HYBRID OR FLEXIBLE – INTEGRATED APPROACH FOR RENEWABLES INTEGRATION

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Abstract: In responds to world environmental concerns, the share of renewables is increasing in the energy mix. This is especially true in Europe where a number of Countries are supporting this process through subsidies or feed in tariff mechanisms. As a consequence for power plant operators, the integration of this energy source is a real challenge and has a strong impact on the operation of existing fossil power plants.

Two potential approaches can be of value for the operator. The first is to increase the operational flexibility of the power plant in terms of spinning reserve and back-up capacity (load gradients, minimum load capability, etc) in order to balance the renewable energies output fluctuations. Another option can be the integration of a renewable energy source directly into an existing power plant. This arrangement allows the plant to balance the fluctuating power output with its thermal and mechanical inertia.

For a successful and cost effective execution of both options, an integrated approach is proposed as this has advantages over a component approach. To incorporate new technologies without an integrated approach and a full review of the affected systems can lead to a less than optimum solution with unexpected surprises when the unit is returned to service.

Alstom Power has developed Plant Product solutions that improve the flexibility and the environmental impact of the entire power plant. In this paper, we describe 2 different integrated options:

- The Solar Boost approach generates renewable power by using concentrating solar thermal equipment and integrating the heat in the water-steam cycle of an existing Steam Unit. The integration in the existing Steam Unit has been optimized to achieve high efficiency and low investment costs compared to a stand-alone Solar Thermal Power Generation solutions requiring completely new Power Plant and Infrastucture.

- The Peak Power technology not only provides the opportunity for additional power but also the reduction of the minimum power output by means of heat storage. This heat will be loaded and

unloaded from/to the water steam cycle. It allows a high degree of operational flexibility and further reduces power limitations for supply of frequency support.

Adapting existing plants provides the opportunity to increase operational flexibility while reducing harmful emissions by using an integrated approach. Based on innovative products the Plant Operator can have confidence in the solution with an effective full integration into the existing systems.

Key words: Renewables, Solar, Peak load, Flexibility, steam power plant, integrated solutions

1. INTRODUCTION

With the combination of worldwide environmental concerns and the setting up of governmental subsidy mechanisms for renewable energy sources the share of renewable in the total energy mix is increasing. The impact on the existing fossil fired power plants has different consequences. Firstly they are typically designed for base load operation and not optimized for rapid load changes, as such are unsuited to meet the challenges created by the introduction of new energy sources. To respond to this first aspect more flexibility in terms of spinning reserve and back-up capacity (load gradients, technical minimum load, etc) is necessary. This flexibility can be reached with the Peak Power Product.

A second aspect of this new set up is the strong support of the authorities to increase the renewable energy share in the portfolio of the energy markets. One of the consequences of the public subsidy scheme is to make renewable energy more viable for the energy companies. This opportunity can be used either by the installation of new standalone renewable power generation (e.g. wind farms, solar power plant) or by the integration of these energy sources directly in existing power plants. This integration is possible through the Solar Boost Product.

2. PEAK POWER

Increasing the renewable energy share has a strong impact on the existing fossil fired power plants and especially on the coal fired power plants. These plants have now not only to respond to demand but also to the intermittent feed-in of electricity produced by renewable energy sources. The residual load and the number of conventional power plants in operation will be reduced and more flexibility is required from the conventional power plants.

As a result, the number of load changes and shutdowns of coal fired power plants increases. This has a negative impact on plant lifetime and operation stability. To store thermal energy can help to reduce the extent of these load changes and shutdowns.

