

Maximizing power plant flexibility

How more flexible, faster combined cycle power plant cycling can help support producer profitability during the energy transition.

White paper

siemens-energy.com

SIEMENS energy

As renewables grow in the energy mix used by North American power producers, keeping generating assets best utilized requires operating them with a flexibility that often exceeds the original capabilities of most plants today. Combined cycle power producers need to get into markets fast – when prices are high – and get out fast, when margins may be low or even negative.



Content

04 Abstract

05 Renewables complicate profitability for North American power producers

05 Challenging journey to a decarbonized energy future
06 Operational flexibility's impact on profitability
07 The impact of renewables on CCPP operating models
08 The growing role of ancillary services in grid stability and reliability

10 From base to cycling operation models: fast, flexible operational concepts

11 Operational flexibility improvement concepts
12 Plant optimization for hot starts: help reduce start-up times up to 50%
13 Plant optimization for warm starts: faster start-ups, lower fuel costs
13 Plant optimization for cold starts: more efficiency, less time to loading conditions
14 Fast plant shutdown optimization: saving fuel and CO_2

15 Summary: Flexibility with speed and reliability, key to better asset utilization and improved profitability

Abstract

Given the steady growth of renewables in the North American energy mix, volatile fuel prices, and current and proposed governmental legislation, the operational profiles of combined cycle power plants (CCPPs) are dramatically changing – from base load to cyclical modes.

In addition, ancillary services are playing a growing role in helping to ensure grid reliability and accommodate an energy resource mix that will continue evolving with more renewables.

These trends affect both regulated and unregulated markets. They require power producers to have more flexibility in their asset utilization in order to meet revenue goals, expand operating margins, and maintain profitability. How fast and reliably they can exercise that flexibility is critical, too.

CCPP operators must not only generate power as efficiently as possible but also have their plants ready to ramp whenever power markets are paying premium prices. Increasing plant operational flexibility can help operators both minimize generation costs during times of low power prices and help capture the margins peak prices offer.

This paper focuses on measures intended to optimize CCPP operational flexibility for North American producers. It explains new operational profiles due to the energy transition, which make enhanced startup and shutdown processes necessary. These include optimized hot, warm, and cold starts, as well as improved ramp-up / ramp-down load gradients.



Renewables complicate profitability for North American power producers

Among the 3,000 utilities operating in the U.S. and the 16 major utilities operating in Canada, no two are alike. Each serves customers of all kinds, from household consumers to heavy industries. They can span different regional geographies with wide variations in seasonal demands, which can change dramatically from year to year.

Their energy sources can vary widely, too, as can the age and composition of their generating capacity. Additionally, individual operators must comply with ever-changing federal and state environmental requirements, and regulated producers must abide by strict tariff structures.

Finally, there are a myriad of other operating variables that can potentially affect a utility's margins and, ultimately, its profitability.

Challenging journey to a decarbonized energy future

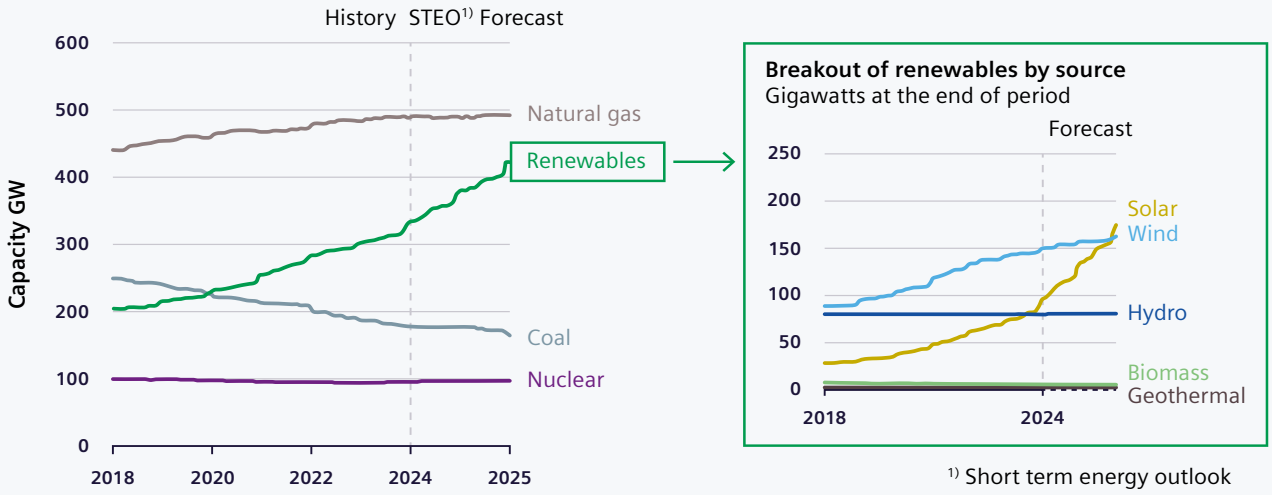
All North American utilities and independent power producers face one common challenge: the rapid growth of renewables in the power-generation mix as the power industry continues moving toward a decarbonized energy future.

