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GE's next generation CCGT plants: operational flexibility is the key

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Modern Power Systems

COMMUNICATING POWER TECHNOLOGY WORLDWIDE

FlexEfficiency* 50: a combined cycle plant designed to increase renewables uptake

Wallchart in this issue

GE's next generation CCGT plants: operational flexibility is the key

As the name suggests GE's new FlexEfficiency combined cycle technology (see also wallchart in this issue) aims to couple unprecedented operational flexibility with extremely high efficiency (over 61%).*

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When they first appeared on the electric power generation scene more than three decades ago, large-scale gas turbine combined cycle power plants were intended as baseload units to replace ageing coal-fired units. With the introduction of F-class gas turbines, their thermal efficiency percentage rapidly reached the high 50s and pushed towards the 60% level via ever-increasing firing temperatures. This, coupled with relatively low natural gas prices and the favourable emission characteristics relative to other fossil fuels, largely ensured that, at least until recently, they maintained their baseload role. Today, however, large fluctuations in natural gas prices, liberalisation of the electricity markets and increasing adoption of renewables (wind and solar in particular) – with their intermittency and unpredictability – have significantly changed the operating duties required of combined cycle power plants. In particular, modern day combined cycle power plants are primarily operated cyclically, at varying load factors with fairly large numbers of shut-downs and start-ups. Therefore, in addition to having a respectable baseload performance rating, the following operability features are imperative for a competitive combined cycle offering:

- Fast start after overnight and/or weekend shut-downs with high starting reliability and good equipment life, with low start-up emissions.
- Ability to run at low loads within applicable emissions regulations.
- Fast load ramping (or start from standstill) upon demand and at short notice, exploiting unforeseen market opportunities (such as loss of load caused by renewable units going unexpectedly off-line).

A combined cycle power plant that offers all of these features provides the owner/operator with the flexibility to make money under a wide range of scenarios while minimising risk and life cycle costs.

GE's FlexEfficiency* 50 combined cycle plant

GE achieves operational flexibility for combined cycle power plants based on advanced F-Class gas turbines by adopting a total system perspective in the design of equipment and control system (Figure 1). GE's next generation of 50 Hz combined cycle product, the FlexEfficiency* 50 plant, is based on the latest advanced versions of the following well-proven equipment:

- 1500°C firing class (turbine stator inlet temp) air-cooled 9FB gas turbine with:
  - 14-stage compressor (pressure ratio of 20) with variable stator vanes;
  - DLN 2.6+ dual-fuel combustor; and
  - four-stage hot gas path (ie four-stage power turbine) with advanced materials and coatings.
- Three-pressure, reheat (3PRH) steam cycle with advanced steam conditions (capable of up to 165 bar/600°C/600°C).
- Three casing D14 steam turbine design incorporating HEAT™ technology with double-flow low pressure section and side exhaust (rated at 180 MW).
- Water-cooled W28 generator (550 MW).

The turbomachinery is arranged in a single-shaft configuration with a synchronous self-shifting SSS clutch separating the steam turbine from the generator in the middle.

First introduced by GE in 1968, the single-shaft design has been generally accepted as the preferred configuration due to its simplicity in terms of control and operation, lower capital costs, and high reliability.

The FlexEfficiency* 50's system-optimised combined cycle platform, with its combination of prime movers and drum-type heat recovery steam generator (HRSG), is capable of 510 MW output and more than 61% net thermal efficiency at ISO baseload.

In addition to exceptional performance at baseload, the new FlexEfficiency* 50 plant also offers the following operability features:

- GE's patented Rapid Response (RR) design allowing (from a hot start following overnight shut-down):
  - gas turbine emissions compliance in 10 minutes;
  - gas turbine and combined cycle to full load in less than 30 minutes;
- Emissions compliance down to 40% combined cycle load.
- Fast load ramps at 10% of the combined output per minute, while maintaining emissions guarantees.
- Ability to meet the most stringent grid code requirements (UK and Europe).
- Fuel flexibility (±10% MWI (Modified Wobbe Index) range, natural gas down to 75% methane content).

The combination of the superior operability features listed above, plus more than 61% baseload and high part-load efficiencies (over 60% down to 87% of baseload) are reflected in what GE calls the **FlexEfficiency rating** (essentially a measure of what might be called "effective plant efficiency"). FlexEfficiency is defined as the ratio of profitable MWh to fuel consumption across the entire operation spectrum during a year. For typical cycling-duty combined cycle plants, the annual operating profile entails more than 200 starts and a mix of baseload, part load and minimum turndown hours. When averaged over the year, including seasonal ambient variation and other factors, this corresponds to an effective load factor of 70% to 80% (and a FlexEfficiency in the mid 50s, in percentage terms).

