Optimization of operating plant performance in view of new market conditions

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1 Abstract

The increasing share of renewable energy in Europe will continue to change the operational profile of the plants. Steam and combined cycle power plants which have been built for base load operation are facing new market conditions:

- less operating hours
- less megawatt generated due to increasing part load operation
- increased number of starts and fast start-up requirements
- increasing control reserve market

With decreasing megawatts generated, the utility will face the need to generate the remaining megawatts most efficient and to be available whenever the energy market is paying premium prices for generated energy or control reserve. The paper will point out the changing market conditions and the relevance for the operating fleet.
2 A view on the current European energy market

Each MWh which is produced by renewable energy sources and sold preferentially via the Merit Order, substitutes the production of this particular MWh in a conventional fossil power plant. Beyond that, lowers the inexpensive renewable energy production (billions of subsidies not considered) the floated electricity price at the spot markets (short-term) and on the long run also on the future markets. Power plant operators will most probably face the problem in the nearer future to sell less MWh at a lower price level, assuming that the current business framework of the energy market is not changed.

But the greater the share of volatile renewable energy sources like wind or solar power, the greater will be the demand for flexibility in the remaining energy system. Effective smart grids and affordable energy storages are still visions of the future, so the balance between demand and renewable production -residual load- has to be taken mainly by the fossil power generation.

Figure 1 shows a comparison regarding base load hours, number of starts and residual load ranges of the year 2010 to a fictive scenario AT40 RE. The AT40 RE scenario assumes a 40% share of renewable energy (RE) production at a constant demand level (AT) compared to the year 2010. It was developed and published by the VDE (Association for Electrical, Electronic & Information Technologies, Germany). Therefore the scenario is slightly outbalancing the target of at least 35% share of renewable energy production in 2020 given by the German Government.
Fig. 1: Comparison of key parameter in 2010 vs. a 40% renewable scenario

The shift in lower ranges of residual load refers to the increasing production capacity of renewable energy and as a result of it, an intense need for flexibility. In 2010 for instance the residual load range down to 35-40 GW was required only 25 times. In the AT40 RE scenario this will happen over 315 times. The residual load range 0-2 GW will occur in 2020 more than 45 times - which basically means that nearly no fossil power generation is needed at all during these market conditions.

This leads to dramatic drop of fossil plants which are currently operating only in base and mid load operation. Future operation will be dominated by increased number of starts, low part load operation and fast ramps serving the strained control reserve market.

The energy providers are facing the challenge of fewer operating hours per annum, dropping average electricity prices and increasing carbon allowances costs. The current market conditions make business plans of new efficient plants less attractive, slowing down new apparatus builds as can be seen in whole Europe. For assets plants, the situation in the UK is already challenging, due to the fact that the spark spread is in a low single-digit range. Some energy providers mothballed their power plants.
The clean spark spread is the theoretical gross margin of a gas fired power plant from selling a unit of electricity, having bought the fuel required to produce this unit of electricity and the necessary carbon allowances. All other costs (operation and maintenance, capital and other financial costs) must be covered from the clean spark spread (see Figure 2).

$$CSS = \frac{\text{Electricity price}}{[\text{€/MWh}]} - \frac{\text{Gas price}}{[\text{€/MWh}]} \times \frac{1}{\text{Plant efficiency}} + \text{Carbon allowances} \times \frac{\text{Emission intensity}}{[\text{t CO}_2/\text{MWh}]}$$

*Fig. 2: The Clean Spark Spread (CSS)*

On the other hand the energy market offers high revenues when participating in the high price periods like the one in February 2012 in Germany. Russia cut the gas export to Southern Germany by almost 30%. Gas fired plants in Southern Germany were throttled or even stopped. In addition, wind energy production in these days was low due to weather conditions. This lead to decent electricity prices at the European Energy Exchange EEX (see Figure 3) and correspondingly to a healthy clean spark spread (see Figure 4).

*Fig. 3: Average electricity prices in February 2012, Epexspot, EEX*
Fig. 4: The Clean Spark Spread (CSS) of a common CCPP

The authors are convinced that asset plants, which have low transcription cost, are able to be cost-effective despite declining utilization grades, if they can realize their whole flexibility potential and take part in high price periods or attractive markets like the control reserve markets. The following solutions should support this formation.
3 Improving hot start-up time with the “Hot Start on the Fly”

As discussed in section 1 of this paper, the prospective future load regime will be defined by the residual load demand resulting by the volatile renewable energy generation. For many CCPP this will lead to an intense daily cycling mode with up to two starts per day, as the morning and evening demand need residual load while during sunny days the residual load disappears. Hence, all measures which reduce the start-up time as well as the start-up efficiency will gain in importance.