In 2023, renewable energy sources – wind, solar, and hydro, chief among them – accounted for 22% of generation.[1] From those sources, new solar projects coming online in the near-term are expected to propel solar's growth 75% by 2025 while wind will grow 11% in that same time period.[2] Looking even further ahead to 2050, solar and wind generation is forecast to provide the energy for between 55% and 85% of total U.S. power generation.[3]

Figure 1 illustrates the forecasted U.S. power-generating mix through 2025, showing solar overtaking wind and both eclipsing coal and nuclear combined.

Figure 1. Energy source trends in U.S. annual electric generating capacity (2018–2025).

Source: U.S. Energy Information Administration



1 Katherine Antonio, Short-Term Energy Outlook (STEO), U.S. Energy Information Administration, January 2024.
2 IBID.
3 Pieter Gagnon et al. 2023 Standard Scenarios Report: A U.S. Electricity Sector Outlook. National Renewable Energy Laboratory (NREL). Revised January 2024.

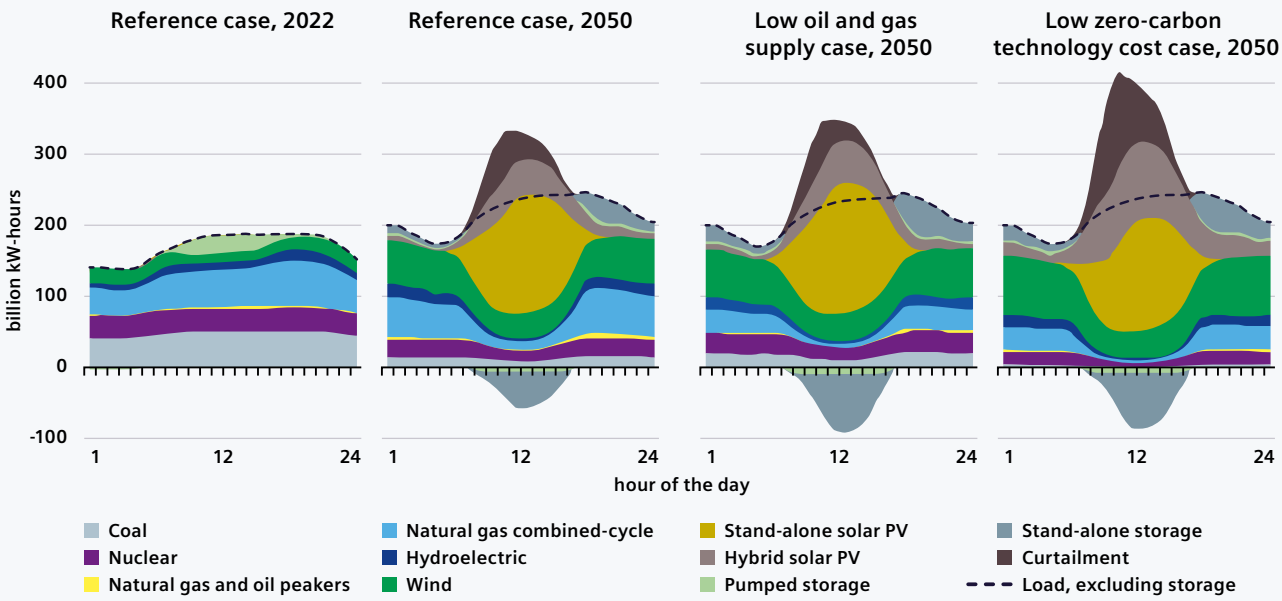


Figure 2. Hourly U.S. electricity generation and load by fuel for selected cases and representative years in billion kilowatt-hours

Source: U.S. Energy Information Administration, Annual Energy Outlook 2023 (AEO2023)

Note: Negative generation represents charging of energy storage technologies such as pumped hydro and battery storage. Hourly dispatch estimates are illustrative and are developed to determine curtailment and storage operations; final dispatch estimates are developed separately and may differ from total utilization as this figure illustrates. Standalone solar photovoltaic (PV) includes both utility-scale and end-use PV electricity generation.

Figure 2 illustrates different forecast scenarios by 2050 for hourly U.S. electricity generation and load by fuel for selected cases and representative years, according to the U.S. Energy Information Administration. Of course, 2050 holds much uncertainty in how these scenarios will unfold, but all scenarios clearly show the diminished role of coal compared to the fuel mix behind power generation in today's grid. Across all long-term scenarios, the gas fleet remains essential for reliable grid operation although the operational profile evolves significantly.

