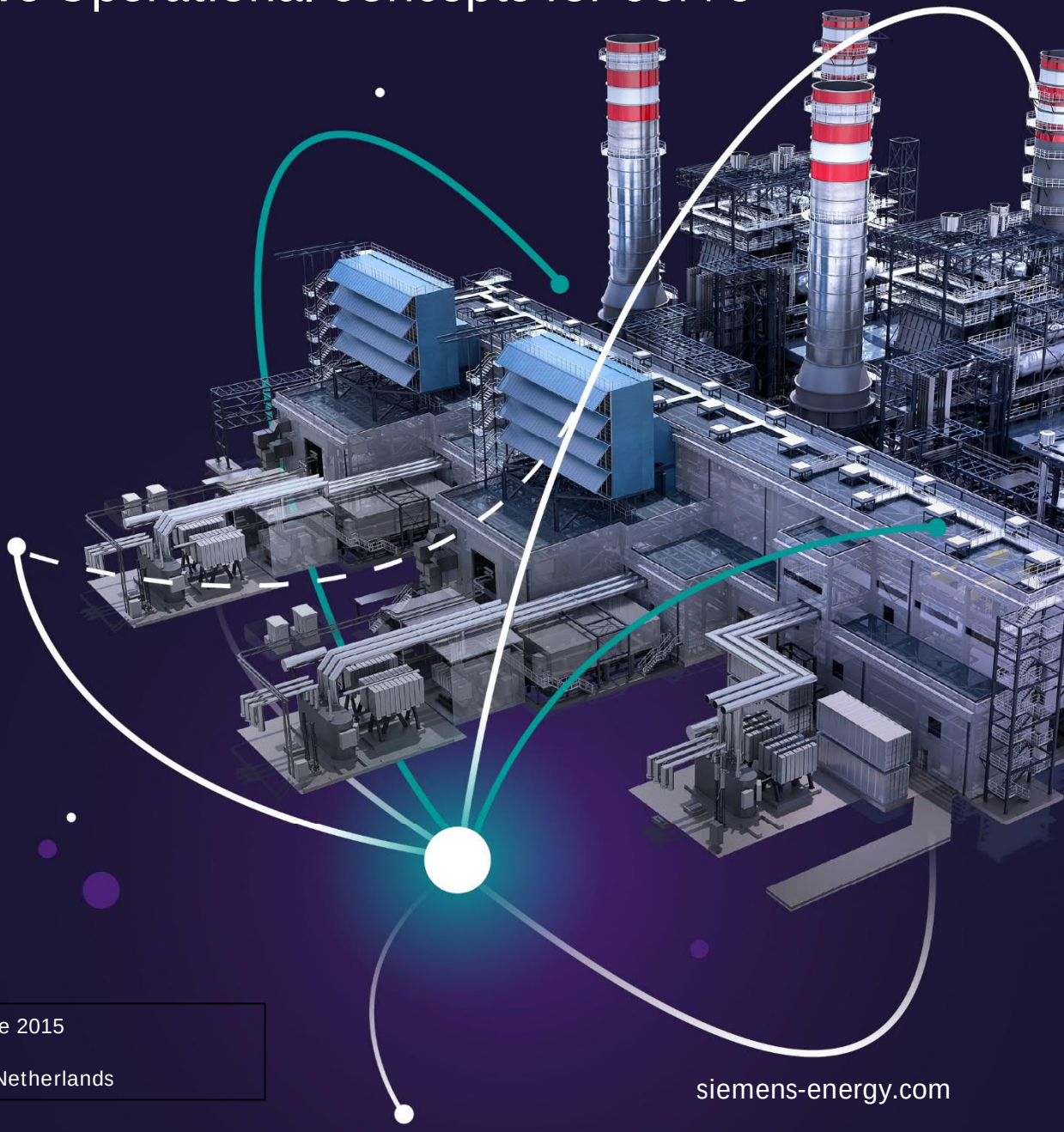
SIEMENS energy

From Base to Cycling Operation

Innovative Operational Concepts for CCPPs



Power-Gen Europe 2015
June 9-11, 2015
Amsterdam, the Netherlands

siemens-energy.com



Presented at:
Power-Gen Europe 2015
June 9-11, 2015
Amsterdam, the Netherlands

Authors:
Dr. Andreas Feldmüller
Florian Roehr

Siemens Energy

Thomas Zimmerer

Kraftwerke Mainz-Wiesbaden AG

© 2021 Siemens Energy

01 Abtract.
Page 3

02 Introduction to the market environment for combined cycle power plants in Germany.
Page 3

03 From base to cycling operation – innovative operational concepts.
Page 6

04 Summary.
Page 10

05 References.
Page 11

06 Disclaimer.
Page 11

© 2021 Siemens Energy

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.

