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Modelling and simulation of a Li-ion energy storage system: Case study from the island of Ventotene in the Tyrrhenian Sea

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ABSTRACT

Energy storage systems (ESSs) are increasingly used in small islands that are not connected to the continental grid and, hence, only rely on local power sources (e.g. diesel generators). The use of ESSs allows to efficiently adapt to load seasonal variations and changes in renewable energy production as well as to increase the efficiency of diesel generators. On the other hand, achieving a proper dimensioning of system components and efficient operation of an ESS in an established power station may be a non-trivial task. In order to assist this process, preliminary modelling and simulation are fundamental steps, as they allow to work on "virtual prototypes" of the plant, enabling efficient components dimensioning as well as the development and test of system operation strategies. In this work, a Matlab-based simulation tool is developed for an ESS installation in Ventotene island in the Mediterranean Sea. The system model is detailed and simulation results are provided, showing that the developed simulation tool is able to describe both long-term dynamics and transient phenomena. The final user of the simulation tool is the industrial partner, i.e. Enel S.p.A., that has provided the technical information on the Ventotene power station.

1. Introduction

In most of Mediterranean minor islands, where the grid extension is difficult, the energy need is supplied by local electric power stations, typically based on diesel generators, whose efficiency is questionable. Indeed, on one hand engine generators represent a reliable and flexible source of power that can be adapted to varying loads, on the other hand the fuel price is high and the transportation and logistics are challenging and costly in these geographical areas.

It is worth pointing out that, tourism represents an important economic activity in these islands and it depends on a reliable, affordable, and environmentally friendly energy supply. In particular, environmental sustainability plays an important role in tourism: the lower the environmental impact of tourism activities, in terms of energy consumption, the longer touristic services can be available to future users and create revenue. Furthermore, as tourists are becoming more aware about their environmental footprint, the demand for sustainable tourism is growing [1].

In this scenario, renewable energy sources may be more economically viable than fossil fuel technologies, as confirmed by the European Commission and the United Nations Conference [2–4], which have highlighted the need to provide this kind of islands with renewable energy. Examples of renewable energy technologies range from solar PV (Photovoltaic) systems to SAC (Solar Air Conditioning) systems, which use solar heat to provide cooling and heating, just to name a couple. On the other hand, the natural variability of these energy sources together with the fluctuations of the electricity demand must be managed appropriately to ensure continuous availability and efficient use of the generated energy.

Energy storage systems (ESSs) are one of the solutions adopted to manage the variability of the sources and demand in the islands [5]. It is worth remarking that ESSs can both integrate renewables and increase the operating efficiency of diesel generators [6,7]. In particular, the latter are typically much more efficient when

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operating at high load factors, and the addition of storage can significantly reduce the amount of time in which they operate in low-efficiency conditions. For this reason, storage can be cost-effective even in the absence of renewables, due to its ability to increase the efficiency of diesel generators. However, ESSs are generally complex and their design, integration, monitoring, operation and maintenance are non-trivial tasks. Before their installation and use, a careful analysis and a simulation effort is needed to elaborate an appropriate ESS design, e.g. the storage capacity, and to develop and test operating strategies; moreover, thanks to modelling and simulation, the performance of the system can be evaluated, e.g. the control system performance, and the evolution of parameters of interest, such as the State-of-Charge (SOC) and the State-of-Health (SOH) of the storage, during typical usage situations can be monitored.

1.1. Potential impact and contribution

In this paper, we consider an ESS installation in a Mediterranean context, the island of Ventotene. This island, with Santo Stefano, Ponza, Palmarola, and Zannone, is part of the Pontine archipelago in the Tyrrhenian Sea, which is located off the coast on the border between Lazio and Campania regions, Italy, Fig. 1. The island has volcanic origins, it has an elongated shape, with a length of 2.7 km, a maximum width of about 800 m, and an area of 1.54 km^2. Ventotene island has a typical Mediterranean climate: mild winters and hot summers with high relative humidity and consistent wind speed. The island has about 750 permanent resident inhabitants, but during summertime this number increases up to about 2500 due to the tourism, thus resulting in a considerable increase in energy needs. The island is not connected to the electric grid on the mainland, and electricity is locally produced by means of a diesel power plant. In particular, the electric energy consumption is shared as follows: 25% domestic uses, 22% commercial uses, 19% civil uses mainly related to the tourist sector, and 11% network losses.

The introduction of an ESS in this scenario would allow to achieve two main results: (1) the efficiency of the diesel power plant can be enhanced by having the generators always operating within their maximum efficiency region, despite the seasonal variability of the loads, thanks to the peak-smoothing effect of the storage system; (2) the future introduction of renewable energy sources to reduce the diesel generators burden, such as PV systems, can be straightforward. However, as mentioned before, careful modelling and simulation efforts are needed before the ESS installation, to allow for proper dimensioning of components and development of operation strategies.

Consequently, in this paper we have developed a Matlab-based simulation environment for the ESS installation in the island of Ventotene. The ESS model includes all the main system components, such as the Li-ion (lithium-ion) batteries, the power converters, the transformers, the protections, the HVAC system, and the control system. The information about the system architecture, technology, and technical data has been provided by the partner Enel S.p.A.

The development of an ESS simulation environments requires models for all the system components, as well as a clear definition of the relations between them. In the scientific literature there are various type of models for the main components of an ESS, offering different degrees of accuracy and complexity. In this paper, we have chosen to use simple models but accurate enough in order to develop a simulation tool which can be effectively employed to simulate the effect of different design decisions, e.g. the storage capacity, or to evaluate the evolution of several metrics of interest, such as the SOC and SOH, during typical charge and discharge cycles. Moreover, due to its moderated computational burden, the ESS model can be potentially employed for real-time applications (e.g. control, supervision, and fault detection). Finally, it is worth pointing out that, to the best of the authors' knowledge, for the first time there is a readily available simulation environment for the power station and energy storage system of Ventotene island.

Fig. 1. Map of the Ventotene island [8].