In fact, coal's anticipated exit from today's grid by 2030 is straining the remaining dispatchable resources, particularly the natural gas turbine fleet, which will be ever more challenged to balance increasing electrical demand and increasingly variable supply.

Asking more from today's fleet creates an opportunity for plant owners to position their assets optimally for their future usage profile so they can potentially maximize both their utilization of those assets and their operating margins.

These described trends are manifesting themselves in today's grid in specific seasonal patterns. This evolution is expected to grow in frequency and magnitude throughout the country over time.

Operational flexibility's impact on profitability

While rapidly falling prices of solar and wind technologies per kilowatt have spurred the growth of their adoption in recent years, renewables have secured government funding incentives to expand their deployments even more.

The U.S. Inflation Reduction Act (IRA) of 2022 offers $370 billion in tax credits to boost the nation's use of renewable energy.[4] Some industry observers estimate these credits will triple the amount of utility-scale green power in the U.S. from today's levels to approximately 750 GW by 2030.[5] While

4 Here's how the Inflation Reduction Act is impacting green job creation. World Economic Forum. March 2023.
5 John Hensley. Inflation Reduction Act: It's a Big Deal for Job Growth and for a Clean Energy Future. American Clean Power. August 2022.

investment tax credits were primary motivators heretofore, the addition of production tax credits may accelerate solar's development even more.

This rapid expansion of renewables will likely require upgrades to North America's grid, including ISO / RTO interconnections. At the same time, the variability caused by the intermittency of renewables means power producers who can become more flexible in how they operate their generating assets from day to day and season to season can improve business outcomes.

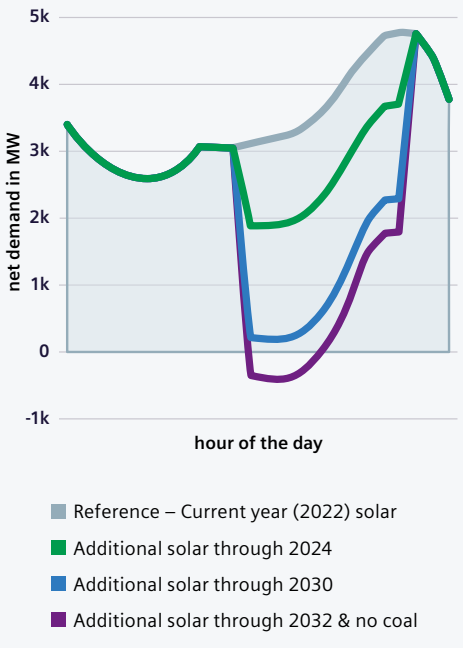
Indeed, utilities are already taking action. Factors such as power price variability, increased emission requirements affecting fossil power, and new market mechanisms are driving a shift in the operating profiles of CCPP assets from base load to flexible cycling modes. To adapt, CCPP assets may need to enhance their operational flexibility through improved start-up and shut-down times, higher load gradients, and other asset optimization concepts.

The impact of renewables on CCPP operating models

These trends are affecting power plants in both regulated and deregulated markets. In the regulated U.S. Southeast market, for example, there is limited wind potential and as solar energy increases in the region's energy mix, producers must balance supply and demand: overgeneration during the day while the sun is shining, versus rising demand as the sun is setting with solar-generated power exiting the grid.

Figure 3 illustrates the expected deepening of the daily net demand ramp-rate curve ("Duck Curve"), a trend that while typically associated with California is now also projected in parts of the Southeast (shown in the figure for a regulated utility), through the anticipated growth in solar capacity by 2032.

What is less commonly understood is how soon CCPPs and others will need to increase their operational flexibility and be capable of high ramp rates. *Figure 4* illustrates how soon and how often system resource planning teams rely on this level of flexibility to maintain grid stability.



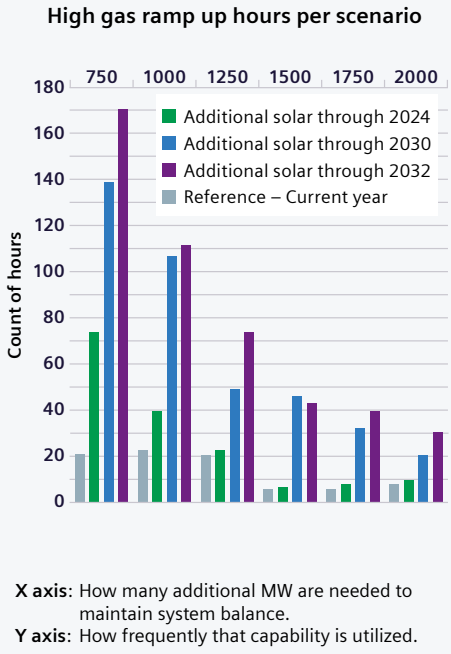


Figure 3 (left).
How solar growth is expected to impact the ramp-rate curve of Southeast U.S. power producers through 2032.
Source: Siemens Energy models.