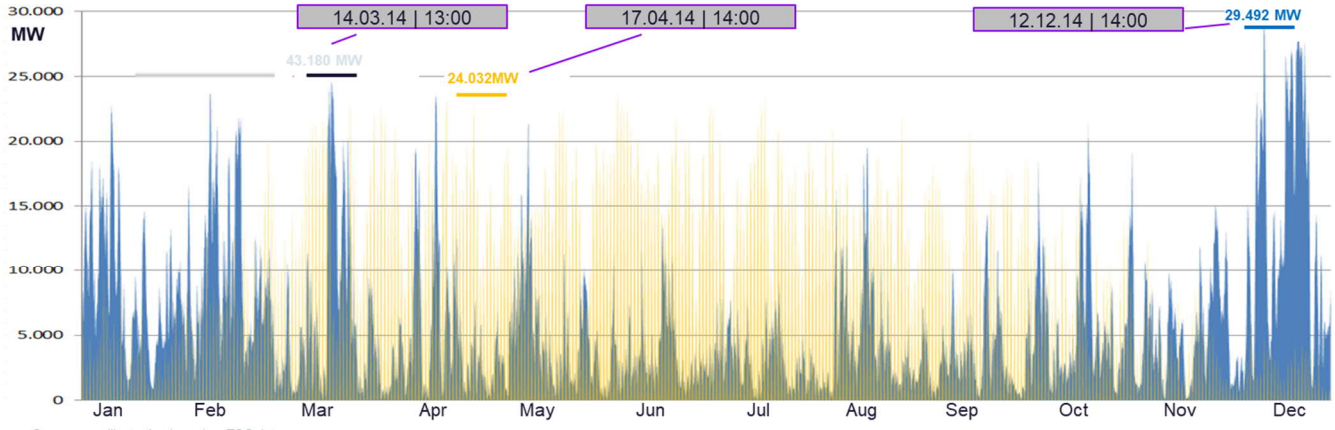
Operational flexibility enhancements successfully implemented in the plant as well as the results of tests for future upgrades and further aspects under consideration will be presented in the second part of the paper.

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. 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.



Source: own illustration based on TSO data

Installed generation capacity in Germany (2014)
approx. 175 GW

approx. 100 GW conventional generation

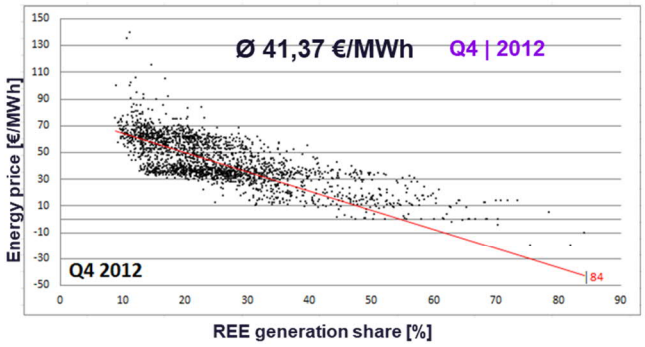
Daily need (min/max)
29,5 GW / 70,5 GW

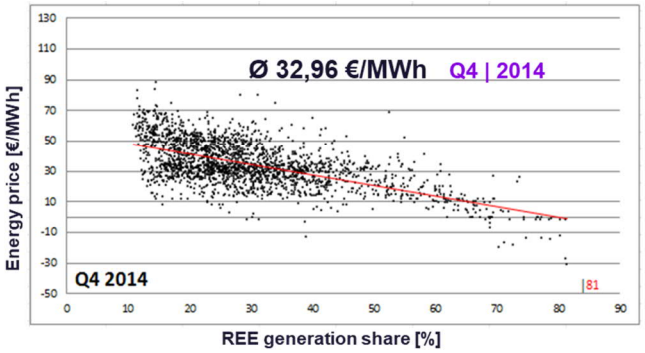
Yearly generation (2014)
456 TWh

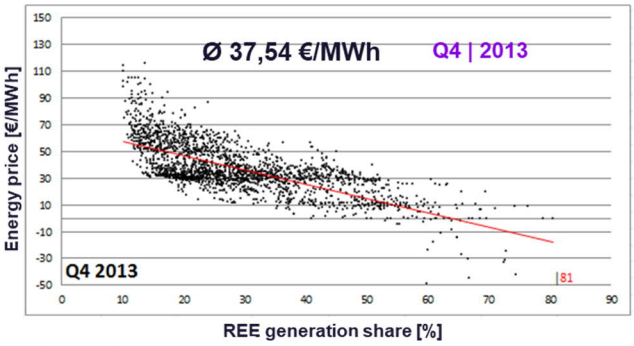
In MW	2011	2012	2013	2014
Wind max.	22.876 [04.02 |20:00]	24.021 [03.01.12 |17:00]	26.040 [05.12.13 |14:00]	29.492 [07.02.14 |17:00]
Wind min.	92 [06.07.11 |10:00]	134 [24.10.12 |16:00]	137 [16.02.13 |14:00]	38 [12.03.14 |12:00]
PV max.	13.177 [09.05.11 |14:00]	22.152 [25.05.12 |14:00]	23.975 [21.07.13 |14:00]	24.032 [17.04.14 |14:00]
Wind und PV max.	27.768 [04.08.11 |14:00]	31.565 [14.09.12 |14:00]	35.741 [18.04.13 |14:00]	43.180 [14.03.14 |13:00]
Wind inst./gen.	29GW / 49TWh	31GW / 50TWh	34GW / 50TWh	34GW / 51,4TWh
PV inst./gen.	25GW / 19TWh	32GW / 26TWh	36GW / 26TWh	37GW / 35,2TWh

