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The contribution of wind-hydro pumped storage systems in meeting Lebanon's electricity demand

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ABSTRACT

Wind power technology is now a reliable electricity production system. It presents an economically attractive possible solution for the continuously increasing energy demand of Lebanon. However, the stochastic behavior of wind speed leads to significant disharmony between wind energy production and electricity demand. Hence, the prospect of creating a combined wind-hydro energy station is found to be a vital issue. This paper is an attempt to analyze the design of a pumping station and the performance of a hybrid wind-hydro power plant, in two dams in Lebanon (Quaraoun and Chabrouh), in order to choose the most suitable dam to store the energy surplus produced by wind power at night. An evaluation of the amount of water that could be pumped in both dams and the energy that could be produced from the stored electricity surplus are carried out in this paper, in order to select the most suitable dam to implement the hydro pumped storage power plant and store the electricity surplus. It is shown that the energy that could be produced in the dam of Chabrouh varies between 17 MWh and 698 MWh, while in the dam of Quaraoun is between 17 MWh and 768 MWh. An analysis of the cost of the energy produced by wind turbines per kWh and the produced water per m^3 are carried out in this paper as well.

Introduction

The challenge of producing sufficient energy to meet the ever increasing global energy consumption, the rapidly depleting fossil fuel reserves, and the serious environmental problems associated with the use of fossil fuels have motivated considerable research attention on clean energy sources. Wind energy is one of the several energy sources that are both environmentally preferable and renewable. Moreover, wind energy is abundant in nature, inexhaustible, fuel free, can generate power near load center, and thus eliminates energy losses associated with transmission network.

Lebanon is facing currently an acute energy crisis, due to lack of domestic energy resources, reduced production capacities and growing demand for energy. Integrating wind

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energy could reduce the impact of this crisis. A study has been made to select the most suitable sites to implement wind turbines in Lebanon and it is shown that five sites are most suitable for this purpose [1]. These sites are: Daher El Baydar, Klaiaat, Quaraoun, Cedars and Marjyoun. The mean annually wind speed of the selected sites for three years (2008–2008–2010) at 10 m of height is shown in Table 1 and its annual average frequency is shown in Fig. 1. As can be observed, the highest annual wind speed of 5.5 m/s is recorded in Daher El Baydar while the lowest of 3.77 m/s is recorded in Cedars.

The wind turbines selected for implementation generates maximum power of 7.5 MW, its total height is 135 m with a rotor diameter of 127 m. The average annual speed extrapolated at the hub height of the selected wind turbines (135 m) is shown in Fig. 2. As can be observed, the highest annual wind speed extrapolated at 135 m of height of 11.5 m/s is recorded in Daher El Baydar while the lowest of 7.8 m/s is recorded in Quaaoun. We found after a topographical analysis that 116 wind turbines could be erected in the five proposed wind farms [1]. After assessing the wind energy potentials of the five different sites in Lebanon, it has been shown that the total expected electricity supply (current and wind farms supply) could be greater than the demand at night in all months except in August and September, and a significant percentage of the demand during daytime could be covered [1].

Wind power production introduces however uncertainty in operating a power system: it is variable and partly unpredictable. To address this issue, more flexibility is required in the power system. While wind energy sources cannot provide energy on demand independently, they can be used together to form a pumped storage system and meet demands collectively. In this simple system of water reservoirs, generators, turbines and wind turbines are used to harness kinetic energy from the wind to power water pump, transferring water from a lower height to a higher height. By filling the higher reservoir, the pumped storage system accumulates hydropower with electricity stored during hours of low demand, via pumping water reservoirs at different heights. Reversible turbine/generator assemblies can act both as pump and turbines. Between 70% and 85% of the electrical energy used to pump the water into the highest reservoir can be regained in this process [2].

In the present work, we combine a pumped hydro storage system (PHS) with wind power generation and designed a wind power pumped hydro storage system to increase the electricity production. In addition, a performance analysis of the corresponding dams and an economic estimation of a pumped hydro storage system are carried out in this paper in order to choose the most suitable dam to implement the PHS.

Table 1 – Mean annual wind speed (m/s) of the sites used in this study (at a height of 10 m). Source: Meteorological service in Lebanon.

Months	Daher El Baydar	Cedars	Marjyoun	Klaiaat	Quaraoun
Annual	5.55	3.77	4.43	4.26	3.93

Pumped hydro storage (PHS)

The PHS is the largest and most mature energy storage available technology [3]. It represents nearly 99% of the worldwide implemented electrical storage capacity with over 120 GW [4]. A typical configuration of a wind-hydro hybrid power plant with pumped storage is given in Fig. 3. The plant consists of two reservoirs at different heights, a set of hydro turbines and pumps with common or separate penstock, and one or more primary wind production unit(s) installed at the same or adjacent locations. The water body at the relatively high height represents the potential or stored energy. During off-peak hours, it pumps water from the lower reservoir to the

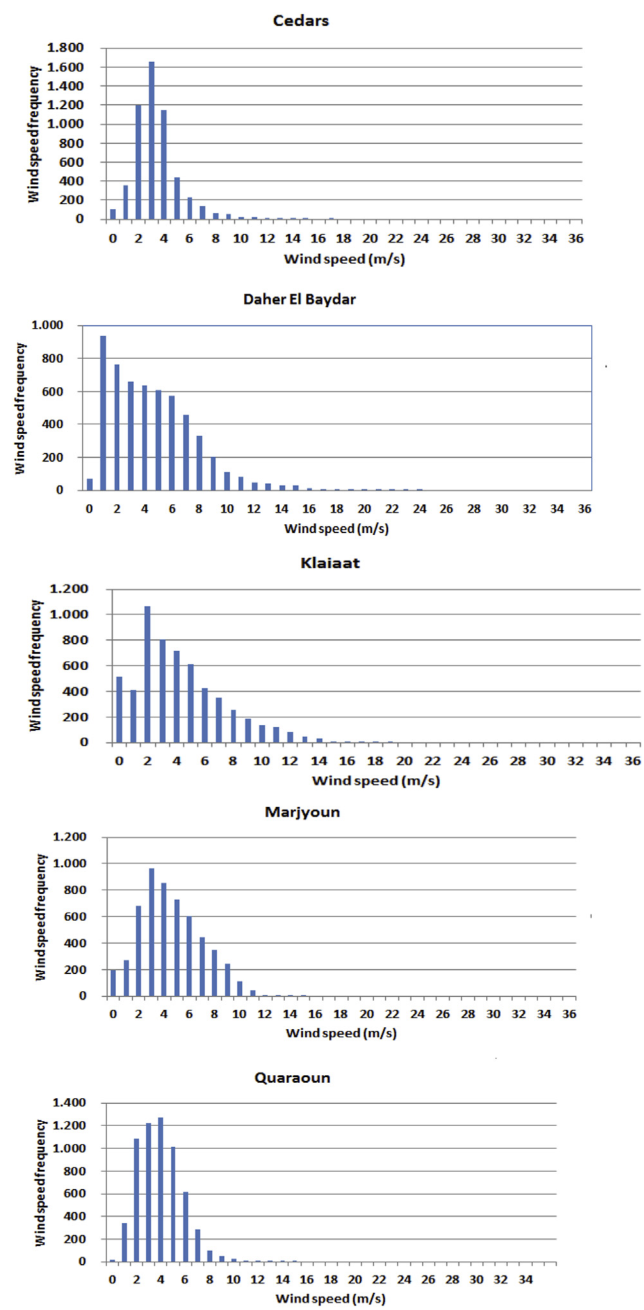

Fig. 1 – Annual average of wind speed frequency at 10 m of height in the five studied sites.