Figure 4 (right).
A Southeastern U.S. utility's forecast of high gas ramp-up hours as the amount of solar grows in years to come.
Source: Siemens Energy models.

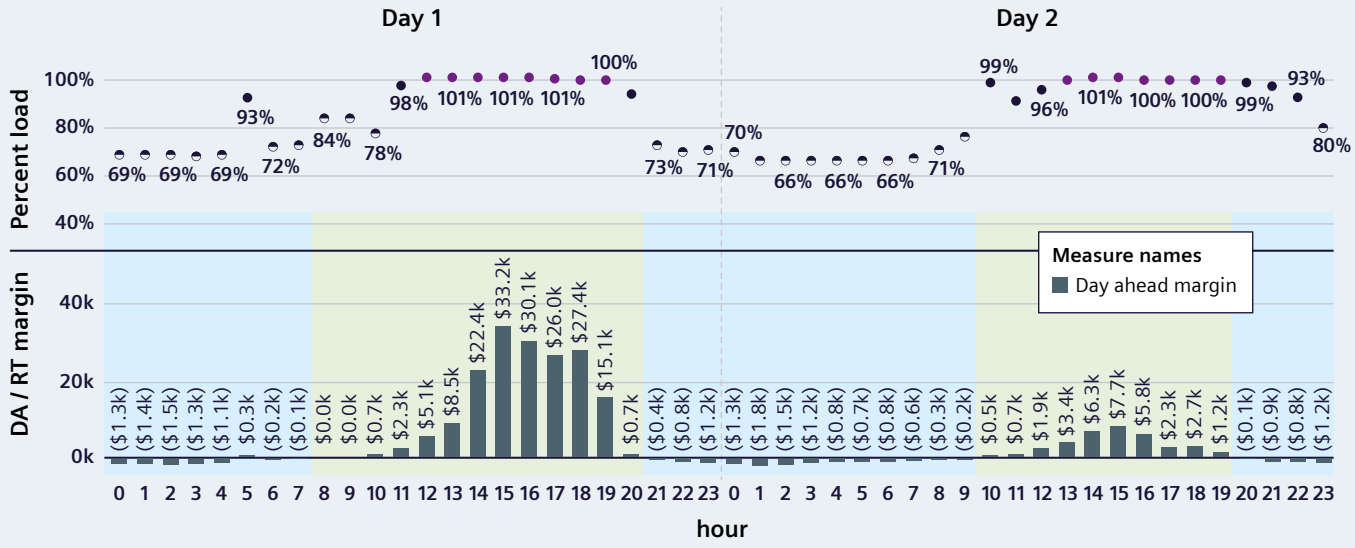


Figure 5. Hourly real-time and day-ahead margins of a large combined cycle Southcentral U.S. power plant plotted against its percent load, showing operating profit/loss durations.

Source: Siemens Energy models.

In deregulated power markets, plants are dispatched based on the offers they submit to the market and the demand of the market. Typically, the most profitable periods are now concentrated during the evening although weather temperature extremes can cause spikes in demand, which can offer additional profit opportunities.

As a result, CCPP operators may need to stay online during low-priced hours despite having negative margins so they can collect the offsetting and more profitable margins the market's higher priced periods offer. This operating model may create losses for the plant during hours when renewable overgeneration occurs and available prices for power are negligible.

One measure CCPP producers can implement to help reduce these potential losses and help increase margins is to lower their minimum capacities during unprofitable hours.

For example, as shown in *Figure 5*, a Southcentral CCPP runs at a 69% load during non-profitable hours and ramps up its power production to 100% during high-margin periods including sub-hourly peaks in the real time market.

If the plant could increase its CCPP operational flexibility, it could potentially reduce its load significantly during non-profitable hours instead of operating at a 69% load.

This strategy could help reduce the plant's costs and losses during low-demand hours while also helping it to capitalize on the higher profit margins available during peak-priced periods, potentially boosting daily earnings. Improved cost structures could increase the likelihood of flexible plants being called on days with marginal demand as well as potentially capturing higher prices during real-time market surges.

The growing role of ancillary services in grid stability and reliability

As the proportion of renewables grows in the North American energy resource mix, their inherent intermittency and resulting variability impacts grid stability and reliability as well as frequency control. In response, ISOs/RTOs are looking to ancillary services to better manage the grid during the transition to lower-carbon and net-zero resources.

