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Natural gas combined cycle power plant aggregated with battery: a flexible hybrid solution providing enhanced frequency and balancing services

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Abstract. The growth of renewable sources and the consequent complexity in the management of the electric grid draw a scenario in which the traditional fossil fuel power plants are asked to improve their performances to continue playing a primary role for the stability of the grid and the safety of the energy supply. The article describes the possible solutions to flexibilize the combined cycle power plants in terms of fast load response and load balancing. In particular, the aggregation of an energy storage system (battery) with a natural gas combined cycle power plant is analyzed in detail. In this context, the fundamental role of the Plant Optimizer, a dedicated Control System developed by Ansaldo Energia performing the function of aggregator, is highlighted. Thanks to the Plant Optimizer, the hybrid power plant can provide enhanced frequency and balancing services and ensure an increasingly aligned response with the needs of the grid operators.

1 Introduction

The ongoing transformation of the energy sector is progressively changing the traditional ways of producing, transporting and storing electricity, with diversification of the energy sources participating to energy markets and ancillary services. Power generation industry efforts aim to ensure a reliable and secure provision of affordable electricity, while meeting the environmental goals. As the share of variable renewable energy increases, so does the need for flexibility to maintain reliability of power systems. In this scenario, emerging opportunities for new actors and business models are created.

2 Volatility of load demand

The load demand must be met instant by instant to ensure the safety and the stability of the system. To do this, the grid operators need flexible resources to be constantly available and ready to start at any time. The traditional source of flexibility for operators is represented by thermal power plants, which are characterized by high availability and

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programmability. Further flexibility is provided by interconnections, pumped hydro, distributed generation and demand-side response. Other emerging sources of flexibility are represented by energy storage and batteries, which are currently starting to contribute too [1].

The ongoing rise of renewables, particularly wind and solar, increases the need for short-term flexibility (reacting to changes within minutes or hours). As direct effect, most of the power plants originally designed to operate in baseload are today asked to follow steeper and unpredictable ramping up and down, with less efficient operation and lower capacity factors. The following figure, referred to the electricity production in Germany in December 2018, clearly highlights this effect [2]. As shown, thermal generation suffers drastic load variations to accommodate the fluctuations caused by renewables.

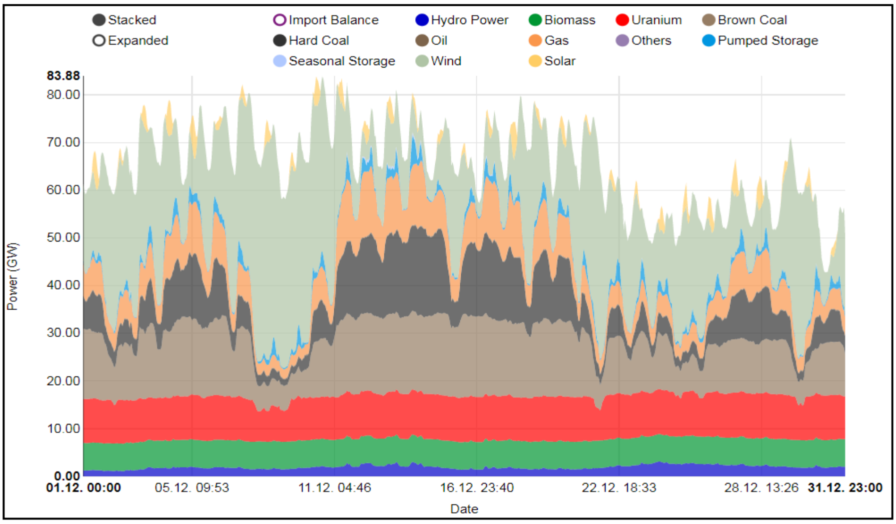

Fig. 1. Electricity production in Germany in December 2018 (source: https://www.energy-charts.de)

3 Effects on profitability

Traditionally, electricity markets developed and operated within strictly regulated frameworks in which vertically integrated utilities handled all or most activities from generation to transmission to retail. Needs were assessed and fulfilled by electricity system planners, and all associated costs were passed on to consumers.

