Analysis of Battery Energy Storage Systems and Preliminary Design Based on Insights from Real Case Studies by Iren S.p.A

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***Abstract*—Originally designed as a support tool for renewable energy integration, Battery Energy Storage Systems (BESS) have evolved into versatile technologies with applications across multiple energy environments. This work explores the architecture, functions, and benefits of BESS, focusing on their role in frequency and voltage regulation. Real-world implementations at the Moncalieri and Turbigo power plants provide concrete examples of their effectiveness in supporting thermoelectric generation. Building on these insights, a preliminary design for an additional storage system at Turbigo is proposed, aimed at improving operational flexibility and enhancing grid stability.**

I. Introduction

The principle of energy storage system, as a system able to store energy in various forms,on a temporary basis, and release it on demand, has slowly revolutionized the energy landscape. Original created to be supportive of unreliable or inconsistent energy sources, with time its applications have increased as have the various technologies to achieve them. Battery Energy Storage Systems (BESS) are the favored technology given their flexibility and now are fundamental in providing ancillary services, improving grid reliability, and ensuring efficient energy use. This article explores the technical and strategic role of BESS through real-life implementations by IREN Energia and presents insights from a preliminary design for future installations.

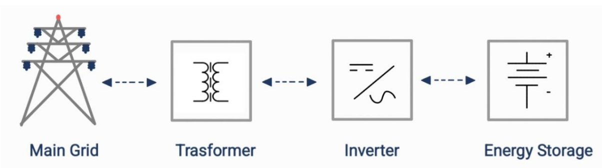

Figure 1: Basic components of a BESS

II. The Role of Energy Storage in Power System

During recent years, BESSs have become widely used, expanding their types and applications. In order to consider the significant potential they have for the future it is vital to outline the most renowned and frequently cited applications of battery energy storage. The different uses can be classified according to the system with which the storage interacts as follows:

- **in support of a production plant**, with roles as Smooth output fluctuation, Frequency and voltage modulation ancillary services, Black start power
- **in support of the grid**, working as Peak-shaving service, relive congestion in transmission and optimization power flow distribution, Microgrid
- **in direct contact with the loads**, with Community energy storage, Power supply in remote areas and Vehicle to grid applications

Each of these application comprehend opportune management changes and plant structure suited to the case. Beyond their technical contribution, they also create new revenue opportunities through services as ancillary services and acting as prosumers. These capabilities make BESS an increasingly valuable asset in the evolving electricity market, where resilience and sustainability are strategic priorities.

III. Real-Life case studies: Moncalieri and Turbigo

IREN Energia has invested heavily in battery energy storage system (BESS) integration. This thesis work studied two real-case BESS plants commissioned by IREN. The first is a 10 MW system supporting the cogeneration facilities at the Moncalieri power plant near Turin, and the second is a 16 MW BESS at the Turbigo plant in Lombardy. The latter was commissioned to strengthen the site's role in grid services.

Both projects were part of Terna's "UPI Pilot Project", which aimed to introduce BESS systems into the ancillary services market by ensuring their use and generating revenue through five-year contracts, while also testing the advantages that these technologies could provide. The plants are designed in accordance with Terna regulations to provide primary and secondary frequency regulation and fast reserve. These basic types of regulation have different requirements and objectives and shown in figure 2

. Frequency regulation is fundamental to grid stability because the power generated must be in constant balance with the power consumed to avoid serious imbalances that could cause sever issues. Frequency transients caused by energy discrepancies can be avoided by releasing or storing surplus energy at the right time. Integrating the storage system with the power plants improves energy quality and

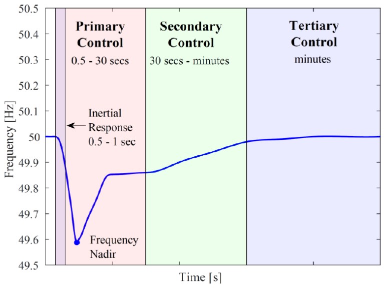

Figure 2: Time responses for each type of regulation

efficiency. Figure 3 shows the areas of regulation for under-frequency and over-frequency transients.

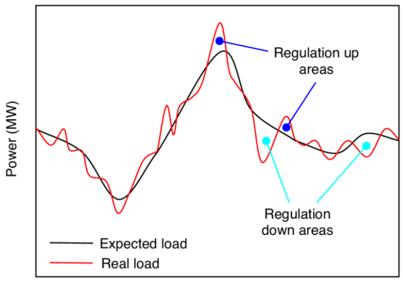

Figure 3: Simplified example of discrepancies in power production and areas of frequency regulation

IV. Future Prospects at Turbigo

Building on the success of the initial installation, IREN is planning additional storage capacity at Turbigo. The next phase involves a new 6 MW BESS to start building by 2026, integrated with the 2022 system and with potential expansion to over 20 MW. The preliminary design provided by the thesis work, carried out with AutoCAD, intends to be a comprehensive blueprint for the new system. The project was developed with in mind the specific requirements from the client, compliance with the existing system, and the necessary characteristics imposed by Terna in order to provide support for frequency regulation.

V. Proposed Layout for the future BESS

A battery energy storage system requires three basic components: batteries, a Power Conversion System(PCS) and a transformer to interface with the medium-voltage switchboard, as was depicted in figure 1.
First, it was decided to use the same type of batteries as those already used for other systems. These were arranged in racks and then in containers, resulting in two subsystems, each with an energy capacity of 3 MWh.
Subsequently, the PCS group and the transformer were studied. Given that the energy dimensions of the subsystems were similar to those studied in the previous case studies, after the necessary verification calculations, the same components already used for the other Turbigo's subsystems were chosen. A modular inverter, typically used for photovoltaic systems, was chosen for the PCS, while a double-winding transformer was chosen for the transformer, for which installation under the grid is recommended. Both componwnts are shown in figure 4.

Figure 4: Photo of the chosen transformer and PCS group

The proposed diagram suggested for the new BESS is shown in figure 5. The principle of redundancy was applied, therefore it was decided to divide the required quantities into equal subsystems, so that even in the event of failure of one of the components, the other subsystems could continue to operate and compensate for the loss. In order to complete the project, the size of all the required installation cables was determined, as were the necessary safety measures.

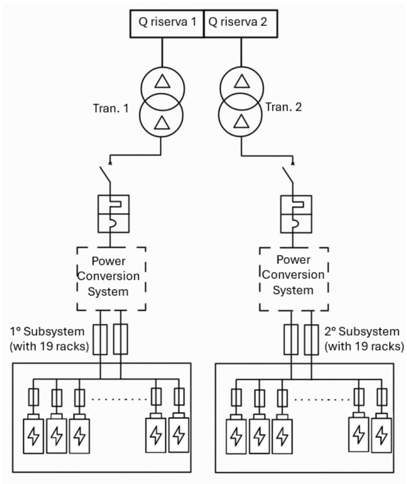

Figure 5: Diagram of the proposed BESS

VI. Conclusions

The case studies and design proposal illustrate how BESS can effectively combine technical efficiency, economic profitability, and environmental goals. By integrating Battery Energy Storage Systems (BESS) with existing thermoelectric plants and with many other applications explained in the text, a tangible contribution can be made to a more resilient and sustainable electricity grid. IREN Energia's initiatives demonstrate that storage integration is a strategic investment in the future of the grid because in itself reveal the potential for profit and advancement in the future electricity market. This work provides a concrete design and strategic framework in the developing and installation of the BESS the planned 2026, in order to facilitate the work of the future assigned engineers on the project.