Figure 1 German generation of wind and PV power 2014

© 2021 Siemens Energy







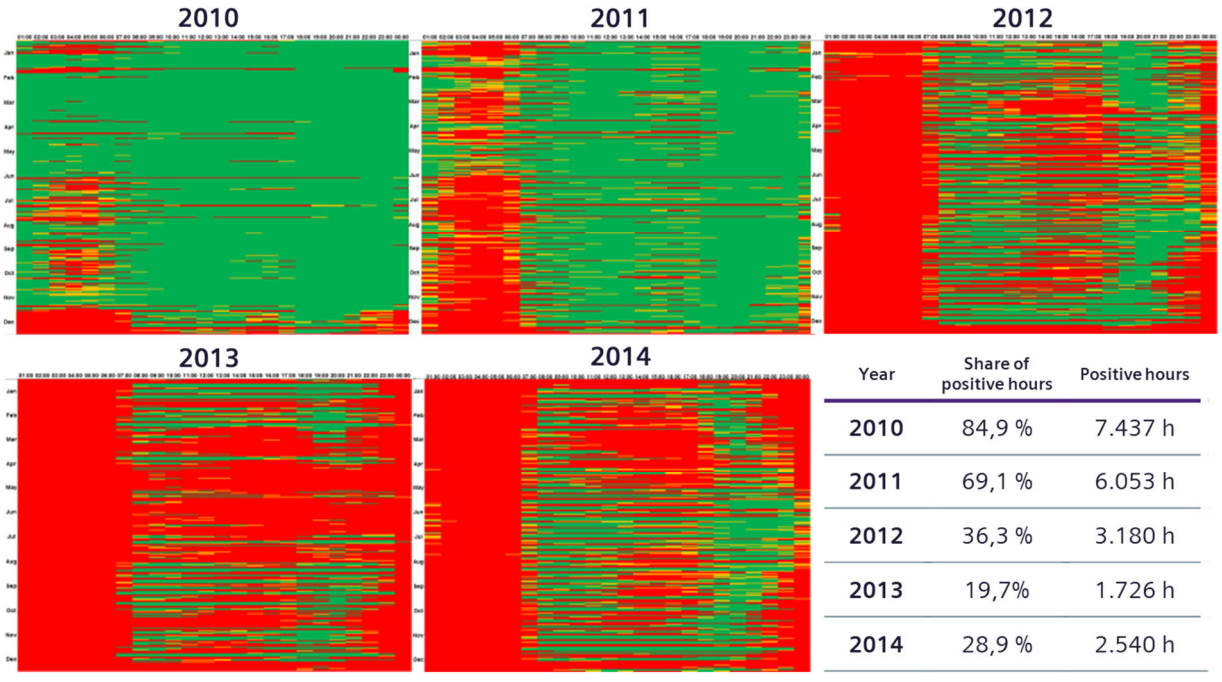
Av. price/ Max. share REE	2011	2012	2013	2014
Q1	51,85 €/MWh 58%	43,38 €/MWh 74%	42,26 €/MWh 77%	31,13 €/MWh 73%
Q2	53,60 €/MWh 62%	40,39 €/MWh 74%	32,59 €/MWh 85%	31,61 €/MWh 84%
Q3	49,16 €/MWh 56%	43,51 €/MWh 72%	38,75 €/MWh 75%	31,43 €/MWh 83%
Q4	49,93 €/MWh 61%	41,37 €/MWh 84%	37,54 €/MWh 81%	32,96 €/MWh 81%

Source: Illustration of 3. Quarter of the shown year on basis of ENTSO-E and EEX Data

Figure 2 Decline of wholesale power prices

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



Year	Share of positive hours	Positive hours
2010	84,9 %	7.437 h
2011	69,1 %	6.053 h
2012	36,3 %	3.180 h
2013	19,7%	1.726 h
2014	28,9 %	2.540 h