During the early 2000s, many highly regulated markets stimulated over-investment, such posing the basis to generate excess capacity and lower activity. This accidentally reduced the profitability for generators and created higher costs to the system. As a matter of fact, today it is not uncommon for many markets to experience a decline in wholesale energy prices, brought about by stagnant demand, low natural gas prices and higher output of generation with low marginal costs. Referring to Spot prices and volumes in Germany in December 2018, reported in the following figure, this tendency becomes evident [2]. As shown, some periods of very low and even negative energy prices were recorded, directly correlated with renewables overproduction.

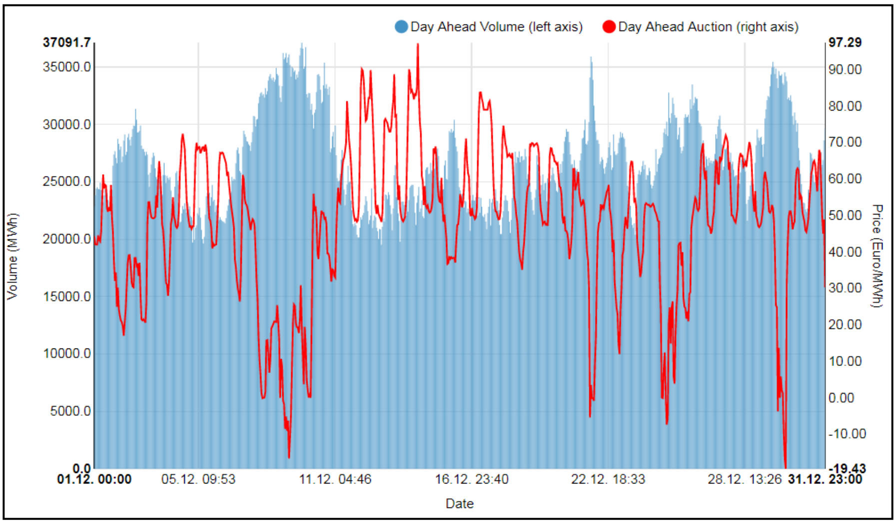

Fig. 2. Spot prices and volumes in Germany in December 2018 (source: https://www.energy-charts.de)

Due to this volatility, the return on investment is no longer safe and the plants must find new forms of remuneration to operate profitably and continue playing a primary role for the stability of the grid and the safety of the energy supply. To do this, thermal power plants shall access new markets dedicated to flexibility and peak capacity, where new players other than traditional generators offer ancillary services such as frequency regulation and balancing services. These emerging markets today provide only a small portion of the total revenues, but most probably over the long term they will account for a much larger share of the overall revenues, eventually becoming one of the main drivers able to attract investments in the electricity sector.

To access these forms of remuneration, thermal power plants are required to improve their performances in order to meet the requirements imposed by the grid operators. Many technical parameters related to flexibility enable the access to these markets: heavy cycling capability, start-up speed, extended turndown, enhanced ramp rates, part load efficiency and reduced environmental footprint. Increased flexibility needs pose both a challenge and an opportunity to improve designs, retrofit current plants or adjust operations to change these variables and make the plant suitable for providing flexibility and peak capacity.

4 Hybrid solution CCPP + BESS

Combined Cycle Power Plants combine two processes in a series whereby the exhaust heat from a gas turbine is fed into a steam cycle. The latter, also referred to as bottoming cycle, produces additional power without requiring additional fuel input, thus increasing the overall plant efficiency. While traditional CCPPs were designed to operate around the clock prioritizing greater full-load efficiency, new advanced CCPPs must accommodate flexible operation, particularly ramping and minimum stable output, to meet the increasing demand for short-term flexibility.

Battery Energy Storage Systems are systems that store energy using a battery technology, to make it available for later use. The term BESS is a generic term formed by a wide range of different technologies. The most suitable technology for power-intensive applications dedicated to short-term flexibility is Lithium-Ion. This type of battery has a high energy density and the main benefit to accommodate frequent cycles of charge and discharge with low deterioration in terms of storage capacity. Its main downside is cost, although it is forecasted to come down progressively in the upcoming years.

