Battery Energy Storage Solution

- Enhancing the operational flexibility of flexible combined cycle industrial gas turbines

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Abstract **–** Maintaining grid stability by balancing voltage and frequency is one of the challenges that occur in particular in isolated and islanded power systems and micro-grids. As consequence of higher penetration by renewable energies stable power system operation gets more and more challenging. Wind turbines and photovoltaic inverters do not have rotational inertia to help stabilizing grid frequency. They can't rebuild a grid in case of black-out. Diesel driven generators cannot contribute to any grid related services as well. Finding viable combinations of conventional and renewable energy is one key solution for the efficient and sustainable running of these types of hybrid power systems.

Many countries are pushing their energy transition to reach their climate targets and absolute installed power of renewables plus hydro has grown significantly over the last two decades. New flexibility assets such as Battery Energy Storage Solutions (BESS) as new components in modern grid structures are heavily promoted and year by year their usage is expanding, especially since their costs have significantly decreased during the last years. There is a greater consensus that various BESS applications make renewables integration and its further expansion a technically sound and competitive option.

However fossil fuels such as coal and gas will still dominate the global generation with an ongoing trend in new installations towards decentralized and smaller industrial gas turbines (<100MW). As a result from these changes, centralized fossil fuel plants - initially foreseen for base load operation - are now requested to ramp much faster, more frequently and act on top of this as spinning reserve generation. Co-locating battery BESS with combined cycle gas turbines (CCGT) can further enhance the startup of CCGTs thus enabling them to provide much faster services such as Enhanced Frequency Regulation (EFR) and Firm Frequency Response (FFR), whilst still being available and running to provide longer duration services such as Short Term Operating Reserve (STOR), secondly as a solution to replace the diesel generator (starter motor) normally used to provide power for black cold start to a CCGT that normally provides services used to rebuild the grid in the event of a black-out, thus providing a much faster restoration service, and further as a resource to support fast ramp up to meet peak demand requirements.

The demand for black-start abilities may increase as well for the above mentioned reasons. Today, only a small percentage of all CCGT power plant installations are equipped with diesel driven generators for Black Start.

I. Introduction

Until start of the 3rd millennium, the power generation was very much centralized and power flow was unidirectional from large power generators to the consumers. The grid in the "old" world was easy structured and balancing of power demand and generation could easily be managed. There was no need for large energy storage assets as power generation simply could follow the demand. Volatility of power generation was low and grid balancing mechanisms were very much effective.

Over the past years, the energy market has undergone a significant change. The sustained increasing share of renewable energy in the power grid results in greater variability in availability due to weather effects than was the case in the past. In an ideal world, renewable power generation systems would produce the exact quantity of electric power required to meet demand.

Until today, grid fluctuations are compensated primarily by conventional power plants. However this is not without disadvantages, as the growing input of renewable energy results in predatory competition rendering conventional power plants less and less cost-effective. Furthermore, statutory authorities are increasingly demanding solutions to reduce emissions that are both technically challenging and cost-prohibitive.

As a result of higher volatility and fewer conventional power plants to provide rotational inertia, the grid faces an increased risk of instability and potential power failures. This rotational inertia is needed to ensure grid stability and avoid blackouts, as well as rebuild the grid in the event of blackouts meaning that these plants will continue to be essential in the future.

Figure 1: BESS collocated to a conventional gas turbine plant

Ensuring that power plants remain economically viable to run means innovative ideas are needed to better optimize the power plants operation to provide more flexibility tools to support modern grid operation. One of these future-oriented innovative ideas is already in demonstration phase and entails integrating large BESS with conventional gas turbines in a hybrid plant and installing these directly at the power plant site. The combination of a BESS and conventional power plant opens up a series of different services for the grid and power plant operators, including black-start capability and regulating services.

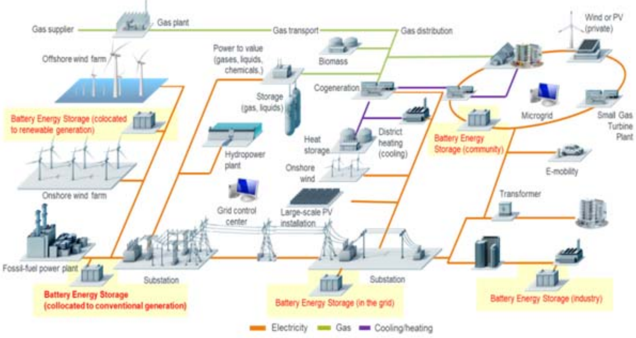

Figure 2: Integration of BESS in modern grid structures

The transition of the energy system is completely changing the old structures and grid balancing has become one of the most complex issues in our "new" world. Lots of new, distributed power generation units are now feeding into the same grid, making balancing of voltage and frequency very difficult tasks for network operators. Sector coupling also brings its technical benefits but also challenges. More and more Battery Energy Storage Systems, as new components of decentralized energy system, are heavily promoted and year by year and their usage in all grid sectors is continuously expanding. Hybrid Storage Solutions, such as stationary BESS collocated to conventional power generation offer many technical but also commercial benefits to plant operators. Integration of utility-scaled BESS during refurbishment or as an extension to existing plants is becoming a sustainable, competitive advantage for plant operators that are aiming to enhance the operational flexibility of their combined cycle industrial gas turbines.

