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Overview of current development in electrical energy storage technologies and the application potential in power system operation

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Анотація

Виробництво електричної енергії різко змінюється в усьому світі через необхідність скорочення викидів парникових газів та впровадження змішаних джерел енергії. Електромережа стикається з великими проблемами в передачі та розподілі для задоволення попиту з непередбачуваними щоденними та сезонними коливаннями. Зберігання електричної енергії (ЗЕЕ) визнано основою технологій, що мають великий потенціал для вирішення цих проблем, завдяки чому енергія зберігається в певному стані, відповідно до використовуваних технологій, і перетворюється на електричну енергію, коли це необхідно. Однак широке розмаїття варіантів і складних характерних матриць ускладнює оцінку конкретної технології ЗЕЕ для конкретного застосування. Ця стаття має намір пом'якшити цю проблему, надаючи вичерпну та чітку картину сучасних технологій, що існують, та де вони будуть придатні для інтеграції в систему виробництва та розподілу електроенергії.

Ключові слова: *Накопичення електричної енергії; Огляд; Система живлення; Технічні та економічні характеристики діяльності; Потенціал застосування.*

Abstract

Electrical power generation is changing dramatically across the world because of the need to reduce greenhouse gas emissions and to introduce mixed energy sources. The power network faces great challenges in transmission and distribution to meet demand with unpredictable daily and seasonal variations. Electrical Energy Storage (EES) is recognized as underpinning technologies to have great potential in meeting these challenges, whereby energy is stored in a certain state, according to the technology used, and is converted to electrical energy when needed. However, the wide variety of options and complex characteristic matrices make it difficult to appraise a specific EES technology for a particular application. This paper intends to mitigate this problem by providing a comprehensive and clear picture of the state-of-the-art technologies available, and where they would be suited for integration into a power generation and distribution system.

Keywords: Electrical energy storage; Overview; Power system; Technical and economic performance features; Application potential.

Introduction

Global electricity generation has grown rapidly over the last decade. As of 2012, the annual gross production of electricity reached approximately 22,200 TW h, of which fossil fuels (including coal/peat, natural gas and oil) contribute around 70% of global electricity generation. To maintain the power network stability, the load balance has mainly been managed through fossil fuel power plants. To achieve the target of reducing CO2 emissions, future electricity generation will progress with diminishing reliance on fossil fuels, growing use of renewable energy sources and with a greater respect for the environment. However, most renewable energy sources are intermittent in their nature, which presents a great challenge in energy generation and load balance maintenance to ensure power network stability and reliability. Great efforts have been made in searching for viable solutions, including Electrical Energy Storage (EES), load shifting through demand management, interconnection with external grids, etc. Amongst all the possible solutions, EES has been recognized as one of the most promising approaches.

EES technology refers to the process of converting energy from one form (mainly electrical energy) to a storable form and reserving it in various mediums; then the stored energy can be converted back into electrical energy when needed. EES can have multiple attractive value propositions (functions) to power network operation and load balancing, such as: helping in meeting peak electrical load demands, providing time varying energy management, alleviating the intermittence of renewable source power generation, improving power quality/reliability, meeting remote and vehicle load needs, supporting the realization of smart grids, helping with the management of distributed/standby power generation, reducing electrical energy import during peak demand periods.

Classification of electrical energy storage technologies

There are several suggested methods for categorization of various EES technologies, such as, in terms of their functions, response times, and suitable storage durations. One of the most widely used methods is based on the form of energy stored in the system, which can be categorized into mechanical (pumped hydroelectric storage, compressed air energy storage and flywheels), electrochemical (conventional rechargeable batteries and flow batteries), electrical (capacitors, supercapacitors and superconducting magnetic energy storage), thermochemical (solar fuels), chemical (hydrogen storage with fuel cells) and thermal energy storage (sensible heat storage and latent heat storage).

<u>Pumped Hydroelectric Storage (PHS)</u>

PHS is an EES technology with a long history, high technical maturity and large energy capacity. With an installed capacity of 127–129 GW in 2012, PHS represents more than 99% of worldwide bulk storage capacity and contributes to about 3% of global generation. A typical PHS plant uses two water reservoirs, separated vertically. During off-peak electricity demand hours, the water is pumped into the higher level reservoir; during peak hours, the water can be released back into the lower level reservoir. In the process, the water powers turbine units which drive the electrical machines to generate electricity. The amount of energy stored depends on the height difference between the two reservoirs and the total volume of water stored. The rated power of PHS plants depends on the water pressure and flow rate through the turbines and rated power of the pump/turbine and generator/motor units, and.

<u>Compressed Air Energy Storage (CAES)</u>

In addition to PHS, CAES is another type of commercialized EES technology which can provide power output of over 100 MW with a single unit. During the periods of low power demand, the surplus electricity drives a reversible motor/generator unit in turn to run a chain of compressors for injecting air into a storage vessel, which is either an underground cavern or over ground tanks. The energy is stored in the form of high pressure air. When the power generation cannot meet the load demand, the stored compressed air is released and heated by a heat source which can be from the combustion of fossil fuel or the heat recovered from the compression process. The compressed air energy is finally captured by the turbines. The waste heat from the exhaust can be recycled by a recuperator unit.

<u>Capacitor and supercapacitor</u>

A capacitor is composed of at least two electrical conductors (normally made of metal foils) separated by a thin layer of insulator (normally made of ceramic, glass or a plastic film). When a capacitor is charged, energy is stored in the dielectric material in an electrostatic field. Its maximum operating voltage is dependent on the breakdown characteristics of the dielectric material. Capacitors are appropriate for storing small quantities of electrical energy and conducting a varying voltage; they have a higher power density and shorter charging time compared to conventional batteries. However, they have limited capacity, relatively low energy density and high energy dissipation due to the high self-discharge losses. According to these characteristics, capacitors can be used for some power quality applications, such as high voltage power correction, smoothing the output of power supplies, bridging and energy recovery in mass transit systems.

<u>Superconducting Magnetic Energy Storage (SMES)</u>

A typical SMES system is composed of three main components which include: a superconducting coil unit, a power conditioning subsystem, and a refrigeration and vacuum subsystem. The SMES system stores electrical energy in the magnetic field generated by the Direct Current (DC) in the superconducting coil which has been cryogenically cooled to a temperature below its superconducting critical temperature. In general, when current passes through a coil, the electrical energy will be dissipated as heat due to the resistance of the wire; however, if the coil is made from a superconducting material, such as mercury or vanadium, under its superconducting state (normally at a very low temperature), zero resistance occurs and the electrical energy can be stored with almost no losses. One commonly used superconducting material is Niobium–Titanium which has a superconducting critical temperature of 9.2 K. In the discharging phase, the SMES system can release the stored electrical energy back to the Alternating Current (AC) system, by a connected power converter module. The magnitude of stored energy is determined by the self-inductance of coil and the current flowing through it.

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