The addition of a BESS system to a traditional CCPP represents a hybrid solution designed to meet the increasing demand for short-term flexibility and peak capacity. Thanks to the intrinsic characteristics of BESS systems (e.g. the ability to provide quick-response power on demand and accommodate frequent cycles of charge and discharge), this solution allows to extend peak capacity, provide frequency regulation and balancing services with enhanced ramp rates, minimize load unbalances, and maximize the overall plant efficiency.

Besides the technical issues related to the physical integration of a BESS within a CCPP, the key-enabling technology is related to their aggregation at the control system level. This delicate aspect is managed by Ansaldo Energia through the implementation of a dedicated control system, the Plant Optimizer, consisting in a proprietary product specifically thought for hybrid power plants [3]. The Plant Optimizer developed by Ansaldo Energia provides a high-level automation system for CCPPs, enabling the integration of multiple generation sources and their coordinated management both in terms of maximization of energy efficiency and minimization of load unbalances.

Designed for the management of CCPPs in different configurations (single-shaft, multi-shaft «1+1» «2+1» «4+1» … up to «m GT + n ST»), it can also be applied to virtual power plants (separated plants with a common plant load profile and single load dispatcher interface). Derived from about 30 installations and over 20 years of experience in CCPPs optimization, the Plant Optimizer provided by Ansaldo Energia is certified by several patents and can be easily interfaced with any existing plant automation system.

The following description refer to a hybrid configuration 2+1 CCPP + BESS, i.e. a power plant which includes 2 Gas Turbines, 1 Steam Turbine and 1 BESS system. The Plant Optimizer dedicated to this solution elaborates the sum of the load profile coming from electricity market and from primary and secondary frequency load contributions, reduced by the non-programmable load generated by renewable sources (wind, solar, etc.), and distributes the results between the gas turbines, the steam turbine and the battery. In this way, all generation sources can contribute simultaneously and in real time to the load variations, providing their maximum ramp rates (MW/min) within their own variation range (maximum / minimum). This intelligent distribution of the load profile is performed by the sophisticated "Distributor" algorithm, illustrated by the automation block diagram shown in the following figure.

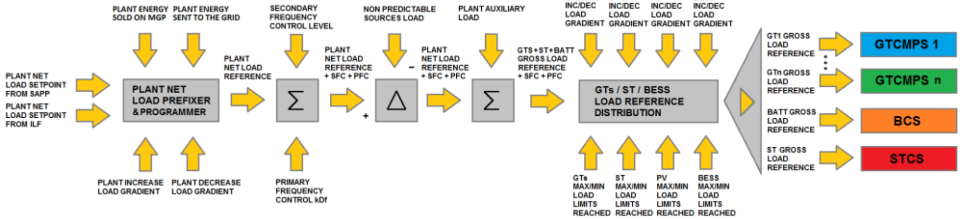

Fig. 3. Automation block diagram of the Plant Optimizer for the application CCPP+BESS

While the contribution of electrical load coming from non-programmable renewable sources, such as solar and wind, is acquired by the Plant Optimizer without significant modulations, more significant is the role of the battery: its capability of supply (and absorption) of electric load with gradient much higher than that of the other sources (within the limits of its energy capacity), allows the battery to compensate the CCPP unbalances and/or increase the plant load gradient. For those characteristics, by means the Plant Optimizer, the operator has the possibility to select the battery contribution in the following control modes:

- Mode 1 - Primary Frequency Control (PFC)
- Mode 2 - Primary + Secondary Frequency Control (SFC)
- Mode 3 - Primary + Secondary Frequency Control + Day-Ahead Electricity Market (MGP)

For a better understanding of the Plant Optimizer capabilities in managing the power plant in different operation modes, three simulations have been performed using Matlab Simulink tool, version 2014b, with a fixed step time of 300ms. These simulations include simplified models of CCPP (electric load and thermal cycle), battery, and relative control systems. On the contrary, the Plant Optimizer is modeled with a high level of detail. The simulations refer to a 400 MW 2+1 multi-shaft CCPP integrated with a 12MW/6MWh BESS, having the following main characteristics:

Table 1. Reference 400 MW 2+1 multi-shaft CCPP + BESS characteristics

	GT1	**GT2**	**ST**	**BATTERY**	**PLANT**
MAX GROSS LOAD [MW]	125	125	132	12	380
MAX NET LOAD [MW]					365
MAX BATTERY ENERGY [MWh]				6	
BATTERY STATE OF CHARGE [MWh]				4	
MIN GROSS LOAD [MW]	0	0	0	0	0
MAX LOAD GRADIENT [MW/min]	30	15		100	

4.1 First operating mode: Δf injection (PFC)

The first simulation consists in a negative/positive frequency injection of 0,1 Hz (firstly from 50,0 Hz to 49,9 Hz and then from 50,0 Hz to 50,1 Hz) causing two power plant load increase/decrease demands of 27,7 MW with minimum required ramp rate equal to 60 MW/min. Simulation trends are resumed in the following figure. The dead band here considered is ±0,02 Hz. In this simulation the battery compensates only the PFC contribution, without having effects on SFC or MGP services.

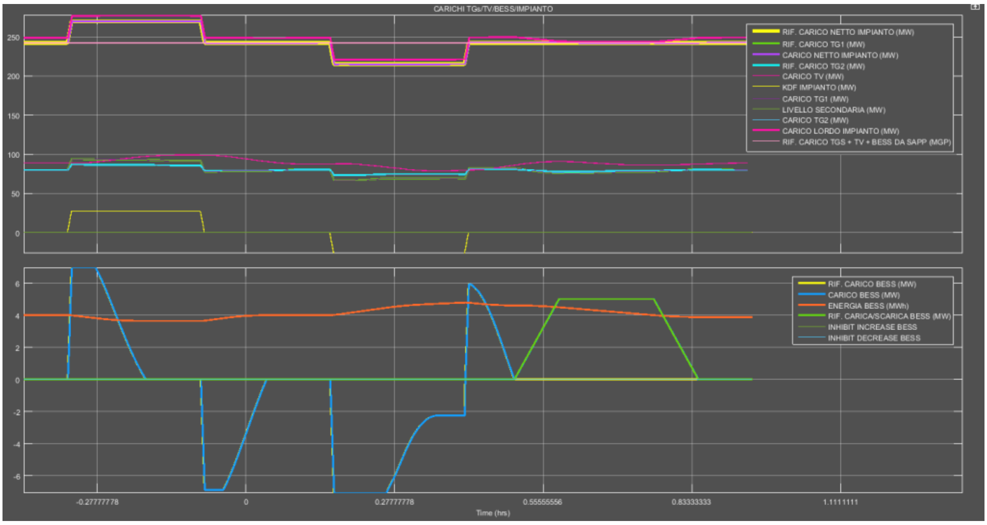

Fig. 4. Simulated plant operation for a 400 MW 2+1 CCPP + BESS subject to sudden load increase/decrease demands due to positive/negative frequency injections of 0,1 Hz with minimum required ramp rate equal to 60 MW/min

When the Plant Optimizer receives the load increase demand, it immediately requires both GTs and the ST to increase their load and the battery to provide additional load to compensate the difference between the required 60 MW/min and the GTs and ST maximum rates. In order to guarantee the continuity of supply, the battery continues ramping-up until reaching its maximum rated power. When doing this, its State of Charge (SoC) progressively reduces according to the discharged energy. After that, with a short delay due to the thermal inertia of the boilers, also the ST starts to contribute. When this occurs, the battery is free to progressively reduce its load down to zero. Once this "neutral" condition has been reached, the battery is allowed to recharge and reset its initial capacity, provided that it is outside from the considered dead band.

It should be noted that during the described transient the net load profile generated by the plant (i.e. the controlled load profile) perfectly matches the required load profile, while the gross load is higher due to the increase of the sum of GTs and ST load which shall compensate the load absorbed by the plant auxiliaries. With similar methods, the Plant Optimizer can reverse the use of use the battery, accumulating energy to compensate over-frequency, to ensure a smart management of resources in all operating conditions associated to flexible operations.

