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A comparative study of a wind hydro hybrid system with water storage capacity: Conventional reservoir or pumped storage plant?

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ABSTRACT

Hydropower reservoirs (of conventional and pumped storage plants) provide dispatchable power and large-scale energy storage. They are a suitable technology in autonomous power systems with high levels of renewable generation, because of their capacity to buffer intermittencies and high variability of renewable energies such as wind and solar power. This paper presents results of a study comparing the operation of a wind hydro hybrid system including a conventional hydropower with a reservoir and including a pumped storage hydropower plant. This comparative study was carried out based on the adaptation of software Homer (The Micropower Optimization Model) to simulate hydropower plants with water storage capacity and to simulate pumped storage hydroelectric plants. The case study of this paper arose from data related to Rio Grande do Sul, in southern Brazil. The case study is based on a river basin in southern Brazil for which two sites were identified; one below where can be installed the engine room and where there is a reasonable area to implement a water reservoir; other above where a reservoir may also be implemented for the case of pumped storage hydropower plant. The results show that the system with pumped storage plant naturally has the highest initial costs, but the optimal solution of the hybrid system with pumped storage plant require a smaller flooded area than the system with conventional reservoir, thus representing a lower environmental impact.

1. Introduction

Besides environmental benefits, one of the main advantages of some renewable energy technologies (like solar and wind power projects) is their reduced construction time. This enables them to provide a more accurate response to the load growth, while minimizing the financial risk that comes with borrowing millions of dollars to finance other types of plants for several years before they start generating their first kW of electricity [52]. However, autonomous power systems with high levels of renewable generation require adequate measures to overcome the intermittency and stochastic nature associated to most of these energy sources, in order to keep the balance between energy supply and consumption. This balance is important to maintain the quality of the electricity supply by regulating the grid frequency and voltage. A combination of dispatchable technologies and energy storage is one of the most common methods to achieve this equilibrium [45].

Besides providing dispatchable power and operating reserve with short start-up times and lower costs, hydropower reservoirs (of conventional and pumped storage hydro) are the main option for large-scale electricity storage in the form of potential energy, enabling their future consumption when the load exceeds the generation capacity available from the renewable source [16]. The generating capacity of conventional hydropower plants with reservoir (HWR) is constrained by site specific features, such as available head, reservoir capacity and hydrological limitations (stream flow entering the reservoir, rainfall, seasonal weather conditions, additional reservoir uses, etc.). Hydropower plants with pumped storage capabilities partially overcome these issues, by recovering rejected (excess) energy from wind or solar farms to refill an upper reservoir, achieving a maximum exploitation of these intermittent renewable resources.

Pumped storage hydropower (PSH), based on the same principles of conventional hydro, is the most widely used large-scale electrical energy storage technology. According to the International Energy Agency International Energy Agency (IEA) [29], at least 140 GW of large-scale energy storage are currently installed in electrical power grids around the world, with 99% of this capacity coming from PSH technologies, and the other 1% from

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a mix of batteries, compressed air energy storage (CAES), flywheels and hydrogen storage. Barnhart and Benson [3] explain that storage is an attractive load-balancing technology because it increases reliability and flexibility of the power grid (especially in locations with ambitious climate-change policies), while at the same time it helps decreasing carbon emissions by reducing the transmission load and enabling spinning power plants to operate at optimum efficiency.

Regarding energy storage through PSH, Glasnovic and Margeta [25] mention that if site conditions are suitable, the smaller reservoirs and different possible configurations of the PSH plants allow building the different components of the hybrid power system close to energy consumers. This would significantly reduce energy losses due to transport, which could range from 8% to 15%. An important consequence of this possibility is the encouragement of new schemes for use of renewable energy resources, such as solar chimneys [42,36].

Regarding the suitability of water reservoirs for application as PSH, Kucukali [34] proposes a basically qualitative method for assessing reservoirs and establish a ranking for the development of storage capacity through plants in an energy system. The method was applied to Turkey and indicated that the reservoirs are suitable for use as power plants. This method can be a powerful tool for the development of legislation that encourages the implementation of this kind of power plants, suitably overcoming the technical requirements.

Increasing the share of renewable energies in the total energy supply is a priority for many countries, caused by economic, environmental and climate change concerns. Unlike fossil fuel power plants, renewable energy sources have a significant impact on the reduction of greenhouse and pollutant gas emissions. However, there are concerns over the ability to effectively integrate large amounts of intermittent power generation, such as solar or wind power, into the electrical grid [16]. Therefore, the main issue for the successful integration of these technologies is how to best manage the intermittency and stochastic nature associated to most of them. Hydropower reservoirs (of conventional and PSH plants) are the most mature and widely used technology to provide dispatchable power and large-scale energy storage, two of the main solutions implemented for a better integration of renewable energies.

