Fast Cycling Capability for New Plants and Upgrade Opportunities

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1 Introduction

Increasing demand for electricity, replacement of ageing plants and ongoing liberalization characterize the Asian power market. The customer focus is the optimization of life-cycle-cost (LCC) driven by features like

- High efficiency, high power output and operational flexibility.

The Siemens Reference Power Plant (RPP) development takes that into account and uses LCC models for the optimization of plant concepts. Additionally, customer feedback and experiences from units in construction and operation are considered in the RPP development and lead to a continuous improvement of the products.

In current research and development projects for combined cycle plants, major improvements regarding operational flexibility could be reached. Focus was on start-up time after overnight shutdown because market analyzes showed that many customers operate their plants two shifts weekdays and perform up to 200 starts/ year after overnight shutdown (approx. eight hours standstill). Experts from steam turbine (ST), gas turbine (GT), balance of plant (BoP) including I&C systems and heat recovery steam generator (HRSG) identified bottlenecks and potentials for improvement. These analyzes were basis for a modified start-up procedure which allows a significant reduction of start-up time after overnight shutdown compared to a state of the art start-up procedure. The steam turbine start-up is modified to enable an early roll-off and fast loading of the turbine. An improved GT control ensures usage of maximal possible load ramps over a wide operating range. To minimize HRSG lifetime consumption, a BENSON® once through system developed by Siemens Power Generation (PG) is implemented in the HP pressure stage. This boiler design does not limit the GT load ramp. Optimized unit coordination logic brings together all improvements on component side and ensures a fast start-up with a "one-push-button" control. Siemens PG as an OEM and turnkey supplier has a detailed knowledge about components' performances and plant operation. Only with this knowledge, the improvement in operational behavior described in this paper can be achieved.

A fast start-up plant gives plant owner business opportunities like utilizing hourly and seasonal market arbitrage, participation in ancillary energy markets or peak shaving. These factors can be implemented in an economic evaluation model and improve the economic benefit of a project.

This paper gives an overview about recent improvements with respect to operational flexibility, the technical features of a cycling plant and it shows an approach for economic evaluation of flexibility.

2 Market environment

Looking at the development of the power sector in Asia, two effects can be identified: A growing demand for electricity and an ongoing liberalization of the market (Figure 1).

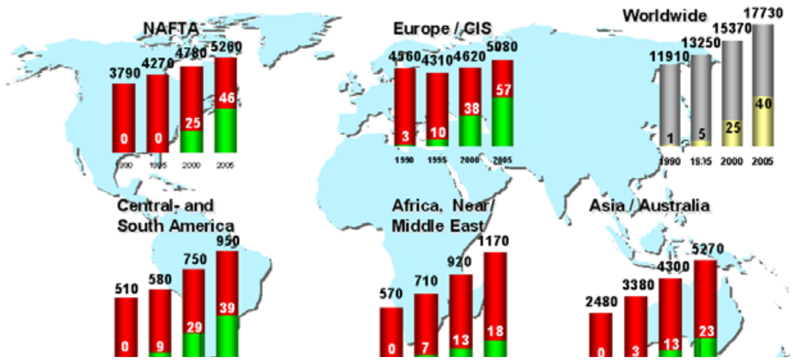

Figure 1: *Deregulated markets:*
Power production [TWh], Share of deregulation [%]

New capacities are added as well as ageing plants have to be replaced. These new power plants must cope with the challenges of liberalized and deregulated markets. Further on, the compliance with increasing environmental requirements is a challenge for new projects. In this business environment combined cycle power plants are favored over steam power plants because of their shorter pay-back periods, advantageous emission levels and excellent operational flexibility.

Looking closer to the requirements of a power plant in modern power markets, operational flexibility becomes a major topic. Drivers for this demand are risks like fluctuating fuel and electricity prices. Additionally a flexible plant opens up new business opportunities like utilizing hourly and seasonal market arbitrage, participation in ancillary energy markets or peak shaving (Figure 2).

