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Techno-economic review of existing and new pumped hydro energy storage plant

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ABSTRACT

There has been a renewed commercial and technical interest in pumped hydro energy storage (PHES) recently with the advent of increased variable renewable energy generation and the development of liberalized electricity markets. During the next 8 years over 7 GW of PHES capacity will be added to the European network while projects are also planned in the USA and Japan. This paper provides a review of existing and proposed PHES plant and discusses the technical and economic drivers for these developments. Current trends for new PHES development generally show that developers operating in liberalized markets are tending to repower, enhance projects or build 'pump-back' PHES rather than traditional 'pure pumped storage'. Capital costs per kW for proposed PHES in the review region range between €470/kW and €2170/kW, however these costs are highly site and project specific. An emergence has also been observed in recent PHES developments of the use of variable speed technology. This technology, while incurring slightly higher capital costs, offers a greater range of operational flexibility and efficiency over conventional PHES. This paper has primarily been prompted by a lack of detailed information on PHES facilities worldwide and reviews current developments in the context of market and generation mix changes. The most recent large scale review of PHES faculties was undertaken by the American Society of Civil Engineers Hydro Power Task Committee on Pumped Storage in 1996. In the absence of data in the literature on new PHES plant development, this review draws primarily on publicly available information from utilities, government bodies and electricity regulators. In the same context this study is limited to a review region of the European Union, Japan and the United States as information on developments outside these areas is difficult to procure. This paper also gives a review of locations and proposed timelines for new PHES development and provides a thorough up-to-date overview of the development trends of this technology.

Contents

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1. Introduction

PHES is currently the only commercially proven large scale (>100 MW) energy storage technology with over 300 plants installed worldwide with a total installed capacity of over 95 GW [1]. In recent years there has been a flurry of interest in the technology resulting in the planning and building of a number of new plants in Europe and Japan. As of 2009, the European Union has an installed PHES capacity of 36 GW accounting for 4.3% of total generating capacity within the region. USA has an installed capacity of 21.8 GW with over 39 PHES plants and Japan with 34 plants (Plant with installed MW capacity >200 MW) has an installed capacity of 24.5 GW. While PHES was previously developed in many countries to facilitate the integration of large baseload generation, there has been a recent renewed interest in the technology with an increase of variable renewable generation such as wind in many countries. This paper examines the drivers and costs behind both new PHES development and existing developments. The majority of information gathered on new PHES development for this review paper comes directly from developer websites as there is a gap in this information in academic literature.

This paper is structured as follows: Section 2 introduces the technology and basic concepts of PHES; Section 3 reviews existing developments in the review region and details the owners of large PHES plant; Section 4 gives a general overview of proposed PHES and looks at the drivers for these developments. A detailed description of each proposed project is given on a country by country basis. Section 5 reviews the capital cost of new and exiting plant while Section 6 concludes with some observations on current trends.

While there are a large number of PHES plants in planning or early development stages in countries like the USA, the authors limited this review to plants deemed to be likely or very likely to be built. The principal criteria used to make this assessment were (1) whether construction has commenced and (2) has the Environmental Assessment Stage of planning been completed.

2. Pumped hydro energy storage

2.1. Technology

The fundamental principle of PHES is to store electric energy in the form of hydraulic potential energy. Pumping typically takes place mainly during off-peak periods, when electricity demand is low and electricity prices are low. Generation takes place during peak periods, when electricity system demand is high. Pumping and generating generally follow a daily cycle but weekly or even seasonal cycling is also possible with larger PHES plant.

The US Army Corps of Engineers distinguishes between two types of PHES [2] namely pure PHES and pump-back PHES. Pure PHES plants rely entirely on water that has been pumped to an upper reservoir from a lower reservoir, a river or the sea. Pure PHES are also known as 'closed-loop' or 'off-stream'. Pump-back PHES use a combination of pumped water and natural inflow to produce power/energy similar to a conventional hydroelectric power plant. Pump-back PHES may be located on rivers or valleys with glacial or hydro inflow. Fig. 1 shows a schematic of both Pure and Pump-back PHES.

The benefits of PHES to electrical system operations are well documented in textbooks and journals [3–7]. Its flexible generation can provide both up and down regulation in the power system while its quick start capabilities make it suitable for black starts and provision of spinning and standing reserve. A summary review of the operational characteristic of PHES in comparison to conventional power plant is provided in Table 1. In terms of operational characteristics and flexibility it is clear that gas turbine peaking plant such as OCGTs (open cycle gas turbine) offer some similar power system operation services, however generally at a higher capital cost. It would be interesting and useful to compare in detail the performance and benefits of PHES with those of OCGT and indeed other plant types. The purpose of this paper however is to provide a detailed review of PHES. The analysis provided in this paper could inform such a comparison.

3. Traditional development of PHES

PHES is a resource driven facility which requires very specific site conditions to make a project viable, i.e. high head, favourable topography, good geotechnical conditions, access to the electricity transmission networks and water availability. The most essential of these criteria is availability of locations with a difference in elevation and access to water. Some of the earliest PHES plants were built in the Alpine regions of Switzerland and Austria, regions that have a rich hydro resource and a natural complimentary topography for PHES. Prior to the emergence of liberalized

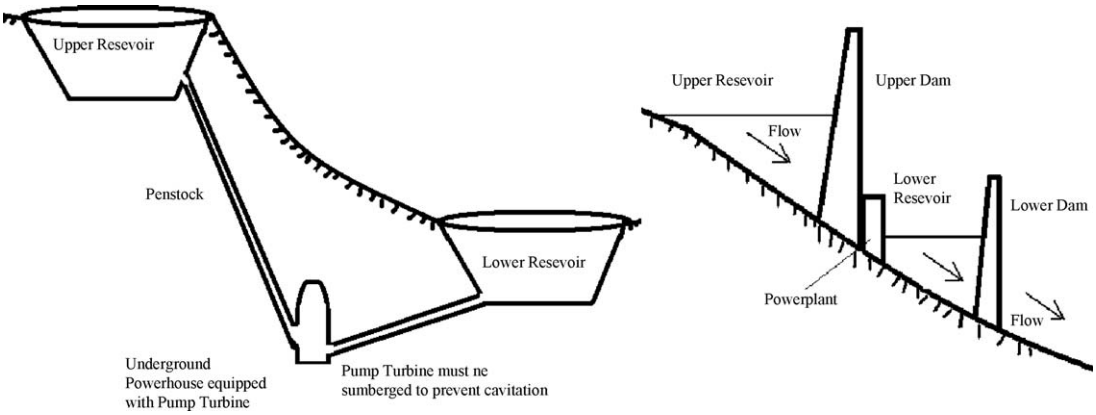

Fig. 1. Pure PHES on left and pump-back PHES on right.