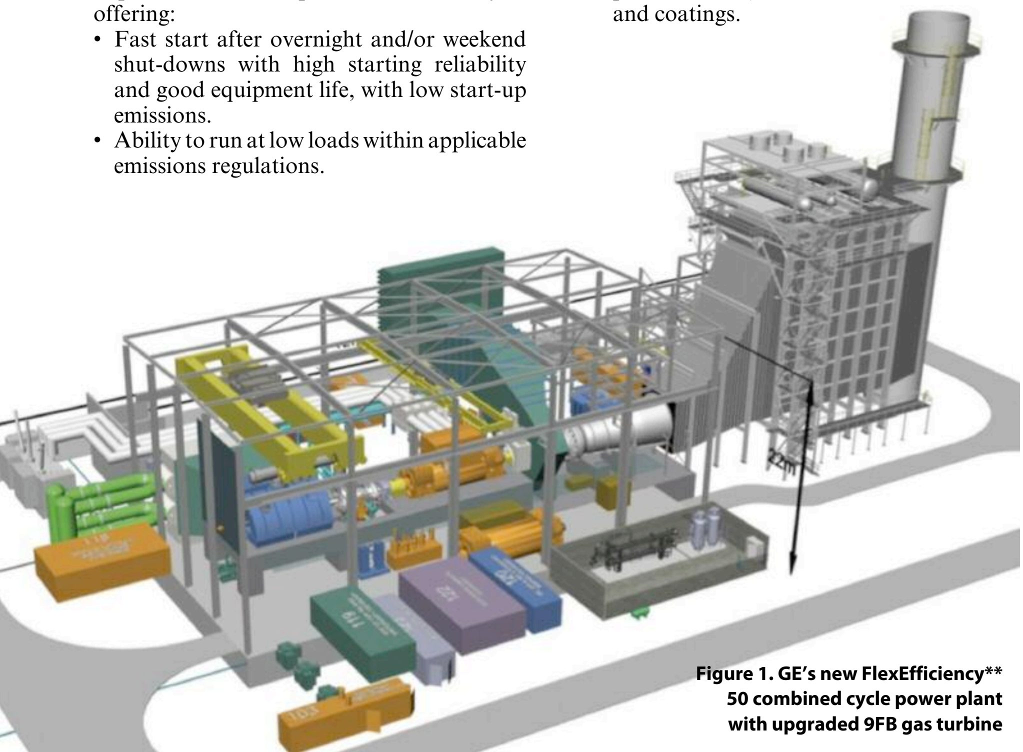
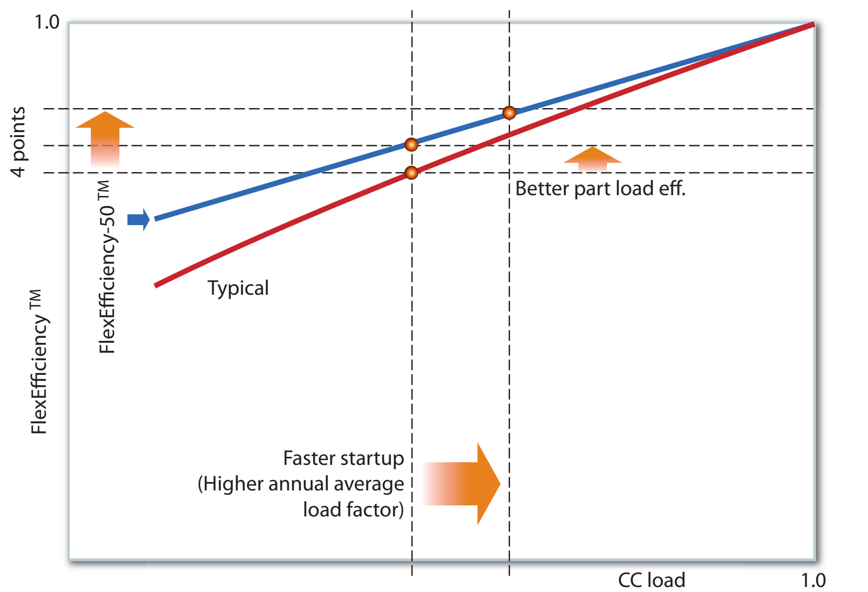


