ARTICLE IN PRESS

Renewable and Sustainable Energy Reviews xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Legislative and economic aspects for the inclusion of energy reserve by a superconducting magnetic energy storage: Application to the case of the Spanish electrical system

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ARTICLE INFO

Keywords:
Energy storage
Superconduction
Economic viability
Legislation

ABSTRACT

With the encouragement from renewable energies, elements of the electrical system are magnified which make possible a suitable connection to the electrical network. Among others, energy storage systems (ESSs) are emphasized because of their impact. This article discusses two essential aspects to take into account for an ESS, that is the regulatory framework and the economic aspect. In particular, it focuses on superconducting magnetic energy storage (SMES) in the Spanish electrical system. An analysis is performed on the legislation and regulations that apply to energy storage systems, which may affect in a direct or indirect manner its inclusion. This is accompanied by an analysis of the legislation in different countries to assess the situation in Spain in this regard, by comparison. Another point to take into consideration, which is crucial for the correct development and inclusion of this type of elements, is the economic viability- showing the costs of manufacturing and maintenance of these systems. Although it is necessary to keep investigating to lower the costs, economic benefits are appreciated, among other things, owing to the increase of the reliability of the electrical network. This increase of the reliability is resultant from a decrease of the cuts of service and the improvement of the quality of the energy.

1. Introduction

The growing concern for the environment and climate change over the past years has led to several voices beginning to question the present electric model. For some decades, the use of energy resources of renewable origin [1], which limits the use of polluting sources, has been promoted. Furthermore, the use of strategies that make more rational and efficient consumption possible, such as demand management, has been encouraged.

Considering the inclusion of sources of renewable energy generation in the electrical system, in which the generation of energy by wind turbines and solar photovoltaic panels stands out [2], the use of elements that make energy storage possible is necessary. This is owing to the generation of irregular power that is largely dependent on weather conditions.

Energy storage systems (ESS) can be characterized by different metrics that facilitate the choice of one device or another [3]. The devices that are currently marketed and/or in development are grouped into four major groups: Electrochemistry (different types of batteries), mechanical (FES, PHS, CAES), electrical (SMES, EDLC) and heat.

Approximately 95–98% of the total, storage at the global level is based on PHS owing to the simplicity and maturity of its technology. In spite of this, the quota of ESS compared with that of PHS has grown from less than 1% in 2005 to more than 1.5% in 2010 and 2.5% in 2015 (a growth rate greater than 10%) [4,5].

These systems should support the proper functioning of the

Abbreviations: AENOR, Spanish Association for Standardization and Certification; AIT, Average Interruption Time; BSCCO, Bismuth Strontium Calcium Copper Oxide; CAES, Compressed Air Energy Storage; CEN, European Committee for Standardizacion; CENELEC, European Committee for Electrotechnical Standardization; CNC, Coal Not Consumed; COPANT, Panamerican Commission on Technical Standards; EDLC, Electric Double Layer Capacitor; EN, European Norms; ENS, Energy not supplied; ESS, Energy Storage System; EU, European Union; FES, Fly Energy Storage; FIT, Feed in Tariff; GDP, Gross Domestic Product; GHG, Greenhouse Gases; HTS, High Temperature Superconductor; ISO, International Organization for Standandarization; LANL, Los Alamos National Laboratory; LTS, Low Temperature Superconductor; PHS, Pumped Hydro Storage; OP, Operating Procedure; REE, Spanish Electricity Network; SMES, Superconducting Magnetic Energy Storage; UNE, Una Norma Española; UPS, Uninterruptible Power Supply; YBCO, Yttrium Barium Copper Oxide

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http://dx.doi.org/10.1016/j.rser.2017.09.012
Received 16 May 2017; Received in revised form 23 July 2017; Accepted 4 September 2017
1364-0321/

Please cite this article as: Colmenar-Santos, A., Renewable and Sustainable Energy Reviews (2017), http://dx.doi.org/10.1016/j.rser.2017.09.012

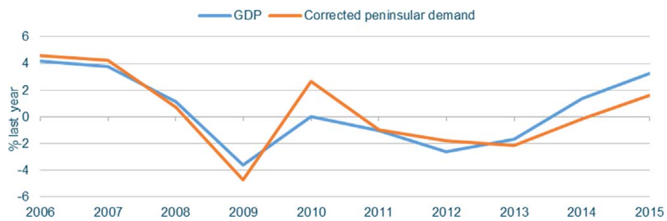

Fig. 1. Comparative GDP vs energy demand [6].

network. It is necessary to bear in mind that the supply and the quality of energy are categorized as a basic need in everyday life. As a result, electricity consumption has been associated with the level of development of a city, region or country, and its evolution has been reflected in its gross domestic product (GDP). Fig. 1 shows the variation of the demand for energy in peninsular Spain in comparison with the evolution of the GDP in recent years.