Source: own illustration based on EEX data

Figure 3 Decline of clean spark spreads in Germany

© 2021 Siemens Energy

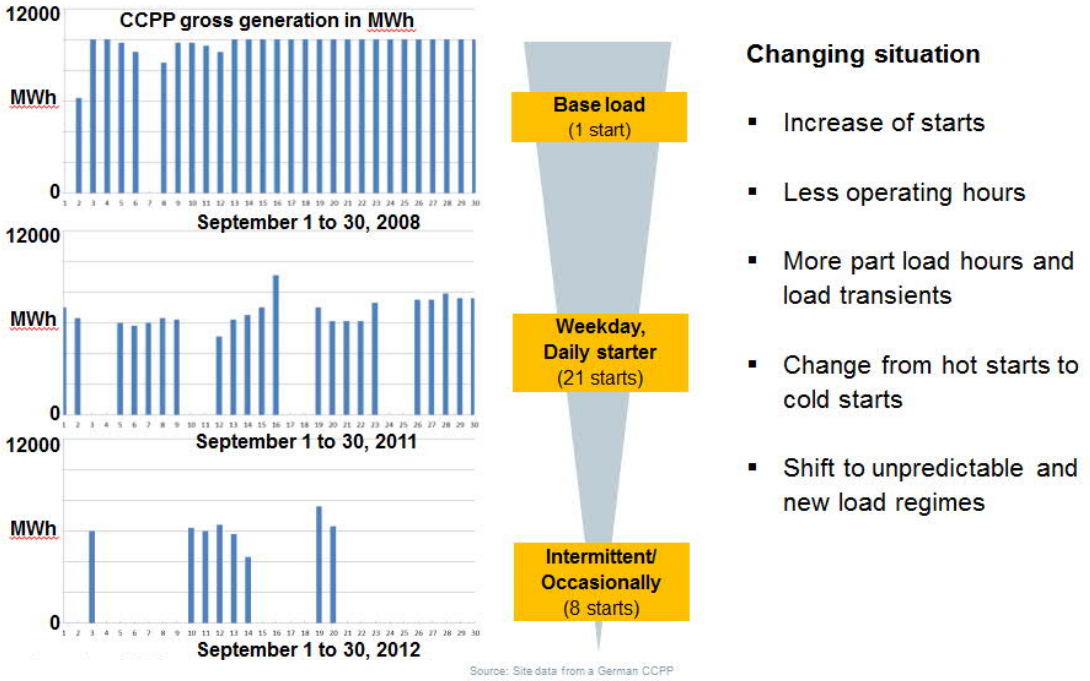


Figure 4 Example of the load regime change at a glance

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.