ERCOT (Electric Reliability Council of Texas), for example, announced the ERCOT Contingency Reserve Service (ECRS) in June 2023. As a daily procured ancillary service supporting ERCOT's reliability-first model for grid operations, it is intended to address growing energy demands in Texas,

mitigating real-time operational issues to keep supply and demand balanced in order to help improve grid stability.[6]

According to ERCOT, ECRS provides "capacity that can respond within 10 minutes to address forecasting errors or to replace deployed reserves."[7] ECRS will backstop four other procured ancillary services ERCOT buys in the day-ahead market to balance the next day's forecasted supply and demand of grid electricity. The debut of ECRS could portend initiatives by other ISOs / RTOs to enhance the ancillary services they use to maintain grid stability and reliability. Overall, the energy transition is expected to drive substantial growth in the use of ancillary services across North America. The U.S. power ancillary service market – led by the Frequency Controlled Ancillary Services segment – is estimated to have been worth $6.1 billion in 2022, with a 6.14% compound annual growth rate through 2028.[8]



6 ERCOT Adds New Ancillary Service to Support Grid Reliability. June 12, 2023.
7 Ancillary Services. ERCOT. December 2023.
8 United States Power Ancillary Service Market. TechSci Research. January 2024.

From base to cycling operation models: fast, flexible operational concepts

Given the continued growth of renewables, today's need for operational flexibility will likely increase well into the future. Operators can help address these challenges by accelerating plant ramp rates to improve plant responsiveness to higher-margin pricing opportunities.

CCPPs that are either currently transitioning or anticipating a shift from base load to cyclical operation will likely need to adapt their generating assets to meet these evolving operational requirements. A detailed plant and process analysis, such as a **Technical Plant Assessment**, is the first step CCPP producers should consider. This in-depth, end-to-end evaluation of a producer's CCPP configuration, operations, and steam/water process can help identify, quantify, and prioritize improvement opportunities.

As illustrated in *Figure 6,* these improvement opportunities include increased power outputs and operating efficiencies, faster starts and shutdowns, improved load ramp gradient, low-load operation, and expanded operating ranges.

To help enable CCPP operators to put these capabilities to work, Siemens Energy has developed a portfolio of advanced flexible operational concepts based on our suites of Flex-Power Services™ and Omnivise Performance Solutions as shown in *Figure 7*.

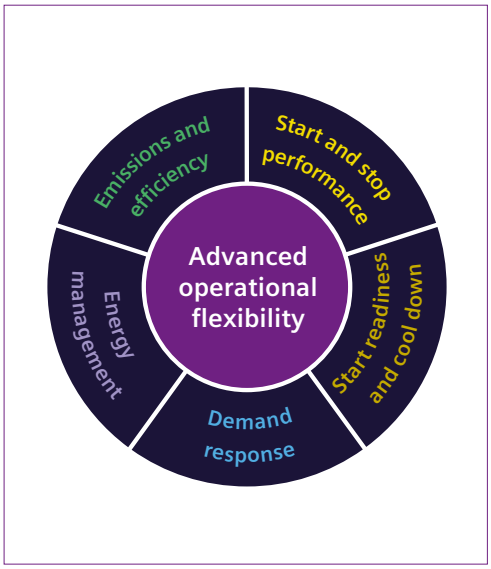


Figure 7. Advanced CCPP flexibility spans five key operating dimensions – all affecting asset utilization, compliance, margins, and profitability.