Figure 1. GE's new FlexEfficiency 50 combined cycle power plant with upgraded 9FB gas turbine**

Figure 2. Conceptual (normalised) part load FlexEfficiency curve. In addition to its exceptional baseload efficiency of 61%, the FlexEfficiency* 50 plant improves average (effective) efficiency over the entire operating envelope via its better lapse (>60% down to 87% of the baseload) and faster start capability (higher load factor and reduced fuel consumption)



The improvement in FlexEfficiency, thanks to better part load efficiency and faster start features of the FlexEfficiency* 50 plant, can be conceptually seen in Figure 2. While actual results depend on site ambient and loading characteristics, customer-specific modifications such as hot-day power augmentation and other factors, a four percentage point improvement in FlexEfficiency is expected in a typical case.

Operational flexibility

A key design philosophy of the FlexEfficiency* 50 plant is what is called Rapid Response technology, which decouples the gas turbine and steam turbine start-up and loading sequences. Another feature is making full use of "purge credit", which shifts HRSG purging (about 15 minutes duration) from start-up to plant shut-down.

In particular, with Rapid Response, the gas turbine is rolled up to full-speed no-load (FSNL), synchronised to the grid and loaded to full load in simple cycle mode while the steam turbine is on turning gear (separated from the gas turbine and the generator by the SSS clutch) and the steam generated in the HRSG is bypassed to the condenser. When suitable temperatures are reached, the steam turbine is brought up to speed and loaded at the highest possible rate within the thermal stress limits.

The start-up of the steam bottoming cycle (HRSG and steam turbine) dictates the overall plant start-up time depending on the length of the plant off time. Gas turbine start-up time (in a simple cycle mode) is not usually affected by the length of time the plant was not in operation. In general, start-ups after shut-down periods greater than eight and 72 hours are referred to as warm and cold starts, respectively. With Rapid Response the plant is capable of one-hour warm starts from around the mid-point of the warm period, and two-hour cold starts.

The FlexEfficiency* 50 plant also introduces two other new start options, **Smart Start** (SS) and **Smart Start Lite** (SS-Lite), as well as the conventional start technology. Both new start options are variants of the Rapid Response technology. Smart Start is optimised for low fuel consumption with low emissions for hot, warm and cold starts, in which the gas turbine is rapidly loaded at simple cycle rates to a moderate load to facilitate quick steam turbine acceleration and loading. Smart Start Lite is intended for highly cycled power plants, with daily shut-down and hot starts. Due to the limited cooling of the steam turbine during an overnight shut-down, the terminal attemperation system is not needed and therefore not supplied, for reduced capital cost.

All GE plants, even when equipped with Rapid Response technology, are capable of starting in the conventional manner, where the gas turbine operates at low load to control the steam temperatures via exhaust gas temperature modulation. This provides a means of backup starting in the event that equipment such as the terminal attemperators or backup feed and condensate pumps are temporarily unavailable. Purge credit is also available for all start-up options.

A comparison of the Rapid Response and Smart Start technologies with the conventional method in hot start-up mode is shown in Figure 3. The advantage of Rapid Response over the conventional start-up sequence is represented by the lower amount of time spent at low loads, which translates into higher average load factor and efficiency, ie, less fuel burned and pollutants emitted, during the start-up.