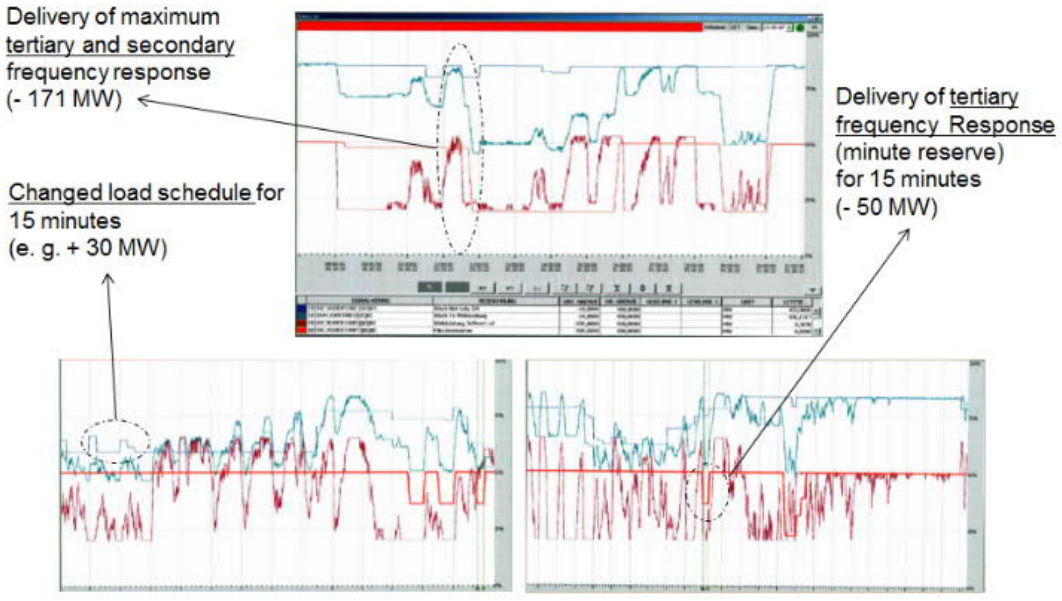


Figure 5 Example of the operational load changes

© 2021 Siemens Energy

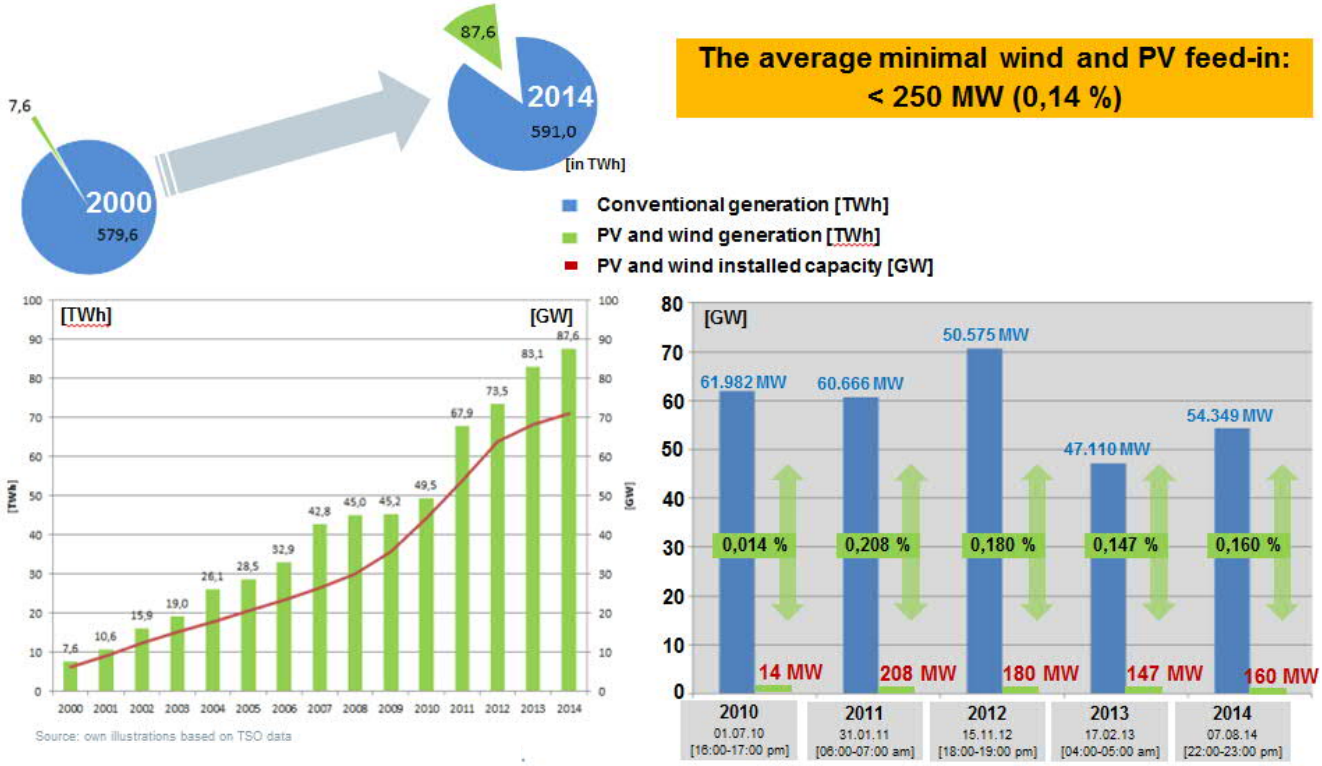


Figure 6 Volatile wind and PV power in Germany

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].
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).

To support plant owners and operators in this period of change, Flex-Power Services™ is an undertaking by Siemens Energy 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.

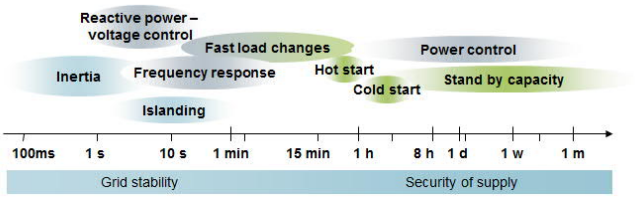


Figure 7 Contribution of thermal power plants to grid stability and security of supply

The important aspect of faster load changes during operation for frequency response has already been addressed in depth in other papers [2, 4, 5].

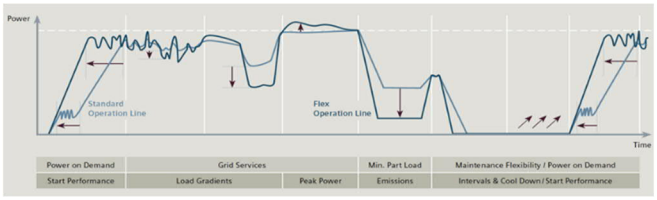


Figure 8 Aspects of Flex-Power Services™

Power station 2
(Combined 340 MW, commissioned 1977)

Winter cold reserve for the transmission grid
One scheduled start/year



Power station 3

CCPP	**SCC5-4000F; combined cycle, multi shaft** Year of construction: 2000
Combined Cycle Power output	**≈ 440 MW**
Gas Turbine	**SGT 5-4000F** connected to SGen5-2000H generator
Heat Recovery Steam Generator	**3 stage HRSG (NEM)** HP/IP/LP: Natural circulation boiler
Steam Turbine	**SST 5-6000** (140 MW_{el}/160 MW_{th}) with axial condenser (SCon4000) connected to **SGen5-1000A generator**
Owner and Operator	**Kraftwerke Mainz-Wiesbaden AG**

Figure 9 CCPP Mainz Wiesbaden

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 Energy, 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 Energy 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.

