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Enhanced-Pumped-Storage: Combining pumped-storage in a yearly storage cycle with dams in cascade in Brazil

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ABSTRACT

The new frontier for hydropower electricity generation in Brazil, the Amazon region, cannot be used for energy storage as the construction of storage reservoirs would have deep environmental and social impacts, thus run-of-the-river dams have been built instead. If Brazil still wants to generate 80% of its electricity from hydropower, there is the need to increase the country's energy storage capacity so that the excess generation coming from the dams in the Amazon region during the wet period can be used during the dry period. This article presents four ways to increase the storage capacity of a watershed. The most innovative alternative involves a large-scale pumped-storage site combined with a series of hydropower dams in cascade, which could store energy by pumping water to a new reservoir during the wet period and generate energy by releasing the stored water during the dry period. Even though pumped storage schemes have an average efficiency of around 75%, it has been calculated that the combination of a pumped storage site and a series of hydroelectric dams in cascade can increase the overall storage efficiency up to 90% and double the storage capacity of a watershed. This scheme was called EPS (Enhanced-Pumped-Storage).

1. Introduction

Storing energy is a necessity that has come to the attention of various research groups and companies. New technologies such as the hydrogen fuel cell [1] and graphene ultracapacitors [2] are being developed but are not technically mature. Another approach proposed is to use electric car batteries to store electricity through a smart grid system [3]. Reviews of different energy storage technologies and their process description can be seen in Refs. [4,5]. However, almost all bulk generation capacity based on storage schemes, equivalent to over 130 GW [6], comes from PS (pumped-storage) due to its low cost and high energy conversion efficiency (70%–85%) [7,8] and this number is expected to further increase [9].

In Brazil around 80% of the electrical energy comes from hydroelectric power plants – unless there is a shortfall of rain [10]. This is because the combination of varying reservoir dams and run-of-the-river dams in the Brazilian watersheds was designed to generate a constant amount of electricity throughout the year. According to this scheme, during the wet period (December to April) some electricity is generated and some water is stored to fill up storage reservoirs. During the dry period (May to November), the stored water is used to generate electricity and the level of the dams is lowered. This design allows the river to generate a relatively constant amount of energy using the installed generation capacity at a high rate, reducing the cost of electricity.

The approach of relying on a constant hydroelectric generation in the Brazilian watersheds is reaching its feasible limit. Run-of-the-river dams that do not have storage capacity and generate power in proportion to the amount of water flowing in the river, are being built in the Amazon region [11]. This dam building approach is followed mainly because the geological formation of the rivers in the Amazon basin is relatively flat. A large flooded area would be required to store a small amount of energy and during the dry season the devastated area between the forest and the river will be so large that a severe impact to the environment and biosphere will result.

Apart from the lack of generation during the dry period, there is some electricity generation potential wasted as water bypasses dams not generating electricity during the wet period [12]. This waste is expected to increase with the development of the Amazon hydroelectric generation capacity (60% of the Brazilian hydropower potential), as there will be not enough storage capacity to store the

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excess energy generated during the wet period. Fig. 1 shows the average monthly energy potential, without including storage, in different regions in Brazil and that the generation in the wet period will considerably increase with the construction of run-of-the-river dams in the Amazon water basin (North), when most reservoirs of the integrated national power grid (Interlinked National System – SIN) should be already full (Fig. 2). A detailed study of the hydropower generation imbalance in Brazil is presented in Ref. [13].

Proposed solutions to reduce this seasonal generation imbalance have been studied. Some of these studies examine whether renewable energy sources could supplement the lack of hydroelectric generation during the dry period. For example, Da Silva et al. (2005) [15] and Riscosti and Sauer (2013) [16] show that wind power in the Brazilian Northeast could complement the lack of hydroelectric generation during the dry period in the region. CEBDS (Brazilian Business Council for Sustainable Development) (2013) [17] shows that the sugarcane harvest happens during the dry season and the combustion of its bagasse has the potential to generate around 15 GW of electricity. An increase in investment in intermittent renewable energy sources such as wind, biomass and solar is foreseen [11]. However, intermittent sources of energy cannot guarantee the supply of electricity and might increase the amount of energy wasted in the system.

This paper analyses four different approaches to increase the energy storage capacity of a watershed, focussing on Enhanced-Pumped-Storage schemes presented here. With these new techniques, the dams in the South, Southeast, Midwest and Northeast regions would generate more of their electricity during the dry period, in order to complement the new dams in the North, Amazon region, which would generate most of its electricity during the wet period.