Economic Risks:
- Fluctuating fuel prices
- Changing fuel qualities
- Unsure fuel availability
- Fluctuating el. Prices (daily)
- Seasonal load/price variations
- Dispatch rank (over life time)

Business opportunities:
- Ancillary (grid) services
- Peak shaving
- Optimized plant operation
- Optimized outage schedules

Plant Flexibility helps to overcome economic risks and opens up new business opportunities

Figure 2: *Risk and opportunities in liberalized markets*

An operating profile optimized for this market circumstances increases the economic value of the plant. Depending on seasonal load and the dispatch rank of the plant, driven by competition and fuel prices, it is likely that the plant will be partly operated as baseload unit and partly as cycling unit over its lifetime. Therefore a plant needs advanced cycling capability and highest efficiency at baseload. Siemens RPPs are developed to meet these market requirements. They show excellent operational flexibility and highest efficiency.

3 Current Cycling Plant Design

Combined cycle power plants dominate the world wide power markets since years. Most of these plants were initially designed for baseload operation due to low fuel prices in the 90ties resulting in low electricity costs. Nowadays, many operating combined cycle plants are shifted to intermediate load and new plants are specified for cycling load regimes because of today's high gas prices. Therefore features for high operational flexibility like short start-up and shutdown times are emphasized by customers. Also the focus of Siemens Reference Power Plant development changed according to these market requirements. In the past, the RPPs were designed for baseload operation with a low number of starts per year. Start-up time for a 400 MW single shaft plant after overnight shutdown (approx. eight hours) was 90 minutes. As an answer to the changed market requirements, Siemens developed a fast start-up concept and implemented it into the RPPs. With this design, a reduction of the single shaft start-up time after overnight shutdown of approx. 50% is achieved. Additionally, the start-up times after a weekend outage (64 h) and an extended outage (>120 h) were also significant reduced. A comparison of the start-up times for a baseload plant designed end of the nineties with a state of the art cycling plant are given in Figure 3.

	Baseload Plant 1990ties	SCC5-4000F Cycling plant
Hot start (8 h)	90 min	45-55 min
Warm start (64 h)	200 min	120 min
Cold start (>120 h)	250 min	150 min

Values for RPP design conditions, excluding waiting for steam purity
All data for information only

Figure 3: *Comparison of start-up times*

To achieve that cycling capability, some modifications in the plant are necessary. The features of a power plant optimized for cycling operation are explained here for the single shaft SCC5-4000F 1S. This RPP consists of a SGT5-4000F gas turbine, a SGen5-2000H hydrogen cooled generator and a SST5-3000 steam turbine. The components are arranged on one shaft with the generator in the middle. The steam turbine is connected through a SSS clutch to the generator. This self shifting and synchronizing clutch allows a GT start-up independent from the ST. This enables an easy start-up and highest operating flexibility. The SGT5-4000F exhaust gas is led to a BENSON once-through HRSG.

Target of the development of a cycling plant was to ensure highest operating flexibility without baseload disadvantages. The plant has an output of 407 $MW_{net,\ iso}$, and 57.7$\%_{net,\ iso}$ efficiency.

As shown in Figure 4, the cycling capability improvements incorporate the whole plant. Major additional/ respectively changed components compared to a baseload plant are:

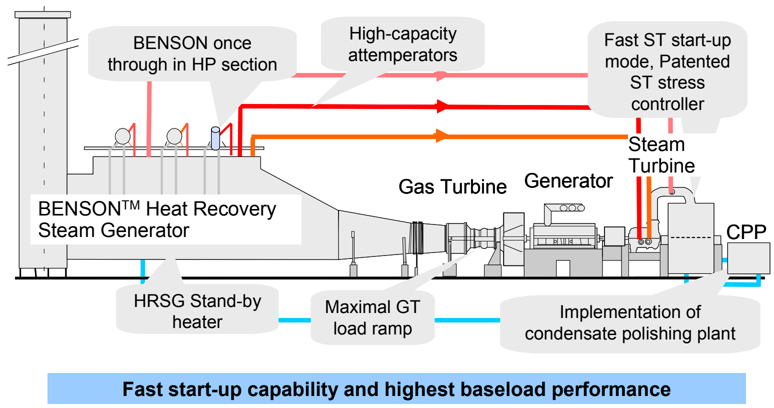

Figure 4: *Features of a cycling plant*

- BENSON HRSG with evaporator steam sparging, stack damper, optimized superheater outlet header and manifold design. This HRSG design eliminates the thick wall HP drum and allows an unrestricted gas turbine start up. The implementation of a drum type boiler is also possible, but leads to increased start-up times or high lifetime consumption.
- Condensate polishing plant to eliminate the waiting time for steam purity and to fulfill the chemistry requirements of the BENSON HRSG.
- Improved steam turbine start-up sequence incorporating the turbine stress controller for fast, load orientated start-up.
- Two stage high capacity attemperators in high pressure and hot reheat steam lines to adjust steam temperature to ST requirements.
- Modified unit control to take advantages of maximal GT load ramp.
- Auxiliary boiler providing low pressure steam used for HRSG evaporator steam sparking and ST seal steam supply.
- High level of automation including fully automated drains and vents that allows fast and reliable start-up without operator interferences.

- Mechanical vacuum pumps instead of steam air ejectors which evacuate the condenser before GT start-up and keep it evacuated during plant stand still.

First plants with these fast start-up features and a drum type boiler are already in commercial operation. A start-up time of 60 minutes for overnight shutdown is achieved. Further units, with BENSON HRSG and drum type HRSG, are under construction at present.

The mentioned features are also implemented in other Siemens RPPs, for example in the multi shafts SCC5-4000F 2x1 or SCC6-5000F 2x1. Further on, it is possible to implement the start-up improvements in tailor made plants or – as a plant specific upgrade package – in existing units.

4 Current Developments for increased Operational Flexibility

The RPP design explained in chapter 3 means a significant improvement of operational flexibility for combined cycle plants. But driven by high competition in liberalized markets (chapter 1), customers ask for further enhancement. Thus, Siemens continues its flexibility R&D projects which emphasis the improvement of hot start capability (eight hours overnight shutdown). The design base for these flexibility projects is summarized in Table 1.

Definition of start-up time	From GT ignition to gas turbine at baseload and HP/ IP steam-bypasses closed
Definition of shut-down time	From initiation of shutdown from base load to flame-off signal of gas turbine
Duration of an overnight shutdown	8-16h
Duration of a weekend shutdown	16-64h
Duration of a prolonged shutdown	>64h
Number of starts after overnight shutdown	200 starts/a
Number of starts after weekend shutdown	50 starts/a
Number of starts after extended shutdown	2 starts/a

Table 1: *Definitions and assumption for Siemens Reference Power Plant*

The start-up incorporates all plant components like gas turbine, steam turbine, HRSG, I&C systems and further BoP components. The authors company looked closely at the start-up process with a team consisting of experts from every involved system to identify the bottle necks, the potential for improvement and to address necessary research and development efforts. These efforts result in an improved start-up procedure. First site testing shows that the modified concept can reduce the start-up time significant. Further development steps are already identified and mid term target is a start-up time well below 40 minutes for a hot starts of a 400 MW single shaft plant. This chapter describes the improvements of the respective plant components.

Focus of the work is not only new plants but also the retrofit and upgrade of existing plants. For an upgrade, Siemens PG analyzes the potential of the plant (e.g. allowable stress in HRSG and ST, GT load ramps, etc.) and offers customers an upgrade package. This will mainly consist of plant control modifications and can be implemented during a regular plant outage.

4.1 Improved Plant Control Concept

Nowadays, Siemens PG uses a sequential start-up procedure. It was optimized in the last years and the already mentioned start-up time of 45 to 55 minutes for 400 MW single shaft hot starts can be achieved with this concept. The sequential plant start-up is performed in the following way: The GT is accelerated, synchronized to the grid and loaded to inlet guide vane (IGV) load. The exhaust gas is lead through the HRSG (no bypass stack) and steam production is dumped directly to the condenser through full capacity bypass stations. At IGV load the ST and steam piping are warmed up as well as steam quality is adjusted to ST requirements. When all preconditions are fulfilled, ST is accelerated, it synchronizes automatically with the SSS clutch and steam is taken over until the bypass stations are closed (operation in fix pressure mode). GT loads up to full load and ST follows with increasing steam production. At higher loads ST operates in sliding pressure mode.

For further start-up time reduction, a change in the start-up philosophy is necessary (Figure 5).