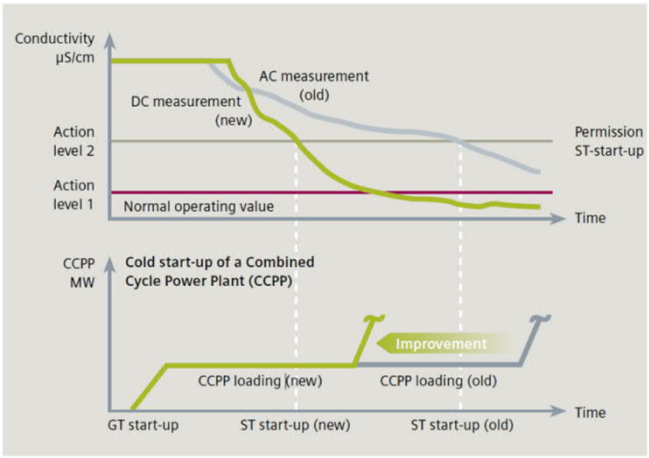


Figure 10 Potential benefits of Degassed Conductivity

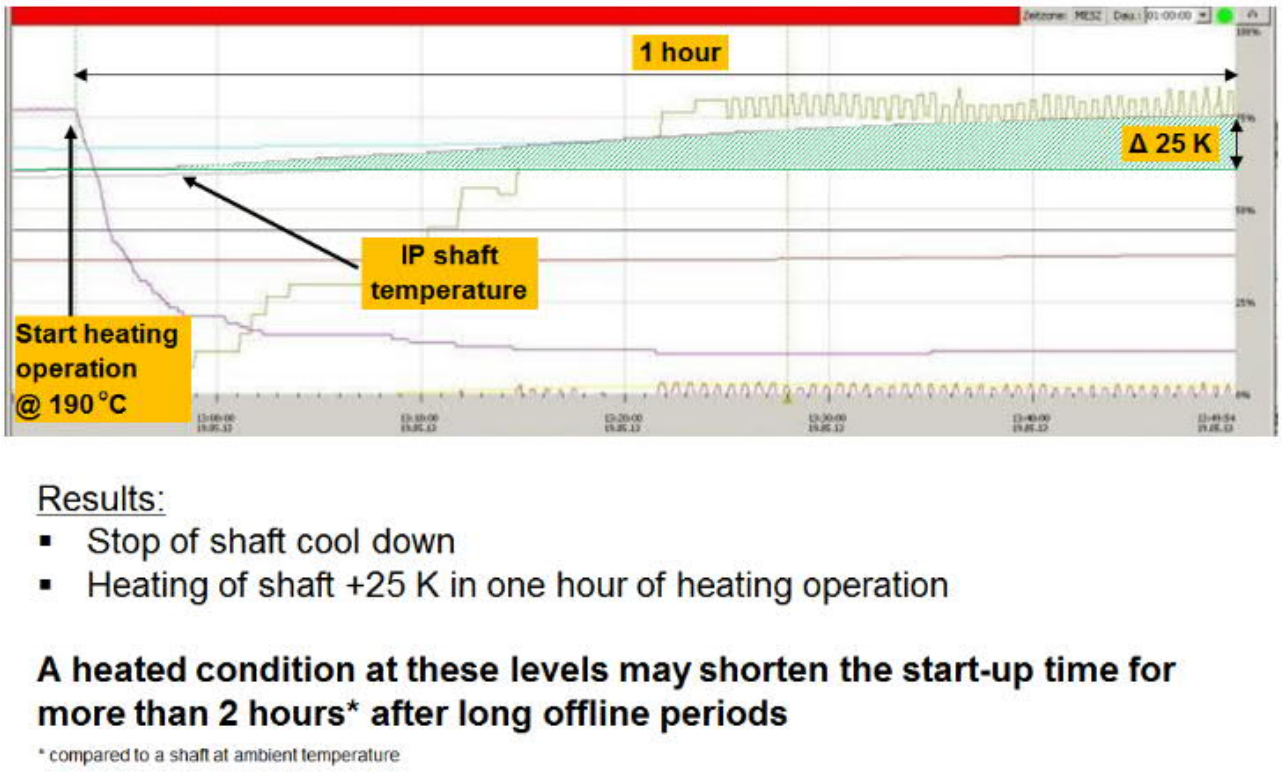


Figure 11 Results from a test to keep the ST in a heated condition

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.

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 Energy experts as shown in Figure 11.

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 Energy. 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 Energy 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:

© 2021 Siemens Energy

- 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.
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 Energy, 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.

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.

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.