II. Challenges for Conventional Power Plants

Fossil-fired power plants are not dependent on weather conditions and therefore have a high degree of reliability. As long as fuel is available, the power plant can supply the required amount of power to the grid to ensure demand is met. Further a conventional power plant can also contribute to stabilization of grid voltage and frequency and can also support restoration of the grid in the event of a power failure or black-out.

However, the majority of conventional power plants cannot start without electric power from external sources, because the turbines must first reach a certain speed before they reach the parameters required to feed their output to the grid. Modern industrial gas turbines are capable of operating quickly to increase and decrease their output. In general only 5 to 10 minutes is required to ramp an industrial gas turbine to rated power. However, this is still far too slow to respond to frequency and voltage variations that happen as a result of changing output from renewable energy.

III. Advantages of Battery Energy Storage System

Large stationary BESS with high-performance Li-ion batteries and intelligent control of the power electronics are now commercially mature systems representing the state of the art. All of the necessary equipment, such as battery racks, grid connection equipment, power converters and control systems can be installed in standardized containers. This flexible and modular design approach enables easy scaling of power and capacity as well as speed of installation vis-à-vis conventional alternatives. Furthermore, the bi-directional nature of BESS means that they can both absorb energy from the grid as well as feed energy back into the grid. Precision operation in the order of seconds requires ultra-modern power electronics and very fast communication between power transformers at the point of interconnection (POI) with the grid and the control equipment.

Figure 3: Battery energy storage system (BESS), Photo Siemens

IV. Hybrid Solution: Fully Integrated BESS + Power Plant

This integrated solution combines the advantages of conventional power plants with those of BESS. The integration of battery energy storage systems in conventional power plants, regardless of the size of the installed output, manufacturer and model of gas or steam turbine is essentially feasible to retrofit in existing plants as well install as part of new ones. Asset Optimization is now focused on hybrid solutions that can provide a conventional power plant with the following additional features.

Typical implementation cases for a hybrid solution

- Black start of a gas turbine on loss of off-site power and support to restore the grid
- Increasing the power gradient on start-up or ramp-up of the power plant and offer fast power response services within less than 1 second
- Provision of regulating capacity with the power plant from cold start or in operation
- Accelerated output adjustment on load changes and stabilization support for volatile load conditions
- Offering up to rated-power plant output and maintaining spinning reserve
- Supporting demand turn up/low output needs below the minimum run threshold of the power plant
- Stabilization of gas and steam turbines during grid outages as well as safe transition of the power plant to island mode

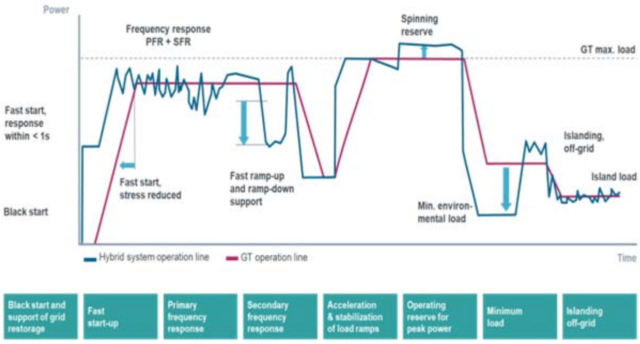

Figure 4: Optimized performance of hybrid system (BESS + GT)

In addition to that, an integrated BESS to provide such enhanced operational flexibility significantly reduces the thermal stress on a gas turbine; with a positive effect on service life. Power efficiency is also increased, resulting in lower consumption of primary fuel and reduced emissions.

V. Black Start of a Gas Turbine on Loss of Off-Site Power and Support to Restore the Grid

Gas turbines require an external energy source to startup. This hybrid solution enables black start of gas turbines in the event of loss of external power source and therefore the capability to enable the power plant to support grid restoration, thereby further increasing supply reliability. Black start capability of conventional power plants was previously based on the use of diesel generators or gas engines. Applications for these diesel generators are generally limited to black start, whilst a hybrid solution with an integrated BESS offers a larger number of further opportunities.