Considering the characteristics of each of energy storage system, there are plenty of cases of the use of elements. The main applications that the ESS are capable of realizing are load tracking applications, energy storage, emergency elements, systems of uninterruptible power supply (UPS), fitness levels of voltage and frequency regulation and elements of protection [7,8].

The main aim of this article is to analyse the storage of magnetic energy by superconductivity (SMES) system. This type of systems has not reached commercial ripeness for generalized use in a network, as reported [9], owing to different aspects. These problems can be summarised as resulting from high cost of manufacture/maintenance, technical difficulty in the application in different environments and the lack of normative support.

An SMES system allows the storage of energy under a magnetic field because the current through a coil is cooled at temperature below the critical temperature of superconductivity. The system is based on a superconducting coil, a cooling system that allows the critical temperature to be obtained, and an electrical and control system for the adaptation of currents and the optimization of the process.

Given the large spectrum of research concerning the solution of the problematic technique for the inclusion of SMES systems in different configurations, this article focuses on two important aspects to enhance its use in power system, that is, legislative and regulatory aspects and the economic aspect.

To perform a correct analysis of this type, the status of capacity of the main characteristics of this type of ESS must be born in mind, as summarised in Table 1. The characteristics of these systems may vary depending on the type of SMES. SMES are categorized according to their critical temperature (Tc), LTS (NbTi) and HTS (YBCO, BSCCO), and according to the configuration for their use [10–17], in which the optimization of the performance of the device is searched for in different processes and systems. This implies betting for the investigations of new alloys with higher critical temperature than the HTS [18], the optimization of the elements of electrical adaptation, as well as investigations in the systems of regulation and control [19] or the study of the inclusion of these systems in the microgrids/smart grids [20,21].

Owing to the characteristics of these type of systems, applications are restricted to a group of potential uses focused on electrical power systems, which are essential for providing an adequate quality system. Table 2 shows the applications of this type of ESS.

The methods used to carry out the investigation of this article are outlined in Section 2. In this section, the legislation on ESS for the application in the Spanish electrical system is shown as an example of a system in which the penetration of renewable energies has had a high impact. The main problem that prevents the complete maturation of the system, the economic casuistry, and a feasibility analysis of such a system are also addressed in this section. This is why the economic impact of its use in the electrical system, from manufacturing costs to maintenance costs, is analysed. The results of the economic study concerning the inclusion of SMES storage systems in the electricity network are presented in Section 3. This allows the possible economic benefits of the inclusion of these systems in the electricity network, and other indirect benefits to be determined.

The legislative and normative issues are discussed in Section 4, both in terms of standardization of the equipment and regulation, conditioning the implementation of SMES systems and its competitiveness with other systems [42]. Finally, Section 5 is reserved to show the main conclusions obtained from the normative and economic study of these systems.

2. Material and methods

For this case study, an analysis differentiated in two parts has been realized. On the one hand, the Department of Energy of Spain has the legislative and normative information relative to the whole process of generation and energy consumption. All legislation approved in relation to the Spanish electricity system is published in the BOE (Official Bulletin of the State), this being an essential reference. This legislation affects, in a direct or indirect way, the systems of energy storage. With regard to the legislation in other countries, information can also be found primarily in the concerned ministries or departments of the State. The normalization and standardization are detailed in Appendix A.

Various documents were analysed for the economic study: the economic cost of the construction of SMES, the potential economic benefits of the inclusion of SMES in the electrical system and the environmental benefit use of an ESS.

Finally, the amount of harmful gasses generated from coal consumption was analysed and the possible saving from the inclusion of the ESS. For the quantity of generated gasses it is necessary to bear in mind the type of coal that is mainly consumed and the proportion of gasses generated by typology for each kilogram of consumed coal. With this information, it is possible to perform an analysis of the large amounts of these gasses that might be avoided thanks to the ESS, as well as determine the economic implications of reducing the emission of these gasses.

2.1. Theoretical framework

At the legislative level, in Spain there is no law or specific regulations that enable the research, development and implementation of these systems. However, the inclusion of other ESS as kinetic energy storage has been promoted. A laboratory prototype has been developed which an emulator for railway catenary, an emulator of consumption of electric vehicles and a unit for the storage of energy based on ultracapacitor have been integrated and tested on a system installed in the underground of Madrid [43]. Also a flywheel of 25 kW, 10 MJ has been adapted for operation in a microgrid, for the application as

Table 1
Main characteristics of a SMES [3,7,8,22–38].

Daily self-discharge (%)	Energy Density (Wh/L)	Specific energy (Wh/kg)	Power Density (W/L)	Specific power (W/kg)	Power (MW)	Response time	Discharge time	Suitable storage duration	Efficiency (%)	Lifetime (yr)	Lifetime (cycles)
10–15	0,2–6	0,5–5	1000–4000	500–2000	0,01–10	< 10 ms	ms-min	min-h	> 90	20 +	$5 \cdot 10^4$