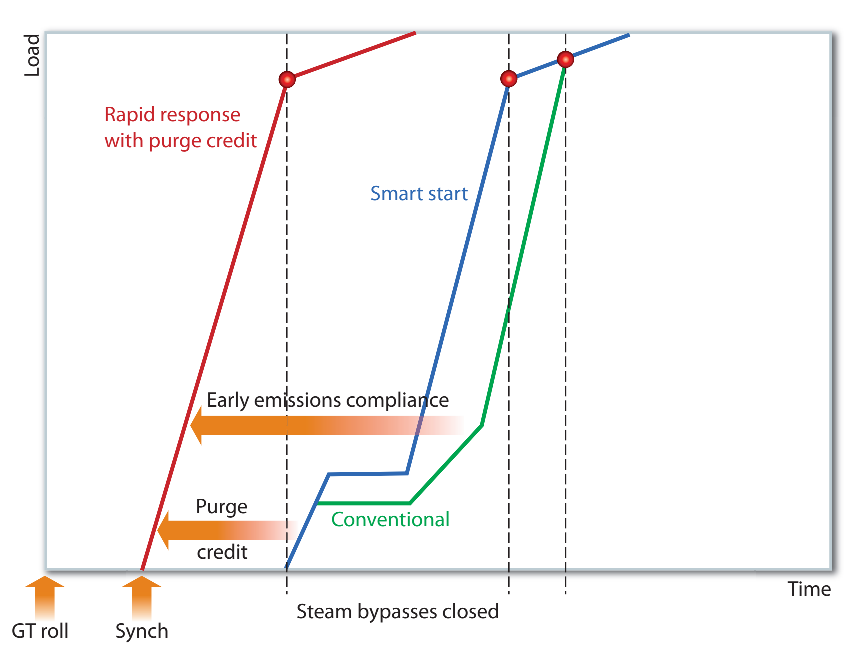
For the Rapid Response start-up shown in Figure 3, about 15% less fuel is consumed during the time required to bring the plant to full load (about 30 minutes) relative to the conventional start, which is about twice as long. This reduction in fuel consumption is accompanied by a concomitant reduction in CO_2, NO_x and CO emissions. All these factors have a direct and favourable impact on combined cycle start costs, with reduced overall life-cycle costs as well as improved dispatch ranking, with more money making opportunities for the plant owner/operator.

The benefit of decoupling gas turbine and steam turbine starts and evading the lengthy steam turbine temperature matching process is readily recognisable. The challenge is how to achieve it without compromising the plant performance, RAM and life cycle cost.

Standard and optional combined cycle power plant design features allowing fast start capability are summarised in Table 1.

As stated earlier, terminal attemperators are not needed if the plant is intended for highly cyclic operation and the customer chooses to forgo the additional capital expenditure while still retaining lower emissions and fuel consumption benefits of the SS-Lite

Figure 3. Comparison of Rapid Response and conventional hot start (overnight shut-down). The conventional hot start is characterised by HRSG purge (no purge credit) and steam turbine temperature matching at spinning reserve with conventional gas turbine exhaust temperature adjustment



technology. If the plant is intended for baseload service or there is a suitable auxiliary steam source already available, the auxiliary boiler can be omitted as well. With the associated infrequent starts, the gas turbine can be loaded to spinning reserve and the HRSG used as the steam source for the steam turbine seals until the condenser vacuum requisite for bypass operation is reached. At this point, the gas turbine is ramped to full load in the conventional start mode. This type of start can also be employed when the auxiliary boiler is out of service.

In addition to the plant-related items listed in Table 1, the following gas turbine-centric design features are key enablers for reduced start times:

- **LCI Pre-Connect:** establish and maintain starting means in engaged state.
- **Fire-On-The-Fly:** Successful ignition and crossfire during acceleration ramp without the need for the traditional warm up period.
- **Closed-Loop Acceleration Control:** Reduce acceleration variability due to seasonal ambient variation by balancing LCI torque and gas turbine fuel schedule from the turning gear to FSNL.
- **Fast Grid Synchronisation:** Advanced control system optimised for faster and consistent synchronisation to the grid.

A key requirement for combined cycle power plants is the ability to respond to fluctuations in grid frequency to preserve the delicate system balance, especially during large disturbances. Detailed requirements are codified in the grid codes of each country and/or group of countries (eg, the European Union). The plant with Rapid Response features is designed to satisfy the UK and EU grid code requirements. The system response to an over-frequency event is straightforward: reduce plant load. The system response to an under-frequency event is primarily achieved by drawing upon the significant reserve power inherent in the gas turbine by rapid opening of the compressor inlet guide vanes, starting the water wash system, increased firing and/or a combination thereof.

Reliability

The key to the full realisation of the life-cycle cost benefits offered by the superior performance and operability features of the FlexEfficiency* 50 combined cycle plant is the systematic approach to running reliability, starting reliability, and availability.

The Integrated Control System (ICS) is designed to meet the fast transient requirements of modern combined cycle power plants while providing high commercial availability and reliable start-up profiles. The heart of the ICS is the GE Mark VIe system, using digital fieldbus technology with an advanced application layer, building on Model Based Control (MBC) applications and including One Button Start capability.

As the communication protocols are digital and connections are easily distributed, field wiring is reduced by over 50%. This also allows pre-site assembly of most motor control cabinets and process control panels.