When designing battery storage capacities with regard to black start capability, it must be guaranteed that there is always sufficient energy reserve in the batteries to ensure performance during multiple starts in sequence. In addition sufficient energy reserve must also be provided for "purging" (removal of residual gas mixtures that are removed from the turbine and the stack with a high air flow rate) – This further improves the power gradient of the supply to the grid on startup of the power plant

Run up and startup of gas turbines require time. However as mentioned previously the output of even the fastest and most flexible power plants are still too slow to respond to grid fluctuations within a matter of seconds and almost impossible to respond to demand down-turn situations. Depending on the scale of the BESS, it can immediately supply power to the grid and absorb power from the grid and can therefore fully or at least partially take over this activity for a brief period. In this mode of operation the BESS would supply power to the grid while the gas turbine is ramping up. The BESS continues to supply fast response power to the grid until the gas turbine takes over and the battery can then be recharged (if needed).

VI. Provision of Regulating Capacity with the Power Plant at Standstill or in Operation

The rotating mass of the synchronous generators in conventional power plants cannot immediately compensate a sudden loss of generated power or a sudden increase in load. In the immediate aftermath of a disturbance, grid frequency has not changed significantly, and primary regulation is not yet active. Any output deficit over this extremely short time period must be covered by the kinetic energy of the rotating mass (rotational inertia). This situation results in a decrease in the rotational energy stored in the synchronous generator and therefore in a reduction in output. Because of rigid frequency coupling of all synchronous generators, grid frequency naturally drops after a short time. Every synchronous generator contributes to what is known as spinning reserve according to its rated output. Renewable energy generators coupled to the grid via frequency converters do not contribute to the spinning reserve in contrary they follow frequency. As a result, further expansion of renewable energy increases discrepancies in voltage and grid frequency. This is because the more variable renewable energy being supplied to the grid, the less is being supplied by conventional power plants. The fewer conventional power plants connected to the grid, the less rotating inertia is available and the more difficult it is to ensure grid stability. In island grids and areas with weak grids, displacement of the synchronous generators and the associated loss of spinning reserve is already a serious and growing problem.

The provision of so-called ‘synthetic inertia’ to compensate for diminished spinning reserve of synchronous generators by fast-response BESS is (to a certain extent) under implementation in Great Britain as Enhanced Frequency Response (EFR) procured by National Grid. The provision of very fast regulation capability using BESS is also expected to be rolled out in other countries in the near future. Going forward, hybrid solutions will be able to ensure grid stability and power quality and reliability for end users no matter how much variable renewable generation is connected to the grid.

The provision of regulation capability using BESS is significantly faster (<1sec) and much more precise than what can be accomplished with a conventional power plant. Power plant operators can therefore generate additional business opportunities by offering this regulation capacity, and operating the plant with more flexibility. On simultaneous implementation of the BESS and the gas turbine, the battery assumes the task of fast response (both positive and negative), while the gas turbine only supplies the energy to deliver extended service requirements and balance the battery charge level. Such an optimized operating mode significantly reduces the stress on the gas turbine. The more uniform, low-stress and optimized the gas turbine can be operated using the coupled BESS, the more nitrogen oxide and carbon dioxide emissions can be reduced and fuel and maintenance costs reduced.

VII. Accelerated Output Adjustment on Load Changes and Stabilization of Volatile Loads

The BESS supports the gas turbine in accelerating output adjustment and stabilization/smoothing of volatile load. The battery can already supply energy before and during gas turbine startup, therefore the overall energy output of the power plant to the grid can be significantly accelerated to respond to sudden load changes.

VIII. Offering up to Rated-Power Plant Output and Maintaining Spinning Reserve with the BESS

Should spinning reserve be required to respond to large grid under-frequency, the BESS can be used to temporarily increase the maximum power output of the power plant at the POI. The otherwise permanently restricted output from the power plant can then by circumvented, and therefore offering power generation capacity up to rated output opens up additional revenue opportunities.

IX. Stabilization of gas and steam turbines during grid outages, safe transition to island mode

In the event of a grid outage, rotating power-generating machines tend to speed up very quickly because the kinetic rotational energy is no longer balanced by a sufficiently high generator load. These situations can occur as a result of total load rejection/disconnection from the grid (either intentionally or due to an unforeseen event), as well as due to a partial load rejection/load island. The basic concept for stabilizing a turbine using a BESS is understood to be the controlled prevention of excessive speed increase due to sudden load reduction, with the objective of maintaining the turbine in steady-state and safe operation. In this transient process, damage to the plant must be prevented and fast and safe stabilization of the generating unit must be ensured whilst maintaining operation. The significant factors for this procedure must be quickly and reliably recognized and a corresponding response initiated. Three factors play a significant role for gas turbines: the response times of the control and valves, the residual energy in the technical process and the violation of thermodynamic and combustion limits. Because the combustion process cannot be varied arbitrarily quickly and arbitrarily far, the fuel flow rate is quickly reduced after a disconnection from the grid, resulting in a fast and large change in the combustion process (very lean combustion). However, the turbine controller then attempts to maintain rated speed, which in turn results in fast opening of the fuel control valves. Ideally, the turbine can be stabilized in island operation, i.e. zero-load operation (rated speed) after a short settling phase. However, the flame is frequently extinguished, resulting in automatic turbine trip. An overspeed can also be reached, which also results in turbine trip. In these two cases, turbine stabilization cannot function and turbine restart is not possible until after an extended run-up phase.