4.2 Second operating mode: Δf injection (PFC) + secondary level injection (SFC)

The second simulation consists in a negative frequency injection of 0,05 Hz (from 50,00 Hz to 49,95 Hz) followed by an increase of the secondary level equal to 0,5, causing a total power plant load increase demand of 40,2 MW with minimum required ramp rate equal to 120 MW/min. The following figure resumes the simulation trends. In this simulation the battery compensates only the PFC and SFC contributions, without having effects on MGP services.

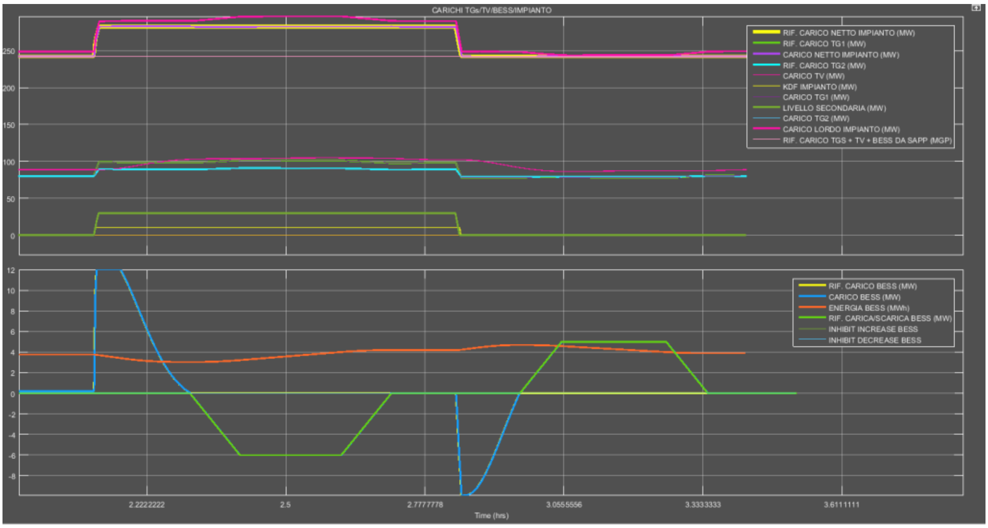

Fig. 5. Simulated plant operation for a 400 MW 2+1 CCPP + BESS subject to a sudden load increase demand due to a negative frequency injection of 0,05 Hz plus an increase of the secondary level equal to 0,5 with minimum required ramp rate equal to 120 MW/min

Same as before, the battery compensates the sudden load variations and then recharges. Once again, during the described transient the net load generated by the plant (i.e. the controlled load profile) perfectly matches the required load profile, while the gross load varies according to the increase/decrease of GTs and ST loads and the load absorbed/released by the battery during its charging/discharging phases.

4.3 Third operating mode: Δf injection (PFC) + secondary level injection (SFC) + day-ahead electricity market (MGP)

The third simulation consists in a day-ahead sold load ramp of 58 MW at 10 MW/min followed by a negative frequency injection of 0,05 Hz (from 50,00 Hz to 49,95 Hz) and an increase of the secondary level equal to 0,5. After that, both primary and secondary contributions are set to zero, while the MGP contribution is kept constant. The sum of all contribution causes a total power plant load increase demand of 98,2 MW with minimum required ramp rate equal to 130 MW/min. The MGP, secondary and primary contribution are added in sequence to perform a more realistic (and stressful) simulation of the Plant Optimizer capabilities. Simulation trends are resumed in the following figure. In this simulation the battery is required to compensate all contributions, supporting all provided services.