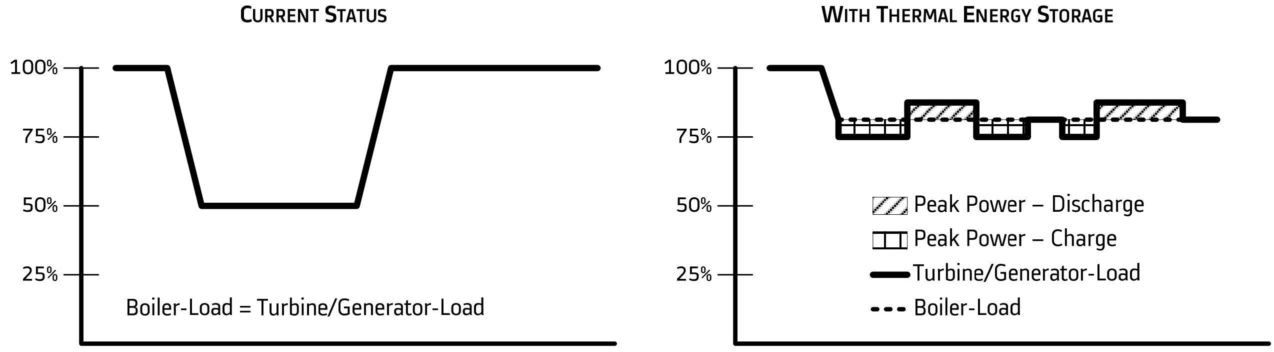

Figure 1: Potential operational benefits through Peak Power

The objective of this Plant Product is to extend the load range of a power plant, smoothen the load gradients for the boiler and additionally increase the income from generation by arbitrage dealings. Additionally, the time on load can be increased, if power plants without are forced to shut down more often because of too high minimum load.

2.1. Peak Power Concepts

To be able to store thermal energy, low pressure storage tanks will be installed parallel to the LP feed water preheaters. The storage tanks are upright cylindrical tanks, which work as “layer storages” or displacement tanks, where cold and hot condensate is only separated by a thermal layer.

Operating Principle

When the electrical output of the power plant shall be reduced, the thermal storage is charged with hot condensate from downstream the feed water tank. To be able to store condensate, the condensate mass flow through the LP preheaters and the feed water tank is increased. This leads to an increased extraction steam mass flow from IP and LP turbine and thus reduces the electrical output of the plant (see Figure 2 below).

When additional electrical output is required, the LP feed water preheaters are bypassed and the cold condensate from the condenser displaces the hot condensate in the storages. The hot condensate is introduced into the water-steam-cycle upstream the feed water tank. As the LP feed water preheaters are bypassed, they do not draw extraction steam. The feed water tank is not bypassed, but the hot condensate from the storage has approximately the same temperature as the feed water tank, it also does not draw extraction/heating steam. The steam mass flow through the last stages of the IP turbine and the LP turbine is increased. As a result, the electrical output is also increased.

As the load reduction of alternative A is limited by the maximum possible condensate mass flow, a second concept, alternative B, with additional storage preheaters is available (see Figure 3).