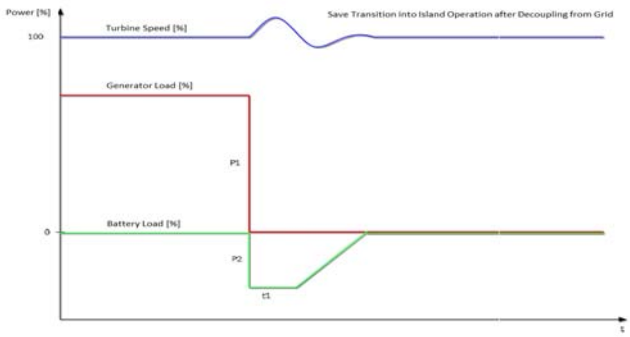

Figure 5: Turbine stabilization after disconnection from the grid

The most important objectives in stabilizing gas and steam turbines on grid outages are thus to limit the speed increase as well as to maintain turbine operation at the auxiliary power requirement or in island mode. On disconnection from the grid, the excess energy in the rotating system must be removed through the generator as electrical energy and input to/stored in the BESS. The residual energy is removed from the process through the controlled instantaneous charge power (P2) for a specific time (t1). Because both P2 as well as t1 depend on the previous output power P1 and on the actual turbine, they must be determined as functions f(P1). This significantly reduces the acceleration and thus the speed increase. Conflicting oscillations between the BESS and the turbine are not anticipated, because the BESS operates in power-controlled mode and the turbine in speed control. The duration of t1 is on the order of 0.2 - 2 seconds. Battery charge power is gradually reduced again after time t1 in order to quickly stabilize the system.

X. Example for a combined-cycle plant

The following scenario is developed to demonstrate the full potential of the hybrid solution: An unfired combined cycle plant with a rated output of 80MW is at complete standstill. The grid, which is supplied primarily by wind and solar power, experiences an unanticipated massive loss of the generation, resulting in a drastic reduction in supply but no change in demand. The grid operator demands immediate provision of full power from the power plant operator in order to prevent a voltage drop and subsequent power failure. In less than 1 second, the full 80MW output is supplied, stabilizing the grid. From the standpoint of the grid operator, the 80MW is supplied and the power failure prevented, however this has been done without the power plant operator having to start up the gas and steam turbines and instead by the BESS that can immediately provide the 80MW output. The BESS also gives the power plant operator the necessary time to analyze the situation and determine whether the unavailability of renewable energy will continue. If this is not the case, a potentially unnecessary startup of the gas turbine can be prevented.

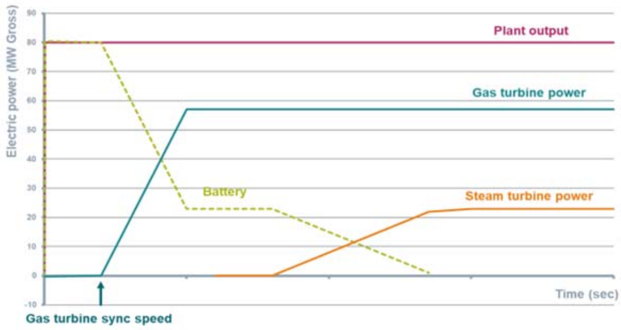

Figure 6: Combined-cycle plant with 80MW BESS

However, if renewable energy is still unavailable to supply power, the BESS can be used to supply both the initial 80MW, as can be seen in the figure before, as well as the energy required for ramp-up of the gas turbine, which can then ramp-up normally to full load. During this time, the battery no longer supplies the full 80MW, but rather supports the differential for the gas turbine to make up the full 80MW output to the grid. The situation can continue with the subsequent start-up of the coupled steam turbine, so that the BESS is not disconnected from the grid until the combined output from the gas and steam turbines reaches the full 80MW. The combined-cycle plant can remain in this mode until the power available from the renewable energy increases or demand decreases. In this example application, the BESS prevented the power failure and gave the power plant operator the flexibility of not necessarily having to start up the conventional power generation system in an inefficient and potentially costly mode of operation.

XI. Summary

Asset optimization with integrated BESS, enhancing the operational flexibility of flexible combined cycle industrial gas turbines can be summarized with the following keywords: Immediate flexibility in operating mode, new business opportunities for power plant operators, immediate black-start capability and intermediate increase in plant reliability. All of this is achieved with optimized operation of the gas and steam turbine and the generator, with the result that fuel consumption and emissions can be reduced.