Challenges in load balance due to renewable energy sources penetration: The possible role of energy storage technologies relative to the Italian case

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ABSTRACT

With the rapid growth of the electricity produced by RES (renewable energy sources), especially those highly variable and unprogrammable (e.g. wind and solar power), the need of energy system flexibility increases significantly.

Since RES currently represent a significant fraction of the power supply, their variable nature poses challenges to power grid operation, such as RES curtail and loss in global efficiency of thermoelectric plants, since they are often operated at part-load as fluctuating back-up power.

In particular, thermoelectric plants recently moved their role from base-load power to fluctuating back-up power. Such a cycling operation represents a less obvious effect of grid flexibility requirement due to RES penetration. Main effect is the increment of both energetic costs, due to reduced efficiency operation, and wear-and-tear costs.

This aspect is deeply analysed in reference to the Italian electricity generation mix in the period 2008–2012. Moreover, the possible coupling of energy storage systems with thermoelectric plants is highlighted as an alternative solution respect to retrofiting of existing plants.

1. Introduction

In the next years, a rapid growth of renewable sources exploitation is foreseen in order to cover with renewable sources up to 20% of the final energy consumption in 2020 and an even larger share by 2050 [1]. In fact, RES (renewable energy sources) technologies are expected to take the leadership in the forthcoming energy generation portfolio in order to achieve a sustainable energy generation. Anyway, their utilization is slowed down by the characteristic intermittency and the fluctuating trend and, moreover, by the inadequacy of electricity networks. To ensure such a penetration, electricity systems need to be flexible in order to balance at every moment generation and consumption.

In some European countries (Denmark, Spain and Germany) the renewable energy share has already exceeded 20% [2], highlighting critical issues such as grid congestion and perturbation [3,4] due to the large number of highly unpredictable, intermittent and fluctuating power plants [5]. Moreover, in order to mitigate the serious concerns indicated above, RES are curtailed during low consumption periods limiting the exploitation of renewable power plants.

What above represents the critical issues, relative to the RES exploitation, usually analysed in literature [6–10] together with the possible solution identified in ESS (energy storage systems) integration, mainly contributing to:

- grid reliability improvements thanks to the reduction in both fluctuating energy delivered to the grid and energy absorption from the grid (leading to mitigation of grid overload);
- reduction in curtailment of unprogrammable renewable energy generation due to network constraints;
- deferring investments of grid improvement.

A further negative aspect to overcome is the RES impact on thermoelectric power generation. In literature, few articles deal with RES implications on conventional power generation; however, some specific studies on wind variability and its effect on traditional generators are available. A model to estimate emissions from fossil fuel generators used to compensate variable wind and solar power is presented in Ref. [11]. Specifically, a quantification of CO2
and NOX emission is provided considering natural gas turbine as power technology used to compensate variable renewables. An interesting model of wind/gas/energy storage generation systems, described in Ref. [12], demonstrates a method for integrating significant quantities of wind energy while reducing power fluctuations, showing the financial feasibility of the solution in relation to the produced wind energy.

In the present paper, the particular issue of RES impact on conventional power generation is analysed with particular attention to the Italian scenario. As detailed in the following, in order to overcome the grid balance problem due to the difference between energy generation and consumption, part of the Italian thermoelectric plants were managed in the last years as backup of RES. The consequent significant negative effects on thermoelectric generation performance are deeply investigated in this work. In fact thermoelectric plants, with particular reference to CC (combined cycles), are operated as part-loaded plants, which can be ordered to increase or decrease output as required, and generally subjected to varying load conditions [24]. Consequently, the installed capacity of CST power plants are still the second power generation technology in Italy.

Moreover, it can be noted that the installed capacity of CST (condensing steam turbine plants) dropped by 5%, from 2008 to 2012, whereas the installed capacity of RP (repowered power plants), GT (gas turbines) and ICE (internal combustion engines) was left unchanged. Even with such a sharp decline in installed capacity CST power plants are still the second power generation technology in Italy.

In order to further analyse the evolution of the thermoelectric sector in the observed period, data about production, consumption and efficiency are provided hereinafter. Figs. 3 and 4 show, respectively, gross and net produced electric energy for each kind of fuel used in thermoelectric plants. For clarity, gross production is
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