoF) if the turbine is still in a hot condition. This is typically the case after an overnight stop, but is no longer possible after a weekend or longer periods offline because the steam cycle cools down during such extended stops.

Any method which avoids the cool down of the steam cycle, especially the intermediate pressure steam turbine rotor, will help to shorten the start-up time, e.g. on a Monday morning.

Figure 10 Potential benefits of Degassed Conductivity
KMW AG has researched an innovative concept that uses steam to keep the rotor in the range of at least around 215°C. This approach utilizes low pressure steam from a waste burning facility which belongs to the overall KMW AG steam system. Details of the heating concept were developed and successfully tested with Siemens experts as shown in Figure 11.

**Figure 11** Results from a test to keep the ST in a heated condition

The tests have shown that it is possible to prevent temperature decreases of the rotors and, furthermore, to increase the rotor temperature from a lower level. Other improvements were also identified during these tests and KMW AG has already implemented some of the features, e.g. an optimized drain concept to maintain heat and pressure levels within the HRSG.

In case of a further reduction of operating hours, KMW AG discussed an improved preservation concept which was developed by Siemens. It allows starting the dryers with minimum effort in case of a stop of several days without any seal steam or vacuum in order to minimize auxiliary power. Preservation can be started and ended by the operators only. This avoids the need for a maintenance team and allows for an immediate beginning of the start-up preparations as soon as the transmission grid operator calls the plant into service.
3.2 Start stop performance for overnight stops – daily cycling operation

Even though the plant was still running at base load, KMW AG anticipated changes in its operation profile and as early as 2010 started technical discussions with Siemens about faster starts after overnight stops. The decision to implement the steam turbine Hot Start on the Fly procedure was finally made in December 2013, as it became clear that the years of base load operation were coming to an end.

The HoF procedure utilizes an improved start-up concept which allows the parallel start-up of both gas turbine and steam turbine in hot start conditions [5, 9]. In 2014, the plant underwent several important modernizations:

- Implementation of GT service pack 7 to convert the engine to a new state of technology with improved GT power (+10.4%) and GT efficiency (+1.3%pts) [6,7]
- SPPA T-3000 upgrade to operate the plant in future with a state of the art I&C system
- Steam turbine HoF implementation

Figure 12 shows the great improvement brought about by the successful implementation of the HoF procedure, reducing the start-up time by approximately 40 minutes to 27 minutes as measured from GT ignition to the condition of HP and IP steam bypass closed and the GT inlet guide vane more than 98% open.

![Figure 12](image-url)

**Figure 12** Results from an improved Start and Shut-down
The HoF process is not just an extremely fast and efficient start with only moderate life consumption, but also a process of great reliability and predictability. Since its implementation, the HoF procedure has been used for hot starts on weekdays and, as of April 2015, has been used for approximately 100 starts without any trip and always with a great accuracy in start-up times.

Thanks to the close working relationship between KMW AG and Siemens, project meetings during the HoF implementation were also used for exchanging further innovative ideas. This resulted in additional tests by the expert team during the commissioning of the HoF procedure.

Concepts for an even more advanced HoF procedure and the highly integrated shut down of gas and steam turbine were also tested successfully, as shown in Figure 12. An evacuated HP turbine at the beginning of the steam turbine start-up process showed the potential for a further reduction in hot start-up time of approximately 4 minutes. The shutdown time was shortened by approximately 6 minutes bringing the plant shutdown time from 400 MW to no load to impressively low 20 minutes.

![Figure 13](image)

**Figure 13** A combination of GT Fast Starts and HoF

Further untapped potential for time reductions and efficiency improvements during start-up and shut-down is evident and may be exploited in the future as well. A fast start-up load gradient of 30 MW/min has been proposed by GT engineering. This could cut down further
minutes compared to the 13 MW/min gradient currently being used during the start-up and described in the figures above. This principle is outlined in Figure 13. Here we see a simplified graphic of the time-saving concept of the HoF procedure combined with the benefit of the increased gradients.

As the fast increase of heat flow passing through the heat recovery steam generator may lead to the sudden production of high steam flows, a further steam turbine improvement will contribute to the overall efficiency and flexibility of the start-up process. Advanced Fast Loading for the steam turbine, as outlined in Figure 15, has been proposed by our engineers. This would allow increased acceleration of the steam turbine shaft so that synchronization occurs sooner as well as a faster steam turbine load gradient.

![Figure 14 Potential benefit of ST Advanced Fast Loading](image)

Finally, the implementation of an ST load controller is being considered by KMW AG in order to improve the predictability of the feed-in power generated by the steam turbine, especially during transient operation.
4 Summary

The increasing share of renewable energy and high fuel prices in Europe have changed the operational profile of the combined cycle power plants dramatically. The consequences of the German *Energiewende* for the profitability and the operating regimes of typical CCPPs were presented in the first part of this paper. In addition, Flex-Power Services™, a Siemens Power Generation Services activity to improve operational flexibility of the power plants, was introduced.

The second part of the paper presented the operational regime changes experienced by the Mainz Wiesbaden CCPP and the measures taken or considered by KMW AG in close cooperation with Siemens in order to keep the power plant in excellent condition and prepared for changing market conditions.

A perfect example of such measures is the successful implementation of the HoF procedure for steam turbines which enables the operators to perform daily cycling in a most reliable, efficient and predictable manner.

The continuous improvement measures at the Mainz Wiesbaden CCPP are resulting in plant capabilities which can successfully meet the challenges of modern energy markets.
5 References

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6 Disclaimer

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