Energy Storage for Wind Integration: Hydropower and other contributions

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Abstract— **The amount of wind power and other time-variable non-dispatchable renewable energy sources (RES) is rapidly increasing in the world. A few power systems are already facing very high penetrations from variable renewables which can surpass the systems' consumption during no-load periods, requiring the energy excess to be curtailed, exported or stored. The limitations of electric energy storage naturally lead to the selection of the well-known form of storing potential energy in reservoirs of reversible hydropower stations, although other technologies such as heat storage are also being used successfully. This paper reviews the storage technologies that are available and may be used on a power system scale and compares their advantages and disadvantages for the integration of fast-growing renewables, such as wind power, with a special focus on the role of pumped hydro storage.**

Index Terms— **Wind power, renewable integration, energy storage, balancing of wind power.**

I Introduction

The fast growing capacity of wind and other time-variable renewable energy sources (RES) is posing a new set of challenges to transmission systems operators (TSOs). One of the difficulties faced by TSOs is the non-dispatchability of these new renewable power sources, allied to daily and seasonal production profiles that, in most situations, do not follow the load consumption profile. Several countries already have a very high wind contribution from these sources: in 2010 Denmark had 22% wind penetration; Spain covered 16% of their electric energy demand with wind power; Portugal had a wind participation of 17% and Ireland had 11% [1]. In order to achieve annual wind energy contributions between 10 and 25% these power systems faced several periods when the percentage of wind power (and other non-dispatchable power stations) was very close to, and sometimes even above, total consumption.

The solutions to handling excess wind power or other non-dispatchable generation are to store the energy, export it or curtail it. Although curtailment of excess wind or solar power seems a solution, its renewable time-dependent nature, the growing capacities being installed and the large investments in renewable power plants encourage, when possible, co-ordination with the existing forms of energy storage, especially when transmission capacity for exporting to neighboring countries is limited. For the future, and in view of the increasing role of variable RES, it is important to assess how systems with higher shares of these sources can be operated and designed for efficient integration without violating system security, while maximizing their penetration and added value. Besides reducing the need for curtailment of RES, energy storage is also used for smoothing net load variations, allowing dispatchable base load units to remain operating when RES generation is high and reducing the need to dispatch peak power units when RES generation is low. Therefore, assessing the role and added value of energy storage, especially for well-known technologies such as pumped hydro storage (PHS), is actually of the utmost relevance for power systems with existing and planned high RES penetration.

Section II of this paper presents typical wind and consumption profiles for different power systems, indicating the necessity of storage, exporting facilities or curtailment. Section III describes energy storage technologies available at the power system scale that are being used among IEA Wind Task 25 member countries, while Section IV provides a cost/benefit analysis of power system energy storage options with a particular focus on the advantages and disadvantages of PHS. Some conclusions are presented in Section V.

II Profiles of Wind Generation and Load Consumption

In principle, large scale deployment of variable RES, namely wind, doesn't necessarily imply the installation and/or reinforcement of the energy storage capability. This is demonstrated by the fact that several European countries have already experienced a pronounced growth in wind capacity without changing (or even planning for) their energy storing capability. Nevertheless, the benefits of coordinating wind generation (especially for high penetrations) with hydro generation in countries and markets has been recognized and extensively utilized by most system operators that possess that capability [2].

The fact that wind generation has little or no power regulation capability introduces the concern of excess wind generation during periods of reduced load. That concern is amplified when some countries such as Denmark, Portugal and Spain exceeded a wind energy penetration of 15% that, as a natural consequence, led to periods when wind power and other RES (added by the required reserves) was sufficient to match the entire system demand. Moreover, several countries have already felt the need to curtail wind generation during periods of excess generation, e.g. Spain

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