Siemens Energy has developed a fast cycling upgrade for CCPP to meet these requirements. The so called Hot Start on the Fly which was successfully introduced in new plants as well as in plant modernization incorporates a revised start-up concept of the overall plant - with a parallel start-up of the gas turbine and the steam turbine. The gas turbine will be started and loaded without any hold in part load operation (see Figure 5). When the first steam is generated by the Heat Recovery Steam Generator, the steam turbine will be also started and loaded during continuous temperature and pressure increase - thus the critical time were cold steam meets hot components is limited to an absolute minimum. Validation shows that the new start-up concept can be implemented in compliance with the existing limitation factors of the plant.

![Fig. 5: A typical Hot Start on The Fly](image-url)
With the *Hot Start on the Fly* solution, a hot start-up time below 30 min could be achieved in a new apparatus CCPP. In an asset plant a potential start-up time reduction of approx. 20-40 min can be granted and will be evaluated in a specific site assessment due to individual plant set-ups.

The following example shows a benefit examination in a European asset plant. Both the asset and the reference plant do have a SGT5-4000F(6) with a SST5-5000 steam turbine in single shaft configuration. All shown trends are based on real data.

As a result of a site assessment, a potential time saving of 25 min compared to a common hot start could be granted when using the *Hot Start on the Fly*. Figure 6 shows a comparison of a typical hot start and *Hot Start on the Fly*. The both trends were scaled to zero time when the inlet guide vanes of the gas turbines are fully open and bypass stations closed - the total plant literally reaches base load. As mentioned before, due to the new start-up philosophy the *Hot Start on the Fly* does not need any waiting times of the gas turbine in less efficient part load operation. Therefore all flat periods of the blue line (Block load) can potentially be deleted. The red-hatched area under the red line (gas consumption) illustrates the additional consumption of a traditional hot start. To go a bit deeper into detail: during the common hot start of the asset plant, 35.000 Nm³ of gas were consumed and 128 MWh electricity were generated. The reference plant with the *Hot Start on the Fly* uses 23.000 Nm³ of gas, generating 94 MWh during the start-up process.
To regain the gap of 34 MWh compared to the asset plant, the reference plant needs 5 minutes of efficient base load operation with another 5,600 Nm³ of gas. So if the same electricity output (128 MWh) should be the objective, the Hot Start on The Fly needs still 6,600 Nm³ less gas.

With this amount of saved gas, approximately 6 minutes of base load operation is possible with best efficiency. Thus, every Hot Start on The Fly generates approximately 40 MWh (green hatched area) more - per start (see Figure 7).
Fig. 7: Additional operation from saved gas in best efficiency area

In Figure 8 a set of curves can be seen which show the commercial benefit of *Hot Start on the Fly* in connection of electricity price and number of starts performed. The lower set of curves reflecting the average area of energy exchange prices across Europe in the past two quarters. To show the benefit in a high price season as it was in Germany in February 2012 please refer to the upper set of curves.
Fig. 8: Commercial benefit of the Hot Start on the Fly

To summarize, the Hot Start on the Fly is the most economic way to start-up the plant. It can be selected as a start-up in the unit coordination of the plant. In an environment of low spark spreads and as a result of it less operating hours, plant operators are able to use periods of strong demand for residual load to maximize plant profit.
4 Improving cold start-up time with the “Fast Release to Nominal Speed”

With less base load operation in volatile markets, plants are often forced to stay offline for more than two days. During this time the steam turbine naturally cools down and than demands an extended heat soak time during an upcoming start - which means the gas turbine has to be operated in less efficient part load operation. With the solution “Fast Release to Nominal Speed” for HP barrel type turbines, the waiting time can be reduced significantly.

To secure a safe and gentle ramp up to nominal speed, superheated steam in all areas of the HP turbine must be present. For this different pressure and temperature measurements will be monitored and criteria were developed. The main criteria which need to be fulfilled are:

The casing inlet temperature and casing temperature need to be above the saturated steam temperature. The cover and base casing temperatures (50% measurements) need to be 10K or less below the saturated steam temperature (see Figure 9).

![Diagram](image)

**To ramp-up to nominal speed, all of the listed criteria have to be fulfilled:**

1. MAAS0CT004/005/006A > T sat
2. MAAS0CT031/032 > T sat
3. MAAS0CT051/052 > T sat -10K
4. ...
5. ...

*Fig. 9: Release criteria for Siemens HP drum type turbines*

When all of these criteria are achieved, the release for nominal speed is given to the operator.
Figure 10 shows operational parameter from the evaluation of the “Fast Release to Nominal Speed” in a European power plant. Like shown, criteria one and two were achieved in three respectively two minutes after warm-up speed. Criteria four and five were already achieved during the acceleration. The third criteria, superheated condition at cover and base casing temperatures, need up to 40 minutes until fulfillment, due the thick components.