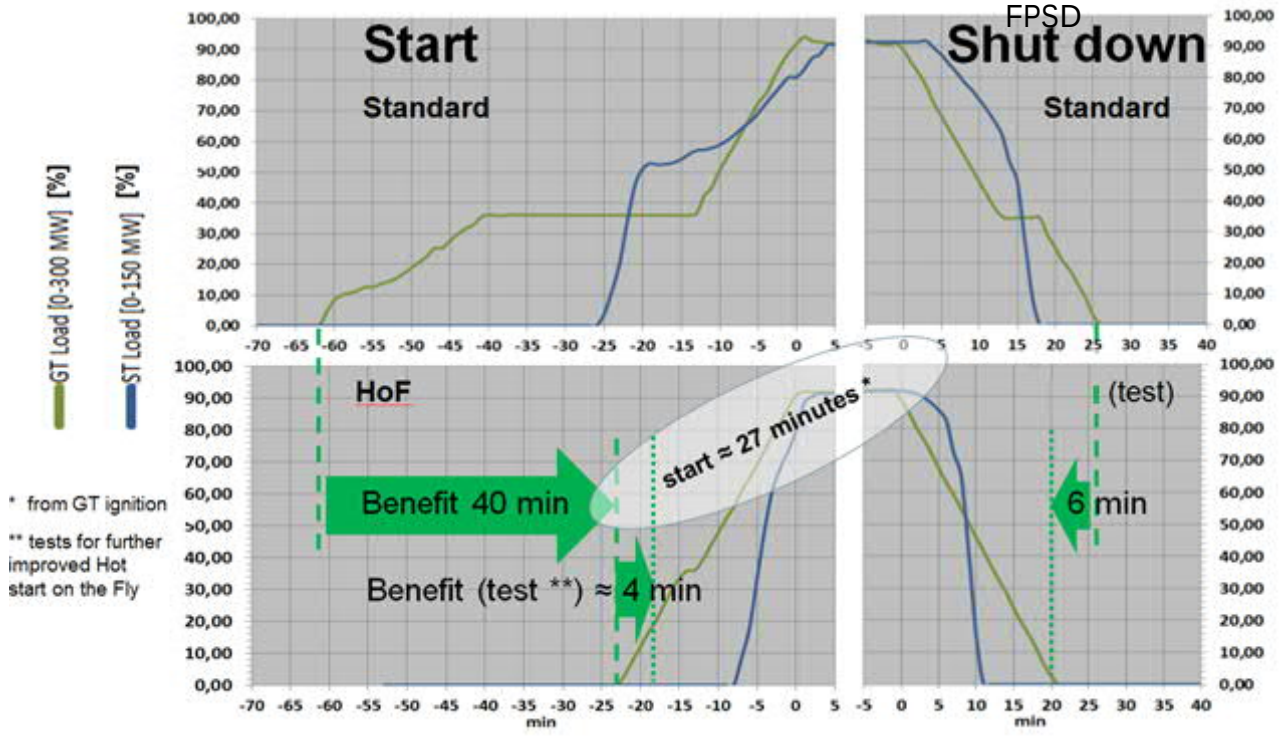


Figure 12 Results from an improved Start and Shut-down

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.

© 2021 Siemens Energy

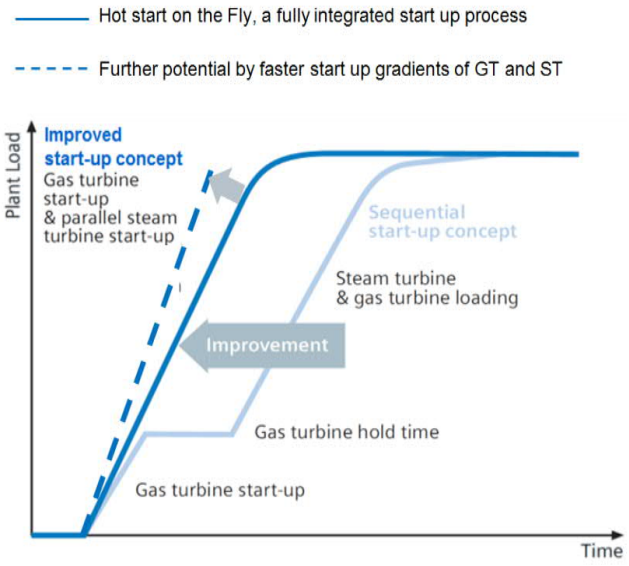


Figure 13 A combination of GT Fast Starts and HoF

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 Energy 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 Energy 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.