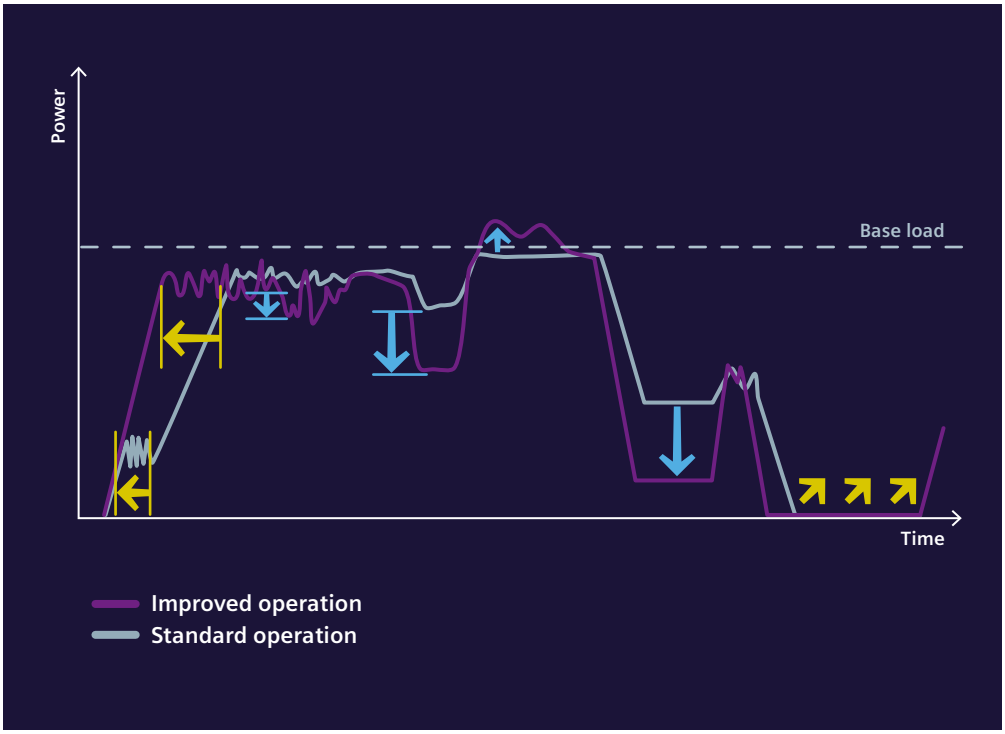


Figure 6. Potential for improved plant operational performance compared to standard plant operational performance after enhancements using Siemens Energy Flex-Power Services™ and Omnivise Performance Solutions.



These advanced flexible operational concepts could potentially result in faster dispatch times, reduced fuel consumption, and lower CO_2 emissions, while also enhancing the capability of CCPP operators to help maintain emission targets for both NOx and CO. These strategies have been successfully implemented by Siemens Energy in combined cycle power plants around the world, particularly in Europe.

Most of these concepts can be implemented via logic upgrades to the CCPP's control software while some may require modifications to plant and auxiliary equipment.

Operational flexibility improvement concepts

The transition from a CCPP base load operating model to a cycling operating model requires producers to consistently achieve fast, efficient, and reliable start-ups of their generating assets regardless of how long those assets have been offline. For this paper, hot, warm, and cold starts can be defined as follows:



Hot start:
Up to 8 hours post-shutdown.



Warm start:
Between 8- and 48-hours post-shutdown.



Cold start:
Between 48 hours post-shutdown and up to 2 weeks post-shutdown.

One core start-up improvement concept, for example, involves the parallel ramping of both gas and steam turbines. Consider the scenario of an overnight shutdown of a CCPP. The next day, parallel ramping may help reduce start-up times to approximately 30 minutes in some cases.

A *Low Load Turn Down* concept can help reduce the minimum part-load capability of the gas turbine. This can assist CCPP operators who seek to enhance the operating flexibility of their gas turbines even further, potentially improving response times to

grid demands and enabling combined cycle applications where part-load efficiency is desired. For example, when applied to an SGT6-5000F gas turbine, this concept may optimize and extend the part-load operation range by as much as 40%.

Plant optimization for hot starts: help reduce start-up times up to 50%

Plant start optimization for hot starts can help reduce CCPP hot and warm start times. Although most CCPPs were originally built as base load facilities, they now must often operate as peak load plants or cycling plants with frequent start-ups due to changing market conditions and fuel prices. This challenges their operators to achieve fast and predictable start-up times while maintaining high dispatch capability and in-market availability. By implementing this flexibility optimization concept CCPP operators can potentially reduce the cost of each hot start and further reduce CO_2 emissions. Additionally, with an improved start-up time producers can potentially generate additional revenue in times of high electricity prices.

The limitations affecting load output include pressure and temperature transients in the steam turbine, waiting times for establishing required steam chemistry conditions, and warm-up times for the steam turbine, balance of plant, and main piping systems.

One key modification is a start-up on the fly process for the CCPP's steam turbine. During this process, the turbine is rolled off with the very first "cold" steam produced in the heat recovery steam generator (HRSG), using full pressure and temperature transients. As a result, a start-up time of less than 50% may be possible for a CCPP after an overnight shutdown.

Figure 8 illustrates the potential improvement a parallel gas and steam turbine start-up process can provide compared to starting them sequentially. This procedure is a highly integrated orchestration of the gas and steam turbine and HRSG operations.