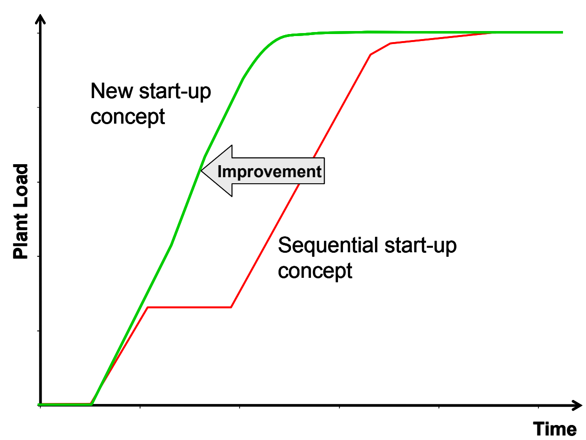

Figure 5: *Comparison of start-up concepts (after overnight outage)*

The new start-up concept bases on a parallel start-up. After synchronization to the grid, the GT is loaded continuously with its maximal allowable load ramp to baseload. Exhaust gas is led through the HRSG. With the first steam produced in the HRSG, the ST is accelerated and loaded. No waiting time for steam purity is necessary due to implementation of a condensate polishing plant. This procedure leads to a start-up time well below 40 minutes. An ambitious control concept for the water-steam cycle and the steam turbine, based on the long lasting experience from Siemens as OEM and turnkey supplier, is currently under development. Commercialization of this new concept is scheduled for September 2005.

4.2 Steam Turbine Operational Improvements

Looking at potentials for start-up time reduction, improvements of the steam turbine operation are fundamental. Currently, the warm-up of the turbine and turbine vales, the waiting for steam quality, turbine acceleration to nominal speed and steam take over is done sequential and takes about 50% of the plant start-up time. An improvement of operational flexibility and start-up behavior would be achieved if the sequential procedure could be done – at least partly – parallel. A first step was a modification of the warm-up procedure. The ST needs steam temperatures a certain value above metal temperature. The exact value depends on the outage time. A longer outage leads to lower ST temperatures. The steam temperature can be adjusted through the adjustment of the GT exhaust temperature – through variation of the GT load – as done often in baseload plants. For cycling plants, this is not acceptable due to the obvious limitations in operational flexibility and the high GT emissions in part load. Therefore, the adjustment in cycling plants is done through two stage high capacity desuperheaters that allow a temperature reduction to ST requirements even at GT baseload.

Bringing forward the idea of a parallel start-up to the whole ST start-up process leads to the concept as it is described in 4.1. The GT ramps-up without any limitation from the ST and ST starts as soon as the steam production starts. This solution uses an advanced control concept which does not need steady state starting conditions but applies ST start and loading during the GT load is ramped up continuously.

First plant tests with a combined cycle power plant SCC5-4000F 1S has shown the feasibility of this enhanced start-up sequence for a hot start after eight hours plant shutdown.

4.3 Improvement of HRSG

The requirements for two shift operation with a high number of starts, short start-up and shutdown times, high plant efficiency, high starting reliability and power availability means a challenge for the HRSG design. In a three pressure reheat drum type boiler the thick wall components in the HP part of the boiler (e.g. HP drum) limit the allowable temperature and pressure gradients during start-up. The slow heat soak of these components limit the potential GT ramp rates or high stresses resulting in high HRSG life time consumption has to be accepted.

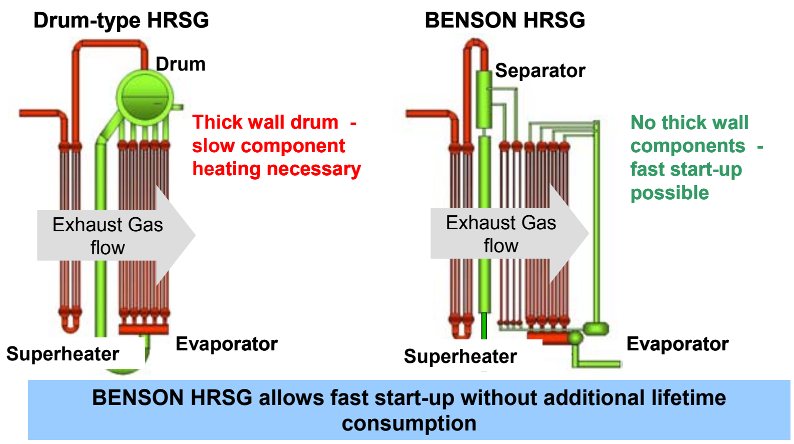

Figure 6: *Comparison Drum type and BENSON® HRSG*

To allow a maximum of design and operational flexibility Siemens has developed a unique once through design for HRSG's (OTSG) with horizontal exhaust gas flow (Figure 6). This patented BENSON OTSG system was introduced in the Cottam Development Center/ UK and is running successfully since the year 1999 in base load and cycling duty.