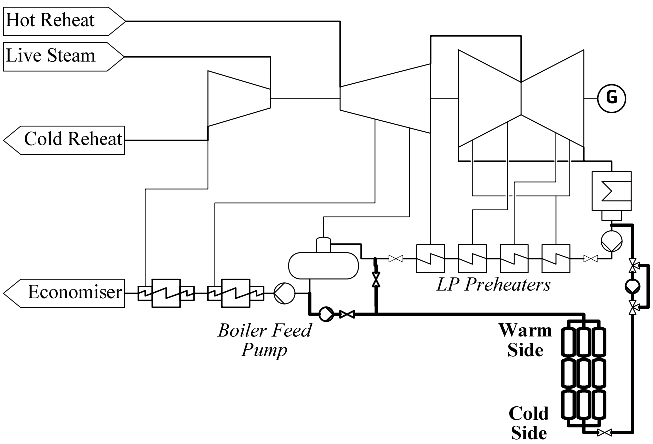

Figure 2: schematic flow chart of Peak Power Alternative A

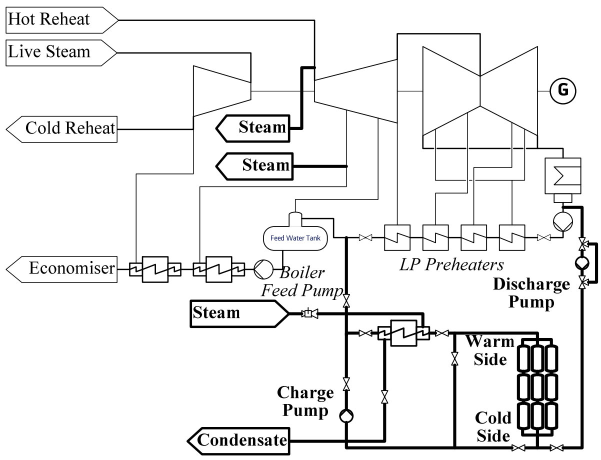

Figure 3: Peak Power Alternative B

During charging of alternative B, steam with adequate parameters is taken from the water-steam-cycle and heats up the cold condensate from the tanks. Here, the charging condensate mass flow is independent from the water-steam-cycle. The load reduction during charging occurs, because heating steam is taken away from the water-steam-cycle. Adding the condensate from the storage preheater to the hot storage condensate reduces the charging time. The discharging process is similar to alternative A. Cold condensate displaces the stored hot condensate. The hot condensate is fed back to the water-steam-cycle upstream the feed water tank.

2.2. Peak Power Benefit

Peak Power has different benefits that are depending on the load a power plant.

Benefit at discharge = increase load

As the operating principle of Peak Power discharge mode is comparable to an "extended condensate stop", the benefit is maximal at full load of the power plant, because then, the impact of the reduced extraction steam mass flow is maximal. Here, approximately 5% of MCR can be supplied as extra power. For a 500 MW power plant, this would typically result in 25 MW extra.

Cycle efficiency

The following charts show that compared to other energy storage solutions, Peak Power is very attractive.

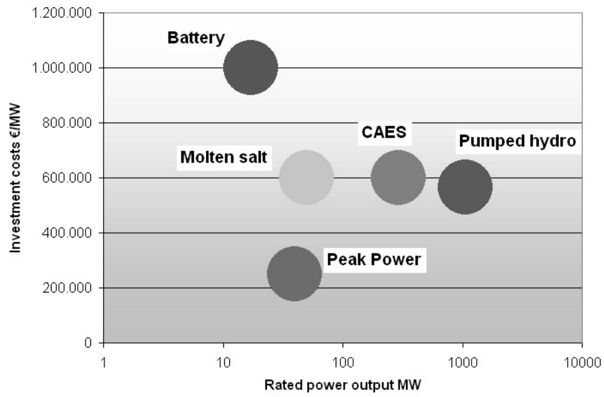

Figure 4: Rated power output vs. Investment costs of energy storage systems

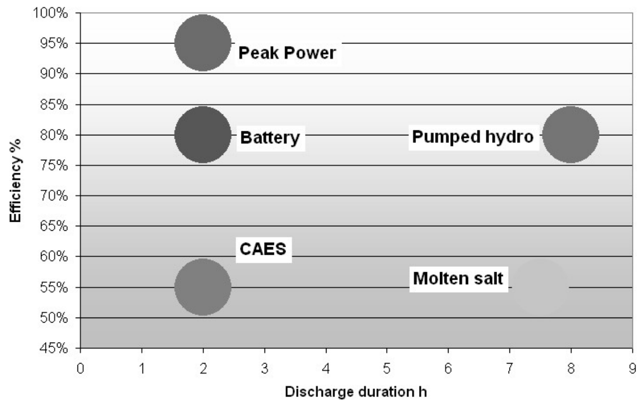

Figure 5: discharge duration vs. efficiency of energy storage systems

Impact on operation range

With Peak Power, the usable load range can be extended as there is no more need of throttled operation to provide primary and secondary control power.