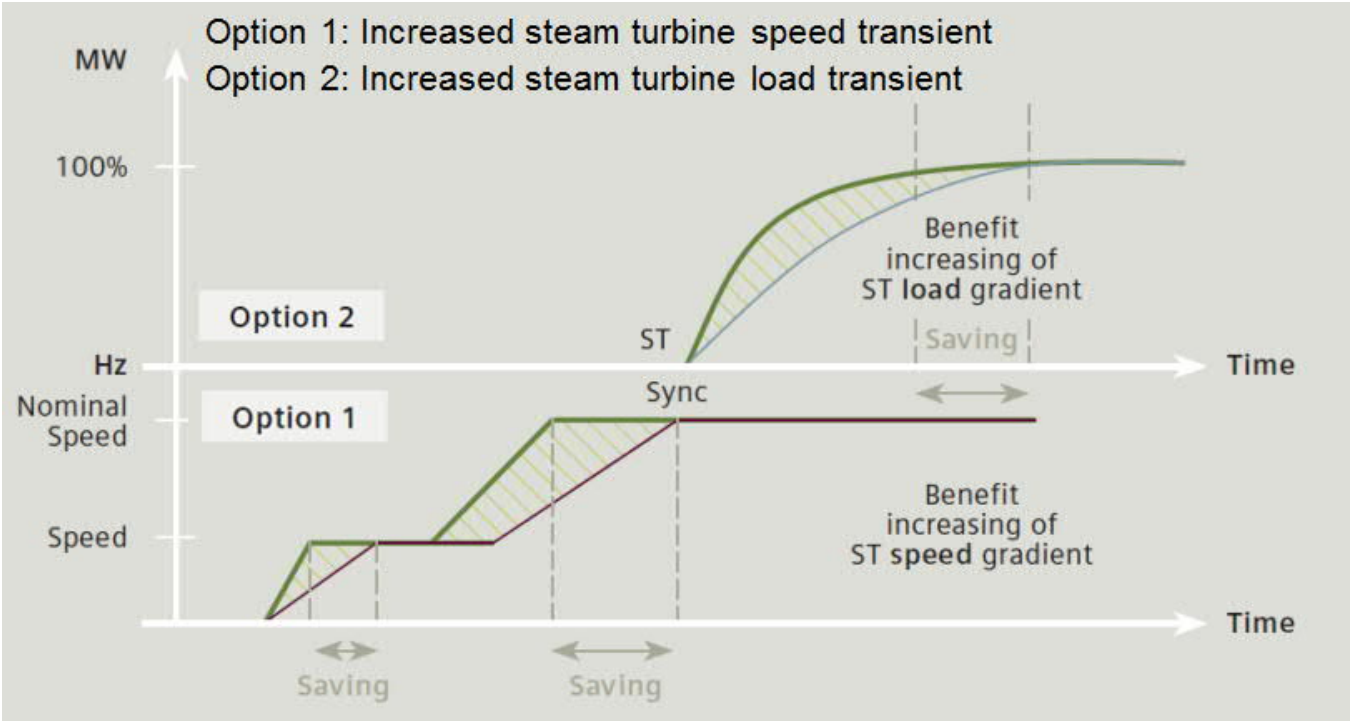


Figure 14 Potential benefit of ST Advanced Fast Loading

© 2021 Siemens Energy

5 References.

[1a] https://www.entsoe.eu/Pages/default.aspx

[1b] http://www.eex.com/de/

[1c] http://www.amprion.de/

[1d] http://www.tennet.eu/de/home.html

[1e] http://www.50hertz.com/de/

[1f] http://www.transnetbw.de/de

[2] Dr. Martin Buschmeier, Thomas Kleinwächter, Dr. Andreas Feldmüller, Philipp Köhne "Improving Flexibility of the Combined Cycle Power Plant Hamm Uentrop to Cover the Operational Profiles of the Future" POWER-GEN Europe 2014, Cologne, June 4th 2014

[3a] http://www.wind-energie.de/infocenter/statistiken/deutschland/installierte-windenergieleistung-deutschland

[3b] http://www.ise.fraunhofer.de/de/veroeffentlichungen/veroeffentlichungen-pdf-dateien/studien-und-konzeptpapiere/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf

[4] Thomas Kleinwächter, Andreas Dibbert, "Flexible gas turbine solutions for the changing European Market", O&M and Lifecycle Management for CCGT Power Plants, Birmingham 2014

[5] Tjark Eisfeld, Andreas Feldmüller "Fast Cycling and Fast Start Capability of Combined Cycle Power Plants with SGT5-4000F Gas Turbines", Institution of Mechanical Engineers, Seminar "Demand Response and Flexible Operation in UK Power Stations", 28 November 2013 Nottingham

[6] Tjark Eisfeld, Andreas Feldmüller, Marc Tertilt „Flexibilisierung von Bestandskraftwerken mit SGT5-4000F Gasturbinen" 9. VDI-Tagung Stationäre Gasturbinen, Nürnberg, 18.-19. November 2014

[7] Michael Strauss, Tjark Eisfeld, Marc Tertilt, Dennis Thiebe "The Challenge of changing markets – Life Time Extension (LTE) and modernization measures on a SGT5-4000F in Power Plant 3 of Kraftwerke Mainz-Wiesbaden AG (KMW AG)", VGB Conference "Gas Turbines and Operation of Gas Turbines" May 2015, Lübeck

[8] Anke Söllner, Michael Rziha, Peter Wuhrmann: „Optimization of Sampling System for a Faster Start-up of Cycling Power Plants", VGB PowerTech 03/2010

[9] Florian Röhr, Andreas Feldmüller: "Optimization of operating plant performance in view of new market conditions", POWER-GEN Europe, Cologne, 12. June 2012

6 Disclaimer.

These documents contain forward-looking statements and information – that is, statements related to future, not past, events. These statements may be identified either orally or in writing by words as "expects", "anticipates", "intends", "plans", "believes", "seeks", "estimates", "will" or words of similar meaning. Such statements are based on our current expectations and certain assumptions, and are, therefore, subject to certain risks and uncertainties. A variety of factors, many of which are beyond Siemens Energy' control, affect its operations, performance, business strategy and results and could cause the actual results, performance or achievements of Siemens Energy worldwide to be materially different from any future results, performance or achievements that may be expressed or implied by such forward-looking statements. For us, particular uncertainties arise, among others, from changes in general economic and business conditions, changes in currency exchange rates and interest rates, introduction of competing products or technologies by other companies, lack of acceptance of new products or services by customers targeted by Siemens Energy worldwide, changes in business strategy and various other factors. Should one or more of these risks or uncertainties materialize, or should underlying assumptions prove incorrect, actual results may vary materially from those described in the relevant forward-looking statement as anticipated, believed, estimated, expected, intended, planned or projected. Siemens Energy does not intend or assume any obligation to update or revise these forward-looking statements in light of developments which differ from those anticipated.

© 2021 Siemens Energy

Published by

Siemens Energy Global GmbH & Co. KG
Freyeslebenstr. 1
91058 Erlangen, Germany

For the US Published by
Siemens Energy Inc.
4400 Alafaya Trail

Orlando, FL 32826-2399, U.S.

For more information, please visit our website:
siemens-energy.com/

Article No. PGSV-T10001-00-4A00

© Siemens Energy, 2021

Siemens Energy is a trademark licensed by Siemens AG

Subject to changes and errors. The information given in this document only contains general descriptions and/or performance features which may not always specifically reflect those described, or which may undergo modification in the course of further development of the products. The requested performance features are binding only when they are expressly agreed upon in the concluded contract. All product designations may be trademarks or product names of Siemens Energy Global GmbH & Co. KG or other companies whose use by third parties for their own purposes could violate the rights of the owners.