High pressure ramp rates caused by high GT load ramp rates are not an issue anymore. The GT can start with its maximal load ramp rate, like a simple cycle plant, on cold, warm and hot start condition. Also a fast shutdown is possible.

This HRSG design is also capable to cope with even higher GT load ramps which are expected in future. It is the basis of high flexible and high efficient plant design.

4.4 Gas Turbine Operational Improvements

In the past, the plant start-up time was mainly limited by HRSG and ST as described above. The maximal allowable load ramp of the GT very often could not be used. Through design improvements like the BENSON HRSG and a modified steam turbine start-up process, it is nowadays possible to use the maximum GT load ramp over a wide load range. Therefore GT start-up time becomes a determining parameter for the total plant start-up time. This results in the need for higher GT load ramps in the future to further shorten plant start-up time. Development activities covering this topic are already ongoing.

4.5 First Feedback from Site Testing

The in 4.1 described parallel start-up procedure was tested in a SCC5-4000F 1S. Prior to site testing, the start-up process was simulated with advanced tools for heat transfer calculation and dynamic process simulation to learn about the HRSG reaction and the ST behavior. A test program for validation of the theoretical data in a plant was developed. The tests have been successfully performed in May 2005 and have proven the potential for start-up time reduction through this start-up concept (Figure 7). Currently, an automated control concept for this procedure is in development and commercialization is scheduled for September 2005.

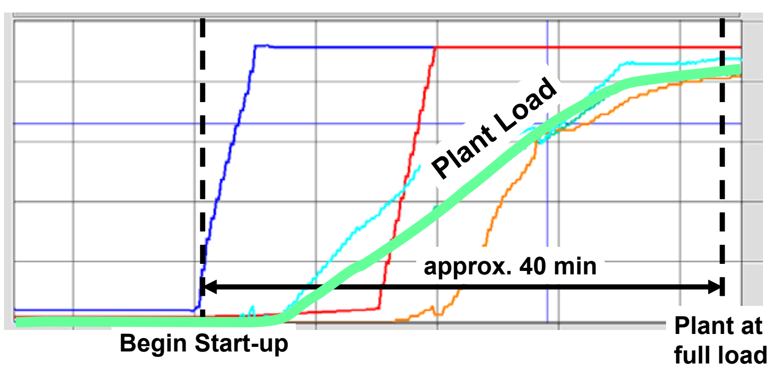

Figure 7: *Site tests show potential of start-up times below 40 min*

5 Benefits from Fast Start-up

The necessary additional/ modified systems for a fast start-up plant (see e.g. chapter three) lead on one hand to a slightly increased first invest. But on the other, fast start-up and high operating flexibility shows economic benefits like reduced start-up costs, new business opportunities like spinning reserve and an improvement in the dispatch rank. Additionally, through a fast start-up the NO_x and CO emissions are reduced and the average efficiency from a load cycle (flame on to flame off) increases due to short GT operation in unfavorable loads. That helps customers to comply with environmental laws. In liberalized markets, the additional investment for fast start-up capability will pay back after a short time. Nowadays, the economic benefit from fast start-up capability is evaluated by only by a few utilities. Compared with the economic evaluation of efficiency – through fuel savings – or increased power output – resulting in higher earnings – the complete evaluation of fast start-up is more complex. Three main influence factors for fast start-up evaluation could be identified as shown in Figure 8:

- Reduction of start-up costs through fuel savings
- Capability for participation in ancillary services markets
- Usage of seasonal or daily market arbitrage

This chapter shows an approach to implement these parameters in an evaluation model.