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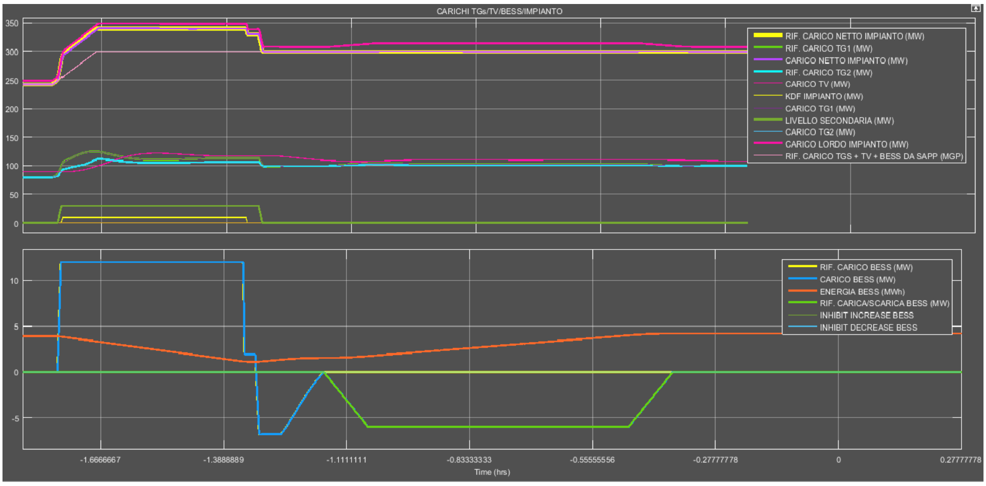

Fig. 6. Simulated plant operation for a 400 MW 2+1 CCPP + BESS subject to a sudden load increase demand due to a day-ahead sold load ramp of 58 MW at 10 MW/min plus a negative frequency injection of 0,05 Hz and an increase of the secondary level equal to 0,5 with minimum required ramp rate equal to 130 MW/min

Similarly, but with a more substantial contribution, the battery compensates the sudden load variations and then recharges. Once again, during the described transient the net load generated by the plant (i.e. the controlled load profile) perfectly matches the required load profile, while the gross load varies according to the increase/decrease of GTs and ST loads and the load absorbed/released by the battery during its charging/discharging phases. Moreover, this operating mode gives the battery the possibility to recharge without requiring power from the GTs when it participates in load absorption. The final net load of 300 MW corresponds to the final load profile sold on the day-ahead market.

5 Conclusions

Thermal power plants are the traditional source of flexibility needed by grid operators to ensure the safety and the stability of the system. Due to ongoing rise of renewables, most of them currently suffer drastic load variations, with less efficient operation and lower capacity factors. This pose a risk on their profitability, mainly due to a decline in wholesale energy prices caused by renewables overproduction. An opportunity for improving their revenues is to access new markets dedicated to flexibility and peak capacity, offering ancillary services such as frequency regulation and balancing services. To do this, they need to improve their performances, and the hybrid CCPP+BESS application presented in this paper could be a valid solution to meet the increasing demand for short-term flexibility and peak capacity with relatively low investment.

In this view, the high costs of Lithium-Ion batteries may actually restrain innovation, but despite that, some locations where this solution begins to be economically sustainable start to emerge. An internal recent analysis on a 400 MW CCPP located in the South of Italy, characterized by many starts and stops interspersed with a consistent number of hours in baseload, has shown that an investment of about 6 M€ to install a BESS package would be paid back in about 6 years, with a resulting cumulative gross margin after 10 years equal to 2,8 M€. This example shows that the proposed solution, although perhaps not yet profitable enough to attract immediate investments, certainly represents an interesting opportunity for power plants owners, with an excellent potential economic return.

Moreover, thanks to the Plant Optimizer developed by Ansaldo Energia, this solution is not only underway for economic advantage but also today technically available for a quick and efficient implementation both within new and existing CCPPs, such posing the basis for a potential flexibility improvement of the whole current power system. If this would happen, a safer and more secure management of the power grid in terms short-term flexibility and peak capacity would be granted, allowing the operators to take advantage of new diffused quick-response sources that are not available to them today. On the other hand, being the proposed solution characterized by a limited storage capacity, the monthly or seasonal energy management issues carried by rising renewables would remain, requiring other forms of long-term storage such as pumped hydro or the emerging power-to-gas-to-power systems, which use hydrogen or methane as energy vectors through electrolysis and/or carbon capture and methanization technologies.

6 References

1. International Energy Agency, *World Energy Outlook 2018*
2. Fraunhofer Institute for Solar Energy Systems ISE, https://www.energy-charts.de
3. A. Giacchino, E. Repetto and A.G. Gianotti, *Hybrid Solutions for Power Generation Industry*, Energy Procedia 148C (2018) pp. 814-821