During recent years, a number of papers have been published on the subject of size optimization of hybrid power systems including PSH to recover excess energy from intermittent sources, in order to serve the loads in isolated (stand-alone) or autonomous (independent, but able to connect to the grid) hybrid power systems. These papers are based on the application of computer models that are ready and available on the Internet (commercially or not) or that were written by their authors. This paper is focused on creating and implementing tools that can find universal access and application, contributing to popularize the results.

Some of them are the works on Greek islands written by Anagnostopoulos and Papantonis [2], Kaldellis et al. [31] or Kapsali and Kaldellis [32]. Anagnostopoulos and Popantonis [2] presents a numerical methodology for the design of a pumped storage power plant which allows the recovery of rejected energy from wind farms due to grid limitations. The method was applied in some wind farms on the island of Crete, Greece, and revealed among other conclusions the possibility of recovery of 40–60% of the rejected energy. Kaldellis et al. [31] and Kapsali and Kaldellis [32] perform an energy analysis in order to find a techno economical solution which proves an optimal design for a wind hydro hybrid system with pumped storage capacity. This analysis has been developed for application to the island of Lesbos in the Aegean archipelago.

An interesting parameter to be considered which may contribute to the feasibility of hybrid systems is the possible complementarity between energy resources. It is difficult to manipulate the energetic complementarity considering an isolated place but complementarity can be a tool for managers to decide on the prioritization of projects over a certain region. The optimal sizing of generating units and reservoirs and energy storage devices can take into account the complementarity of energy resources, possibly resulting in reduced costs and increased efficiency, as discussed by Beluco et al. [7], Beluco et al. [8].

An important component in this process is the system design considering market linkages and the works of Bayón et al. [4], Malakar et al. [37] and Souza et al. [51] discuss the wind systems operating with reversible hydro power plants inserted respectively into the Spanish, Indian and Portuguese markets. Bueno and Carta [12] also consider this combination to increase the penetration of renewables in the energy system of the Canary Islands. Dursun and Alboyaci [20] studied the influence of this kind of system to meet the electricity demand in Turkey. Ming et al. [38] present an interesting discussion on the participation of reversible hydro power plants in Chinese integrated system, which experienced a large increase of these plants over the past decade. Nejad [39] and Sangi [47] present similar results for PV systems and solar chimneys in Iran.

Glasnovic and Margeta [25] and Glasnovic et al. [26] explore the Concept-H, based exclusively on the use of renewable resources and predominant use of water reservoirs as energy storage. Foley et al. [22] perform a long term study on the cost of power plants considering their influence to firm large wind farms. His model was fitted with the WASP IV software and applied to the electrical system of Ireland and Northern Ireland. The WASP (Wien Automatic System Planning) is a software tool created for the study of the expansion of energy systems. It is a comprehensive study that takes into account technical, economic and environmental aspects. Among others, it is also possible to cite the publications by Castronuovo and Lopes [15], Krajačić et al. [33], Nyamdash et al. [40] and Chang et al. [16].

According to Sinha and Chandel [50], and with thousands of users around the world, Homer is the most widely used tool in research studies related to hybrid power systems, mainly due to its user-friendly interface and detailed documentation. Homer is described by Georgilakis [24] as a computer model that assists in the design of hybrid power systems, including several different power generation technologies for this purpose (PV modules, wind turbines, run-of-river hydropower, batteries, generators, etc.). Homer is mainly an economical model dedicated to system selection and pre-sizing which models the physical behavior and lifecycle cost of a power system. Connolly et al. [17] analyzed 37 different tools for simulation and optimization of hybrid systems and clearly Homer is emphasized among others as one of the most comprehensive tools and simultaneously an easier access tool.

Homer executes three main tasks: simulation, optimization and sensitivity analysis. About the simulation, performing energy balance calculations for each of the 8760 h in a year, Homer estimates the cost and determines the feasibility of a system design. A complete and detailed output is produced for every feasible system configuration in the search space. Regarding optimization, after simulating all the possible system configurations, Homer sorts the feasible projects according to the Net Present Cost (NPC). And, finally, most numerical input variables in Homer (with exception for decision variables) can be sensitivity variables. By assigning more than one value to each input of interest, this capacity of the model is useful to observe how the results could vary, either because the range of values is uncertain or because they represent a variety of possible applications. And one of its greatest advantages is the way the data are presented, allowing full and immediate access to the results.