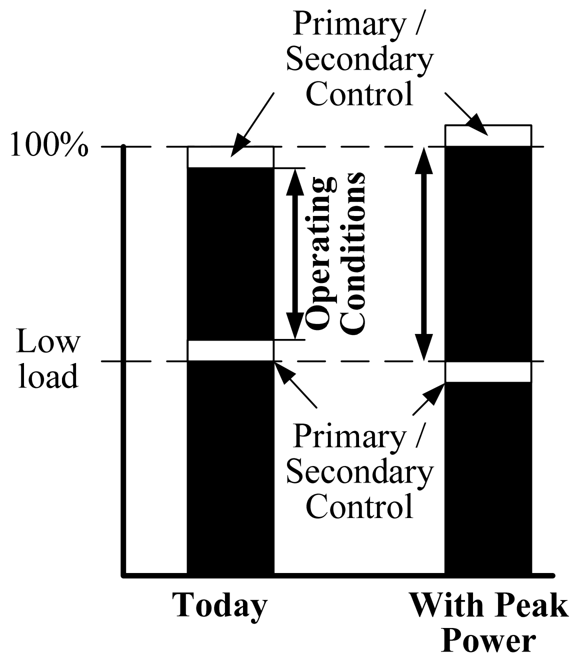

Figure 6: Impact of Peak Power on the operating range of a Power Plant

The feasibility of the Peak Power Product has to be evaluated with an integrated approach of the specific water-steam cycle because of the numerous effects on the components. For example the mass flow changes in the low pressure preheating train, which will have impact on the turbine that needs to be assessed.

3. SOLAR BOOST

The first aspect of the increase share of renewable energies is the necessity to adapt the power plant to the new flexibility requirements. The second aspect is the increased public interest, governmental subsidies for renewable energies (such as Feed-In Tariff, green certificates or CO2 Credits) to compensate the high costs of these technologies. These parameters make the utilization of renewable energies more attractive for the energy companies. One option is to adapt existing conventional power plants to the growing share of renewable energies. Another option is to integrate a renewable share directly in the existing power plant, which allows the operator to combine the environmental advantage of the renewable energy with the economic advantage of the fossil energy.

Figure 7: Fresnel collector

Figure 8: Parabolic Trough collectors (Source: Darren Baker, www.pictolia.com)

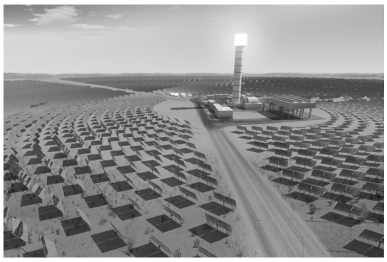

Figure 9: Solar Tower collector

The second concept presented in this paper consists in the hybridization of a fossil-fired steam power plant with solar energy. Regarding the different solar technologies available on the market only the solar-thermal technologies could be integrated directly in the water steam cycle and consequently in the power plant normal operation (photovoltaic panels convert the solar energy directly in electrical energy). Analyzing now the different solar-thermal technologies, the operating parameters and the potential impact on the power plant, one type of technology is preferred: concentrated solar-thermal technologies, which includes the Fresnel (see Figure 7), the Parabolic Trough (see Figure 8) and the Solar Tower (see Figure 9) collectors.

