Optimization Model for Design-Operation of Pumped-Storage and Hydropower Systems

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Abstract: Due to the importance of pumped-storage systems as a cost-effective energy producer and the high cost of those projects, this paper addresses the simultaneous design-operation optimization in the design phase of pumping systems in reservoir power plants. The optimization model maximizes the net benefit of installations in reservoir systems and is employed to design Khersan 1 and 2 power plants in the Khuzestan province of Iran. An optimization model is developed to determine design decision variables, including volume of reservoir, installed capacity of power plants, diameter of water transmission installations, and also operation decision variables including output volume of the reservoir at each time step and number of hours the power plant works in a day. To estimate the potential of pumped-storage power plants, two models of design are considered in (1) hydropower form and (2) pumped-storage form. The optimal design and operation of each of the aforementioned modes is accomplished by employing the nonlinear programming (NLP) code contained in the (language for interactive general optimization) *LINGO 11.0* software package. Results of pumped-storage systems design and operation are compared to individual hydropower systems in the same area to determine the economic advantage of pumped-storage systems. Four criteria are considered to compare those two systems: (1) net benefit; (2) ratio of benefit to cost; (3) system efficiency criteria; and (4) mean, firm, and secondary-generated energy. Results indicate that pumped-storage systems have better outcomes than individual hydropower systems, based on the aforementioned four criteria. **DOI: 10.1061/(ASCE)EY.1943-7897.0000169.**

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Introduction

While water allocation and management are important, supply and distribution of the resource by means of new or existing projects is costly. Reservoirs can be used to store and supply water. During the past four decades, simulation and optimization techniques have been used in the planning and management of multipurpose reservoir systems (e.g., Mariño and Mohammadi 1984; Mohammadi and Mariño 1984; Labadie 2004).

Moreover, many optimization techniques have been developed and applied for optimization in all aspects of water resources systems such as reservoir optimum operation (Afshar et al. 2010; Bozorg Haddad et al. 2008b, 2008c, 2009, 2011a); optimal cultivation rules (Moradi-Jalal et al. 2007; Noory et al. 2012); optimal pumping scheduling (Bozorg Haddad and Mariño 2007; Rasoulzadeh-Gharibdousti et al. 2011); optimal design of water distribution networks (Bozorg Haddad et al. 2008a; Soltanjalili et al. 2010; Fallah-Mehdipour et al. 2011; Ghajarnia et al. 2011; Sabbaghpour et al. 2012). There may exist complexities in all aforementioned references but only a few of those studies address the design and operation of a hydrosystem.

A pumped-storage power plant is operated to use the power that is not consumed by generating this power at times of need. When electricity consumption is low, those power plants have the ability to increase hydraulic capacity by pumping water from a lower reservoir to a higher reservoir. When the electricity requirement is high, the pumped water returns to the lower reservoir and generates energy.

Hreinsson (1990) addressed the optimal design of hydroelectric power systems. A mathematical model was presented to determine project sizing. The interaction between sizing and sequencing decisions was also investigated. Design rules were determined for choosing the optimal size and marginal cost for individual projects, and showed the interdependence of scaling and sequencing decisions. Also, results showed that the current marginal cost of each new project is equal to the discounted weighted average of the long-term marginal unit cost for all future projects. In their study, the optimal design of a power system was only addressed, disregarding its optimal operation. Anagnostopoulos and Papantonis (2007a) used a numerical method for the optimal sizing of a plant comprised of two hydraulic turbines operating in parallel. The analysis was performed by using an evaluation algorithm that considered single- and two-objective modes, as maximization of the produced energy and the best exploitation of the streamflow potential. Results indicated that the use of two turbines of different sizes enhanced both the energy production of the plant and the economic

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