
Optimal Operation Control of Pumped Hydro Storage in the South African Electricity Market

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Abstract

In this paper, an optimal bidding strategy for PHS operation for purchasing and selling electricity in the South African electricity market is developed, taking advantage of the Time of Use tariff. For this purpose, a mathematical model describing the optimal scheduling of PHS to be implemented is developed. Thereafter, the performance of the developed model to maximize the proposed PHS is analyzed through a case study simulated using Matlab.

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1. Introduction

The mismatch occurring between electricity generation and consumer demand is one of the main operating challenges experienced by any power system. A number of options to solve this problem are currently available, which were initially developed to solve the fluctuations in demand and to protect against the loss of generation power plant. These options are: interconnections between power networks; energy storage; smart grids; and demand-side management [1].

Utility-scale energy storage system for electricity systems mainly include reservoir-based conventional hydropower, Compressed air energy storage (CAES) whereas batteries and other technologies offer smaller storage capacities [2].

An alternative to traditional hydropower storage (using dams) is pumped hydropower storage systems (PHS), which is the most established technology for utility-scale electricity storage. By using a pump to push water to the upper reservoir, PHS systems gives the possibility of storing excess electricity in the form of the potential energy of water; by releasing it through a turbine connected to generator, they allow the conversion back to electricity. This supports
the integration of electric energy from non-flexible power sources (such as nuclear or power coal plant), and, lately, of variable renewable energy sources (such as wind or photovoltaic systems) [3].

Like battery storage systems, small scale PHS can also assist at the demand side by providing the extra energy needed to avoiding consumer discomfort or dissatisfaction that may be caused by load shifting during peak load or pricing period [4].

With the aim of achieving the full earnings potential in a given electricity market, PHS owners, must actively implement an optimal operation strategy to maximize income by seeking profits. Therefore, converting PHS scheduling information into an effective bidding strategy to make sure that in the electricity market, the plant owners achieves maximum benefit is a key research area.

Therefore, in this paper, an optimal bidding strategy for PHS operation to bid for purchasing and selling electricity in the African electricity market is developed, taking advantage of the Time of Use tariff. For this purpose, a mathematical model describing the optimal scheduling of PHS to be implemented is developed. Thereafter, the performance of the developed model to maximize the proposed PHS is analyzed through a case study.

2. Description of the grid connected PHS system

The proposes system analyzed in this work is composed of a pumped hydro storage system connected to the grid with the power flow is shown in Fig. 1. The load demand is principally covered by PHS through its turbine-generator set on condition that there is enough water stored in the tank. When there is more than enough energy in the tank to supply the load, the surplus of generated energy is fed into the grid. However, when there is an insufficient energy from the PHS’s upper reservoir to supply the load, the extra energy needed is provided from the grid. The changing electricity tariff play an important role in determining whether the load is supplied from the grid or from the PHS also in determining the power flow from or into the grid.

The following control variables to be optimized are represented by the arrows in Fig. 1. $P_{\text{GRID TO LOAD}}$ is the grid power used to directly supply the load; $P_{\text{PHS TO LOAD}}$ is the power generated from the turbine-generator set to supply the load; $P_{\text{GRID TO PHS}}$ is the grid power for driving the motor-pump set to fill in the upper reservoir; $P_{\text{SOLD}}$ is the power from the turbine-generator set fed into the grid for revenue (credit) generation.

3. Optimization algorithm

3.1. Objective function

The objectives of this work are to minimize the cost of energy drawn from the grid while maximizing the energy sold under the TOU tariff scheme. Therefore, a multi-objective cost function can be derived consisting of p two main parts:

- The first part is the cost of purchasing electricity from the grid, which is used to supply the load demand and fill in the reservoir of the PHS system.

$$f_1 = \sum_{j=1}^{N} \rho_j (P_{G-PH(j)} + P_{G-L(j)}) \Delta t \quad (1)$$

- The second part is the revenue (credits) generated from selling electricity to the grid. The third part is the wearing cost of hybrid system. The total function can be expressed as:

$$f_2 = -r_k \rho_k \sum_{j=1}^{N} P_{PHS-G(j)} \Delta t \quad (2)$$

Where $r_k$ is the contracted ratio of the peak price $\rho_k$ for selling power during the peak pricing period.

3.2. Variable constraints

- Turbine-generator set’s output constraints:
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