3.1. Concept Description

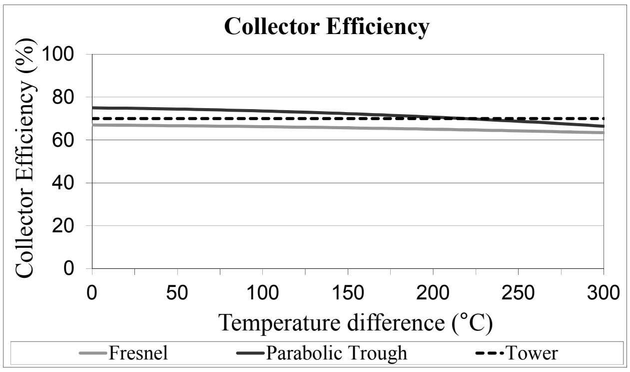

Figure 10: Collector efficiency for different solar thermal technologies

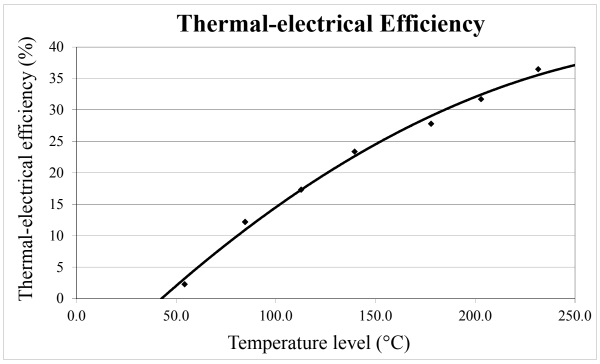

Figure 11: Thermal-electrical efficiency evolution with the integration temperature

The concentrated solar-thermal collectors can be integrated at different locations. To define the most appropriate locations in terms of performance and cost several parameters have to be taken into account. The performance or the efficiency of the system can be divided in two different sub-categories: the solar-thermal efficiency, which corresponds to the efficiency of the solar system itself and the thermal-electrical efficiency, which corresponds to the efficiency of thermal power conversion into electrical power. The solar-thermal efficiency of a solar system depends on the temperature difference between the ambient air and the heat transfer medium (usually water, steam or thermal oil). This efficiency decreases when the temperature difference increases (see Figure 10). The average thermal-electrical efficiency increases with the water (or steam) integration temperature (the medium temperature when it is integrated) (see Figure 11). Consequently a compromise between both parameters needed to be formed. The most effective way in terms of efficiency and risks is the top level of the high-pressure preheating train, where the operating temperature reaches a level of about 250°C. Principally there are two different possibilities to feed the solar heat into the water-steam-cycle: either the heat transfer medium coming from the solar field is mixed with the water or steam of the water-steam-cycle and the solar heat is transferred directly (direct integration) or the heat is fed in indirectly by means of an additional heat exchanger (indirect integration). The main advantage of the direct integration is that the integration costs could be reduced whereas it is possible to separate completely the solar field to the existing water steam cycle with the indirect integration and increase the theoretical security of the both system.

Table 1: Different parameters of considered technologies

	Fresnel		Parabolic Trough		Solar Tower	
Heat Transfer Fluid	Wet steam	Superheated steam	Thermal oil	Steam	High pressurized water	Superheated steam
Max. Pressure level	80 bar	110 bar	10 bar	30 bar	220 bar	172 bar
Max. Operating Temperature	270°C	450°C	396°C	300°C	300°C	585°C

Based on the sated facts and based on the usual operating parameters of the different solar-thermal technologies (see Table 1) two different concepts were selected:

- TOP HP Heater Bypass System: The Solar Boost system is installed in parallel to the last HP pre-heater and bypasses partly or completely the feed water mass flow. The feed water will be heated through the Solar Boost system up to the feed water end temperature.
- Additional HP Heater System: This concept is the integration of an additional HP preheater in the preheating train of the power plant. The feed water end temperature is then increased at the boiler inlet.

Both concepts can be adapted to direct and indirect integration.

3.2. Solar Boost Benefit

The integration of an additional heat source at the High Pressure preheating train offers on the one hand the possibility to increase the power output of the plant at constant coal consumption or on the other hand to save coal respectively reduce the CO_2 emissions at constant power generation. Figure 12 shows the simplified load curve of a typical coal power plant with the two different operation mode possibilities of the Solar Boost Product.