In addition, the MBC methodology significantly enhances control of the turbines and plant interactions as it “replicates and models” the true operating condition from real-time GE engineering models and available sensors, at the same time correcting for unique equipment variation and transients. MBC further enables prediction of equipment capability for more intelligent bid and dispatch decisions, such as supporting more accurate maintenance schedules and reducing lifecycle cost.

Reliable operation in highly cyclic missions with many starts and low hours per start requires equipment design for long life and maintainability. The turbine section of the new 9FB achieves that via a combination of proven GE materials and coating technology, double-shell design for better thermal gradient management, and adoption of selected aircraft engine technologies (eg, in rotor sealing).

The combustion, hot gas path, and major inspection intervals for the new 9FB gas turbine are planned to achieve up to 40% more starts compared with the existing 9FB gas turbine. Rotor life is the equivalent of four full hot gas path inspection intervals based on 20 operating hours per start, which is over 50% more than the industry norm for cyclic missions.

Steam turbine thermal stress control during start-ups, which is embedded in the ICS, is a vital feature of the FlexEfficiency* 50 plant. Of equal importance is the HRSG design and the achievement of thermal stress management commensurate with the highly cyclic operational profiles. GE has collaborated with HRSG suppliers to engineer designs optimised to meet the demands of FlexEfficiency* 50 plant operational flexibility. HRSG design features include:

- Full penetration tube to header welds in the high pressure (HP) superheater and reheater sections (detailed transient analysis has shown these hottest sections incur the majority of fatigue life consumption during fast gas turbine loading).
- Reduced drum nozzle stresses, utilising techniques such as elongation of drums and use of higher grade steels.
- Use of multiple, smaller, drum penetrations for evaporator risers and downcomers.

The FlexEfficiency* 50 plant base offering is a drum-type HRSG designed to ASME standards (with an HRSG designed to EN standards also available), the HP drum providing the storage volume necessary for successful start of the back-up boiler feed water pump in the event of an on line pump failure.

In order to achieve the high reliability and availability described above, the FlexEfficiency* 50 plant will undergo individual component, subsystem and unit validation tests in the new test facility in GE’s Greenville, SC, manufacturing plant. This new test facility, equipped with advanced control and data acquisition technologies, is the largest of its kind in the world and provides full-speed full-load (FSFL) gas turbine test capability including variable speed operation with gas and liquid fuels. Following the validation of GE’s new 7FA compressor and gas turbine, currently underway at the test facility, the new 9FB gas turbine, which uses a scaled-up version of the new 7FA compressor, will undergo extensive mapping and load testing on the test facility, leveraging the results from the 7FA compressor validation programme.

A platform for all seasons

Summarising, GE’s new FlexEfficiency* 50 plant offers exceptional baseload thermal performance, capability to run at low loads while emissions-compliant and ability to start in the shortest possible time to reach baseload while burning less fuel and limiting emissions. As such, it offers the owner multiple ways of making money and the flexibility to choose between them as dictated by the prevailing market conditions:

- Low start and life cycle costs for improved profit during normal (scheduled) operation.
- Additional income and profit from ancillary market services such as ten-minute spinning (or synchronous) or thirty minute (or supplemental) reserve power.
- Ability to participate in day-ahead or real-time hourly markets to exploit unforeseen opportunities

The economic life of a power plant is 15 to 20 years with the actual life often longer. It is difficult to foresee how combined cycle plants commissioned today will be operated five or ten years from now. It is even possible that they could return to baseload operation. Whatever the case may be, the new FlexEfficiency* 50 is designed to be a reliable and profitable electric power generation platform for all seasons. MPS

Table 1. Fast start plant features

Feature	Function	Standard/ optional
Purge credit	HRSG purge conducted after shut-down in compliance with NFPA-85	Optional
Steam turbine stress controller	Loading steam turbine at the highest rate by operating at the thermal stress limits	Standard
Terminal attemperators in main and reheat steam lines	Separating gas turbine operation from the bottoming-cycle	Optional
Modified unit controls	Enable maximal gas turbine load ramp	Standard
Auxiliary boiler	Establishing steam seals and condenser sparging prior to start-up	Standard
HRSG stack damper	Reduces heat loss from HRSG during shut-down	Standard
Mechanical vacuum pumps (for water cooled condenser)	To improve steam quality by keeping condenser in vacuum conditions during shut-down	Standard
Automatic drain/vent system	Reduces pipe warming duration during start-up	Standard