1.1. Energy storage shortage in Brazil

For Brazil to supply its electricity demand, it stores energy during the wet period for generation during the dry period. In the nineteen seventies, the energy stored in the reservoirs, when full, had the capacity to supply energy for three to four years. Today, with the current demand for energy, these reservoirs can store energy for around 5 months, when full. Fig. 2 shows that the total

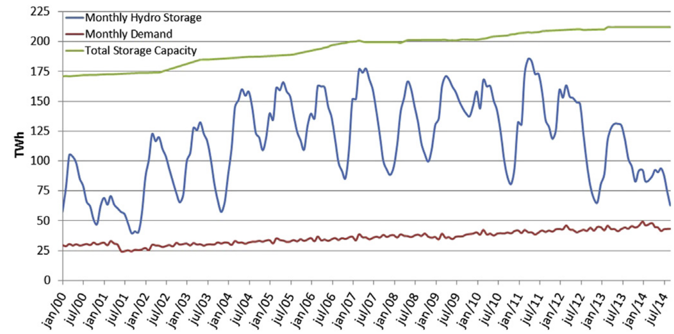

Fig. 2. Monthly hydropower storage, demand and total storage capacity in Brazil.

storage capacity increases with the increase in monthly demand for electricity. However, the total storage capacity will stop increasing but the monthly demand will continue increasing. Thus, the system will rely less on energy storage, resulting in a more volatile monthly hydro storage capacity and compromising the energy security of Brazil. The amount of months of hydropower storage is found by dividing the 'Monthly Demand' line by the 'Monthly Hydro Storage' line in Fig. 2. It should be noted that the 'Monthly Demand' is not only supplied with hydropower. Thermoelectric and other sources of energy also contribute to the supply.

As can be seen in Fig. 2, in July 2001, the monthly demand had to be considerably reduced, because there was not enough stored energy. This resulted in a deep energy crisis. This graph shows that this crisis impacted the economy so hard that the energy consumption only returned to the same level in January 2005.

In the beginning of March of 2014, a similar trend is appearing. In the Southeast, the volume of water in the reservoirs fell to the same level as in 2001, 34% [18]. However, since 2001 much has happened to reduce the risks of a new energy crisis. Transmission lines were installed, increasing the ability to transfer electricity from one region to another (in 2001, the energy that could have been generated in the South or in the North could not be transferred to the Southeast and Northeast due to lack of transmission lines). The country also received considerable generation capacity reinforcement, which totalled 33.8 GW in 2012, with thermoelectric power plants and

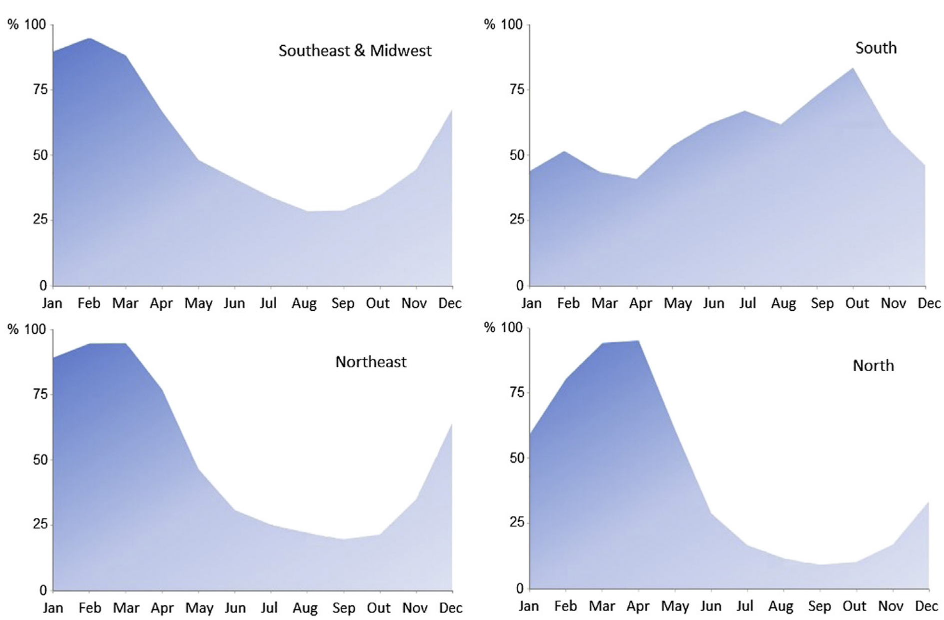

Fig. 1. Average monthly energy potential, without including storage, in different regions of Brazil for 1931–2009 [14].