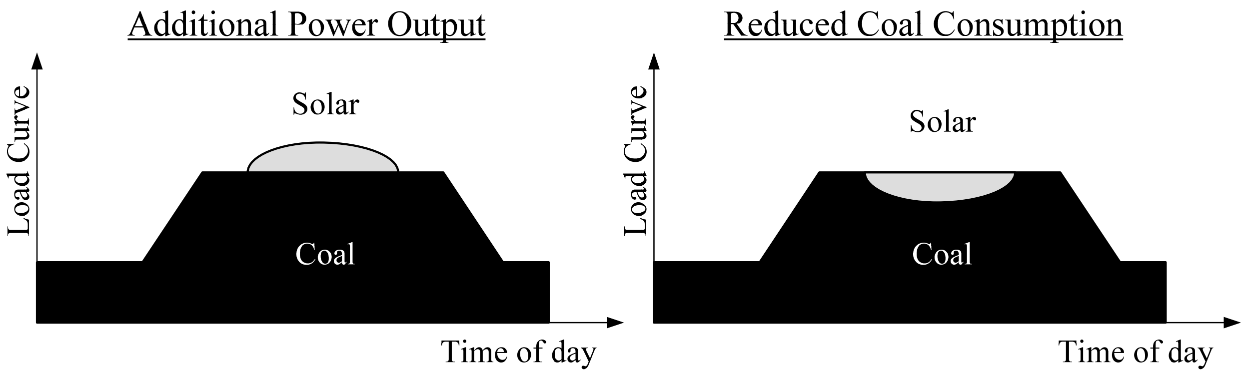

Figure 12: Solar Energy Utilization

The potential of Solar Boost can be presented through a case study. This evaluation is based on one 600 MW unit located in South Africa for a land area of 500 000 m². This unit is selected due to the high amount of solar radiation and the large available space around the power plant. The first operation mode (additional power output at constant coal consumption) is considered.

The integration of solar thermal energy in this existing steam power plant shows promising results. An increase of about 5 to 10% of the current power output is possible for the TOP HP Heater Bypass System (see also Table 2).

Table 2: Case Study – Technical results for the different technologies

	Fresnel	Parabolic Trough	Solar Tower
Mirror Area [m²]	267 000	181 000	228 000
Annual Efficiency [%]	12.0	17.1	15.5
Equivalent Electrical Power Generation [MWh_{el}/a]	72 950	68 430	78 420
Additional Peak Electrical Capacity [MW_{el}]	38.7	38.7	38.7

Compared to a standalone solar-thermal power plant the Solar Boost Product presents several advantages:

- An optimized available water-steam cycle: The existing water-steam cycle of the power plant is thermodynamically optimized with higher steam parameters (540°C and higher) compared to solar-only plant (400°C for one-axis technologies) and has more stable steam parameters.
- No storage needed: To compensate the strong fluctuation of available solar energy the solar-thermal power plants need a storage installation. For Solar Boost the existing power plant can be used to balance these fluctuations. The power plant will compensate this fluctuation with internal thermal and mechanical inertia.
- Lower Investment Costs: Major components of the necessary installation are already installed in an existing power plant: access to the grid, infrastructure, water steam cycle, turbine and generator, etc. This fact contributes to decrease the general investments and make the solar-thermal energy more viable.
- Short Implementation Time: The implementation can be stepwise organized and in a short time, as the needed scope is smaller than for standalone solar-thermal power plants.

The impact of Solar Boost on the power plant is marked on the water-steam cycle (power output increase of 5-10%) components: the mass flow in the turbines will increase, the operating conditions of the boiler will change and the power output at the generator terminal will potentially increase. These effects have to be assessed before the installation of Solar Boost and this assessment needs an integrated approach of the whole power plant.

4. CONCLUSION

The two Plant Products presented in this paper address the growing challenge posed by the introduction of new energy sources to the power market. Peak Power is able to smoothen the load gradients, to extend the load range of a power plant and finally to respond to the new flexibility requirements. Solar Boost is able to provide a competitive solution based on renewable energy sources and support energy companies to reach the renewable goals defined by the authorities. Both Plant Products use an integrated approach, which ensures an optimized solution, a successful adaptation of the Plant and minimal disruption to operation, thereby maximizing the value for the Plant Operator.