To shorten the start-up process, the measurement of the 50% HP cover and base casing temperature (MAA50CT051/52) which have severe time delays with respect to the increasing steam temperature will be replaced by a new temperature measurement. It is possible to identify a new, fast responding location to check the steam temperature and to implement the new measurement at this position. All validation runs indicated that the new measurement reliably indicates a superheated steam condition. In Figure 11 it is shown (green line) that the new criteria is achieved nearly simultaneous (after three minutes) with criteria one and two.
Fig. 11: Improvement of new criteria

With the “Fast Release to Nominal Speed” the cold start can be shortened by approximately 30 minutes and gas of up to 17,500 Nm³ (based on a typical Siemens 400 MW class CCPP) can be saved.
5 Low load study of SPP with steam extractions

One main pillar of Europe’s energy system is the electricity generation made by solid fuels such as coal and oil. Roughly one third of the European power demand is covered by Steam Power Plants (SPP) fired with the mentioned fuels. It is obvious that these power plants also have to contribute in the fluctuating residual load.

The low load study presented as follows was carried out in a 400 MW class hard coal fired SPP in continental Europe. The Siemens steam turbine is an SST5-6000 configuration with special design of the intermediate and low pressure turbine to allow for six extractions for condensate respectively feed-water preheating and to provide process steam as well as steam for district heating. On the one hand this kind of power plants have to fulfill the contractual commitment to deliver process steam and district heating to their customers, but on the other hand electricity generation is technically and commercially fluctuating. Facing these conflicting targets, a study was performed to investigate new operation conditions of the plant. One objective of the study was to investigate permanent operation in a scenario of minimized electricity generation while maintaining heating and process steam delivery. Figure 12 shows the investigated low load scenarios in correlation with preheater in or out of service and temperatures of hot reheat steam (t RH) and extracted steam flow (t F),

Fig. 12: Different investigated low load scenarios
To give a release for permanent operation in these scenarios, the following aspects were investigated:

**Maximum HP exhaust temperature**
To maintain steam deliveries of a certain pressure for process and district heating, the IP control valves need to be throttled to assure a defined minimum pressure at the extractions. As a result of this a higher back pressure in the HP turbine takes place compared to the normal sliding pressure operation. Thus the HP exhaust temperature might increases to a maximum allowable value in stationary operation. In addition the maximum gradient for transient operation needs to be considered.

**Maximum IP exhaust temperature**
The maximum permissible IP exhaust temperature was calculated with state of the art engineering codes. The analysis, which considered the impact of this measure to all related turbine parts (casing, shaft, blading and cross over pipes), resulted in an increase of the permissible temperature.

**Maximum IP differential temperatures**
The specific design of the IP applies a sealing wall within the casing having steam of different temperatures on both sides of this element. As a protection for high differential temperatures at this wall, a thermal isolation was part of the original design. An extreme low load operation would change the temperatures at this element as far as a deformation process might be started. The new temperature conditions in low load operation needed to be simulated with the finite element method.

**Erosion**
Another field of the study was the aspect of corrosion due to erosion. Droplet impact erosion for instance emerges from the impact of water droplets on the leading edge of the LP blades carried by the steam mass flow. For the evaluation of risk exposure a new erosion factor needed to be determined for each LP stage.
**Thrust**

As the pressures and the steam flows in the turbine shall be changed for the new operating conditions, the axial thrust has to be analyzed and compared with the allowables of casing fixings and the rotor thrust bearing capabilities.

As one result of the study, which was performed by an engineering team including experts in thermodynamics, mechanics and blade design, a considerable lower electricity load could be granted without violating existing safety margins. To implement the new operating conditions and to ensure a safe permanent low load operation, recommendations of I&C changes (warning & alarm values) were given as part of the study.
6 Future prospects

When the future markets will reward even higher flexibility, it might be commercially attractive to accept a reduction of component life in exchange of this flexibility.

The priority of the renewable energy generation in the merit order is by nature consequential - the generation of renewables is environment friendly and has no fuel costs. Nevertheless, leaving only a reduced number of operating hours and the burden of volatile residual loads and its consequences to the remaining fossil fleet without sufficient commercial compensation cannot be the final solution. It is expected that the design of the energy markets in Europe will change in the years to come, which will lead to risks, but also opportunities for fossil plants.

Like the examples shown in this paper, Siemens Energy Service will continue to develop customized solutions to strengthen the competitiveness of fossil fired power plants.
7 Disclaimer

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