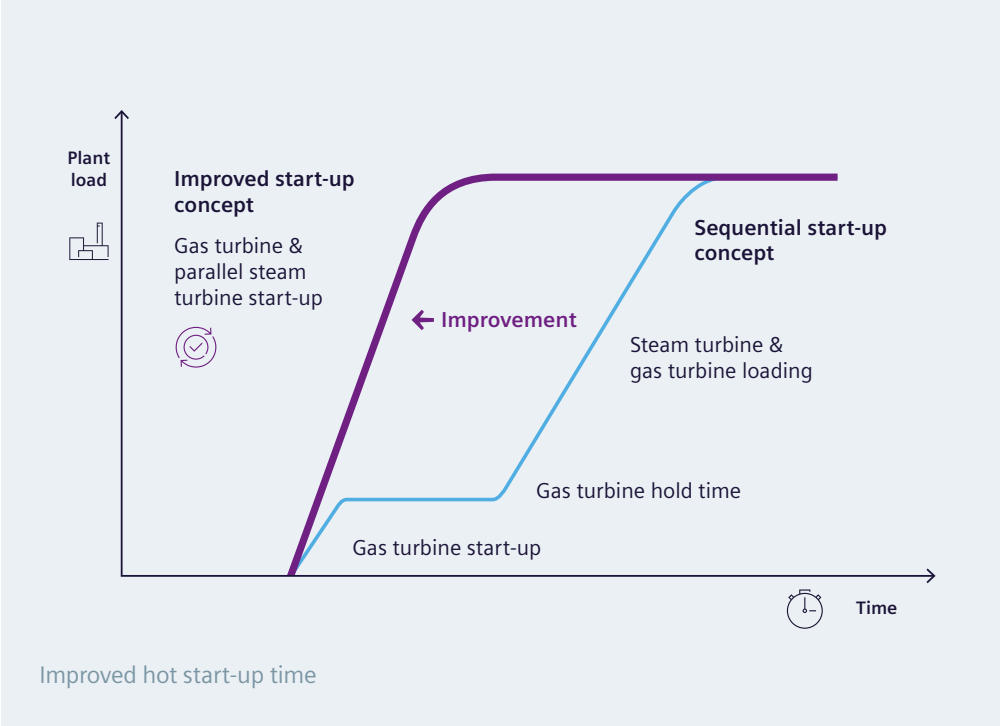


Figure 8. The hot-start concept using parallel gas and steam turbine start-ups can accelerate load ramping times by as much as 50%.

Plant optimization for warm starts: faster start-ups, lower fuel costs

Plant start optimization for warm starts uses many hot-start techniques to help reduce CCPP start-up times by up to 50% when the plant block is still warm. For instance, if the start-up time of a warm start at a SGT6-5000F GT can be reduced by 50 minutes, a CCPP operator can use the warm-start concept to potentially cut start-up fuel consumption by more than 800 MMBtus, saving fuel costs and potentially avoiding associated emissions of up to 44 tons of CO_2 per warm start.

The savings depend on the size and temperature of the gas turbine and can potentially increase responsiveness to transmission demand signals from ISOs/RTOs.

Figure 9 illustrates how the plant-start optimization concept can substantially improve CCPP start-up efficiency. This can significantly reduce combined cycle warm start-up times, in some cases to less than 60 minutes.

The potential for time reductions and efficiency improvements during start-ups can be fully tapped by implementing a fast start-up load gradient of up to 30MW per minute, although this load gradient can vary across different gas turbine frames.

Plant optimization for cold starts: more efficiency, less time to loading conditions

The ability to start-up a CCPP's turbine block much faster from longer shutdowns can make a difference in dispatch in competitive markets. During extended offline periods of several days or longer, the steam cycle will cool down, especially its high and intermediate pressure steam turbines.

Implementing a steam turbine hot standby method, such as using electrical heating blankets, to either prevent or limit this cooling can shorten start-up times during a shutdown phase of up to two weeks.



Figure 9. The load ramping speed of using the warm-start concept can be substantial.

If the plant was built without a gas-fired auxiliary steam boiler, an electrical auxiliary steam generator can be retrofitted. The electrical auxiliary steam generator's objective is to provide enough steam to seal the steam turbine and create a vacuum in the condenser before the gas turbine starts.

This helps allow early steam condenser bypass operation and helps avoid long low load operation times with the HRSG venting valves.

Keeping the steam turbine sealed and under vacuum also helps prevent air ingress, improve the feedwater quality, and minimize water-chemistry related hold times during the start.

This concept is intended to help:

- Increase responsiveness to transmission ISO / RTO demand signals.
- Shorten start-up time, in some cases up to 50%.
- Boost efficiency in the start-up process.

In addition, the degassed conductivity concept may shorten the start-up time of a combined cycle power plant – especially for cold starts as the waiting time for steam purity may be significantly reduced. This method controls the steam purity and distinguishes between the corrosive contaminants and less harmful CO_2 by re-boiling the sample downstream from the cation column to remove CO_2.

Fast plant shutdown optimization: saving fuel and CO_2

CCPP shutdowns can require considerable time and fuel for conducting the necessary unloading processes. In competitive markets, the ability to shut down a plant faster can help reduce time spent in transient conditions with non-optimal efficiencies and enhance responsiveness.