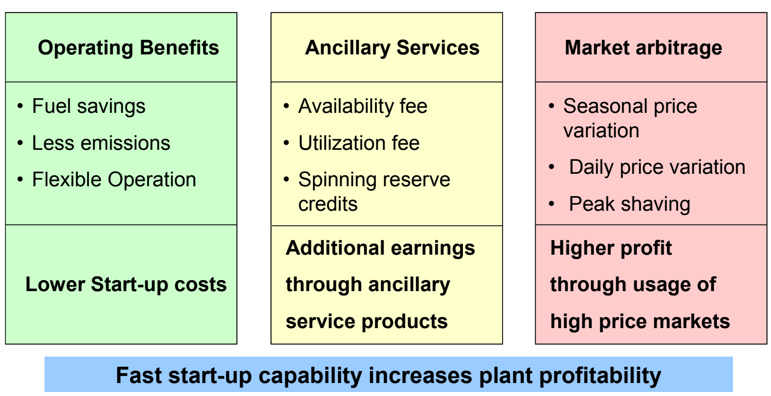

Figure 8: *Economic benefit of fast plant start-up*

5.1 Reduction of Start-up Costs

Start-up costs include costs for fuel, O&M and other consumables like chemicals and water. A reduction of these costs means a direct increase of the customer value. Target of the Siemens PG Reference Power Plant development is to reduce fuel costs and to keep for fast start and normal start O&M cost and cost for additional consumables on the same level.

Fuel savings are mainly caused by short gas turbine operation in unfavorable loads at low efficiency and through fast change over from steam bypass operation to combined cycle operation. The overall efficiency during start-up increases. The value of fuel savings can be calculated through a detailed comparison of fuel consumption and electricity output of a fast and a normal plant start.

5.2 Additional earnings through participation in ancillary markets

Ancillary services, sometimes also called grid services, are traded as independent products in liberalized markets. Ancillary services are necessary to guarantee grid stability and comprise frequency response, reactive power compensation, spinning reserve, hour-reserve. A fast start-up plant can participate in markets for spinning reserve, which means the plant must provide a guaranteed output after a few minutes, and as well in hour-reserve markets where the output must be available after one hour. Depending on the grid operator, other services like minute reserve or fast start are defined. The earnings in these markets normally split in a payment for the capability to provide the power (availability fee) and a payment for every generated kilowatt hour (utilization fee), which is normally significant higher than the intermediate or peakload market price. Plant owners can optimize their load profile participating in ancillary service markets and power markets. This leads to an increased profitability of the power plant.

5.3 Increased revenues through usage of market arbitrage

A big question mark in liberalized markets is the future development of electricity prices. The only known fact is that prices will change. A flexible plant can be shutdown in case of electricity prices below variable costs and it can be online when prices exceed variable costs. These plants benefit from high prices but do not have to operate with a deficit when electricity prices are low. The changes of electricity prices in the future can be derived from both, using historical data from the energy exchanges and statistical methods. Understanding these market developments and the implementation in an economic model leads to a more accurate picture of a projects' profitability than assuming a constant electricity price. Nowadays not all project developers use such a complex approach to evaluate investment decisions. But the above discussed importance will focus the implementation of more complex economic models in future.

6 Conclusion

Fast start-up is an essential feature to ensure economic success in a liberalized market. There are three major drivers for economic evaluation of start-up time: a reduction in start-up costs through fuel savings, additional earnings through participation in ancillary services and optimized profit through usage of electricity price fluctuations.

Siemens Reference Power Plants are developed as an answer to the requirements of a competitive deregulated power market. The current design is optimized for fast start-up and highest operational flexibility as well as for highest efficiency and power output at baseload operation. In particular, the start-up performance has been improved in recent research and development projects. The steam turbine start-up is modified to allow an early roll on and fast loading. An improvement of the gas turbine control enables the use of the maximum load ramp over a wide operating range. Together with the implementation of a BENSON once through heat recovery steam generator, a gas turbine start-up with its maximum load ramp is possible. Optimized unit coordination logic brings together all features and ensures an easy "one-push-button" start-up. These efforts result in a start-up time between 45 to 55 minutes for a 400 MW single shaft combined cycle plant after an overnight shutdown. Further improvements are already addressed and a start-up time below 40 minutes for a 400 MW single shaft is expected in the near future. Siemens as an OEM and turnkey supplier can develop a concept considering all components and integrate them in an ideal way into the plant.