The *fast plant shutdown* concept was developed to significantly shorten a CCPP's shutdown time, in some cases to less than 30 minutes. As shown in *Figure 10*, the concept leads to less fuel consumption and potential improvements to both operating costs and profitability.

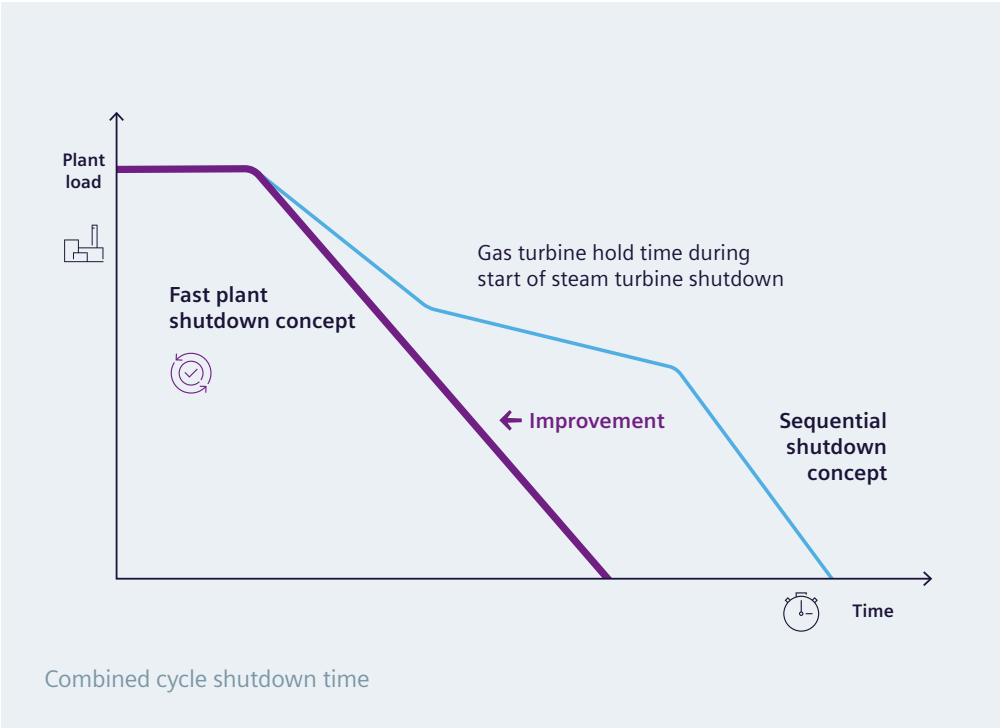


Figure 10. The fast plant shut down concept can shorten the time to less than 30 minutes in some cases, saving fuel costs while potentially improving profitability.

Summary: Flexibility with speed and reliability, key to better asset utilization and improved profitability

In the past decade, the operating profiles of CCPPs have significantly shifted due to the growth in renewables in producers' energy resource mix as well as volatile fuel prices and governmental legislation. The impact of these trends on the current and future operations and profitability of typical CCPPs necessitate a shift from outdated base load to cyclical operation.

CCPP flexibility and responsiveness to market signals are critical to sustainable margins and profits. To help achieve these capabilities and prepare their CCPPs for current and upcoming market conditions, operators can implement fast start-up concepts across hot, warm, and cold turbine conditions along with fast shut-downs and load gradient improvements to potentially improve their competitiveness, asset utilization, and profitability.

To that end, Siemens Energy **Advanced Operational Flexibility** solutions based on Flex-Power Services™ and Omnivise Performance have been developed to help CCPP operators address operational flexibility. Implementation of plant-specific recommendations including the flexible CCPP operating concepts can result in plant capabilities that can successfully meet the challenges of North American power markets today and far into the future.



Authors:
Matthias Nickl, Thorsten Wolf, Robert Hostetler,
Nicola Erhard-Winterberg, David Fernandes,
Cristina Becle

Published by

Siemens Energy Global GmbH & Co. KG
Siemenspromenade 9
91058 Erlangen
Germany

For the U.S. published by

Siemens Energy, Inc
4400 N AlafayaTrail
Orlando, FL 32826
USA

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

This publication is provided for informational purposes only and you should not construe any information presented as legal, tax, investment, financial, or other professional advice. The content is of a general nature and does not address the specific circumstances of any particular market, event, application or installation, nor does it constitute a comprehensive or complete statement of the matters discussed or the laws relating thereto. Any information about Siemens Energy products and services is subject to change without notice. Expected capabilities or benefits may not apply in specific applications or be realized in all cases. Nothing in this document shall be deemed or construed to be a warranty or guarantee of the information, product(s), service(s) or method(s) described herein.

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.