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Optimal operation of cascade hydropower stations using hydrogen as storage medium

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HIGHLIGHTS

- Using hydrogen as energy storage medium for hydropower stations.
- Increasing electrical energy generation by reducing the amount of abandoned water.
- Using ten-day inflow forecast, hedging rule curves.
- Using the third version of generalized differential evolution.
- Achieve optimal utilization of water resource.

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ABSTRACT

The use of forecast information for cascade hydropower stations is one of the effective ways to increase the electricity generation reliability and economic benefit. However, the uncertainty of forecast is high when the forecast horizon is long. It is a common practice for hydropower stations to abandon water during flood seasons due to the limited capacity of the associated reservoirs. If forecast is accurate, the stored water can be discharged early before the flood peak arrives. This would effectively reduce the amount of water being abandoned and increase electricity generation. But there is a risk that the water stored in reservoirs would become less than expected if the forecast fails or in dry periods. In order to reduce the negative impact of forecast uncertainty, hydrogen production and storage as energy harvested by electrolysis of water using the electricity from the cascade hydropower stations is proposed and used in this study. Hun River cascade hydropower stations in China are selected as a case study. By integrating ten-day inflow forecast with hedging rule curves (HRCs-TDIF), the feasibility of optimal operation of cascade hydropower stations using hydrogen as energy storage is analyzed. Hedging rules curves of hydrogen production (HRCs-HP) is established for analyzing the relationship between electricity generation reliability (EGR) of the cascade hydropower stations and equipment utilization (EU) of hydrogen production under different equipment scales (ES). The results show that the proposed methods for the selected cascade hydropower stations may lead to high EGR and less water being abandoned.

1. Introduction

Forecast information has been widely used to improve the efficiency of utilizing water resources in reservoir and hydropower operation. The development of hydrological forecasting and operation models may reduce the uncertainty of inflow forecast. Therefore, the accuracy of forecast information and the efficiency of operating hydropower stations can be improved. Because the duration of a flood event is usually short, maximum capacity of the reservoirs may be reached and water must be abandoned to ensure the safety of the hydropower stations. If the practicable inflow forecast information can be obtained, abandoned water will be used effectively. In reservoir operation, various forecasting operation models have been analyzed [1,2]. When the forecast horizon is long, the forecast uncertainty becomes a key factor affecting effective decision making. The relationship between forecast horizon and forecast uncertainty is demonstrated and the effective forecast horizon is proposed for reservoir operation by Zhao et al. [3]. It was proved that forecast uncertainty is the main

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Nomenclatures

AFW	abandoned flood water
AO	actual operation
ATAW	annual total abandoned water
ATHG	annual total hydropower generation
EGR	electricity generation reliability for power system
EU	equipment utilization
ES	equipment scales
GDE3	the third version of generalized differential evolution
HRCs-TDIF	integrating ten-day inflow forecast with hedging rule curves
HRCs-HP	hedging rules curves of hydrogen production
WRAF	water released ahead of the flood

factor to improve the water allocation in dry seasons [4]; and monthly updated climate forecasts were used to improve intraseasonal water allocation [5]. Using ten-day forecast information is beneficial to hydropower generation and water transfer project, and the results are better than the models without considering the forecast [6,7]. However, none of these studies has investigated the influence of forecast uncertainty and the risk resulted from the uncertainty for the reservoir operation. If the actual inflow is larger than the one being forecasted, a part of abandoned water is used for generating electricity in advance. However, more water must be abandoned without considering the forecast if floods come. On the other hand, If the actual inflow is less than the one being forecasted, the water level in the reservoir may be lower than the required minimum level due to the release of water ahead of flood, which may lead to reduced or even no power generation from the hydropower stations for a certain period, and the electricity generation for power system will be low, which means that electrical energy cannot meet the required power output.

Thus, firstly it is desired to have an optimal operation strategy for cascade hydropower stations to reduce the amount of abandoned water and utilize water resources more effectively. That is, when the water stored in the reservoir is released ahead of the flood (WRAF) and used to generate electricity, it will leave more capacity to store the flood water. As a result, more electricity will be generated from the stations. In other words, water resources are used more efficiently. Secondly, on condition that the electric energy is converted into other forms and stored in advance, the electric energy is divided into two parts. The first part is transmitted to the power supply network, and the second part is used to store as another form of energy. The stored energy will be available for using to generate electricity in the period when the electricity generation cannot meet the required power output caused by the uncertainty of forecast or natural dry season. Therefore, energy storage in another form may increase the amount electricity generation and the reliability for power system, and reduce the risk of water shortage for hydropower stations if forecast failed or in dry periods.

At present, the methods of electrical energy storage for hydropower stations are mainly pumped-hydro storage and battery energy storage. Over 99% of worldwide installed storage capacity for electrical energy is pumped-hydro storage [8] and the efficiency of such systems mostly ranges between 65% and 77% [9]. However, the pumped-hydro storage is limited by geographic locations, large investment cost, long construction time and the payback period for pumped hydro schemes is typically 40–80 years [10]. Battery energy storage has been widely used for a long time but the storage capacity is limited, ranging from 17 to 40MW h with limited maximum output at 20 MW and having efficiencies of about 70–80% [8,11]. The life spans of batteries are also very limited, between 200 and 10,000 cycles [11]. The factors that mostly affect the operation of a battery system are the depth of discharge, the temperature of operation, the discharge–charge control and the periodic maintenance [12]. Clean and renewable energy is gradually and widely accepted when more and more concerns for urban pollutions, climate change and other global environmental problems. As the demand for electricity has been increasing worldwide year by year, it is necessary to harvest more energy from the hydropower stations with optimal management of water resources. In this way, it will effectively reduce abandoned water during the flooding seasons. Hydrogen can be used as the medium for energy storage, especially when the electricity demand of power system is reached. As the most abundant and simple substance of the universe, hydrogen has been used in fuel cells and internal combustion engines for transportation, power station in some developed countries. Hydrogen can be derived from different resources, such as nature gas, coal and other fossil fuels, as well as renewable energy, e.g. wind, water, solar and bioenergy [13]. As for producing hydrogen in hydropower stations, the most convenient resources are water and electricity. Furthermore, water electrolysis is a more environmental friendly way of hydrogen production without considering carbon emissions. Water electrolysis may combine with hydropower station, wind power station in order to produce efficient, clean and safe hydrogen conveniently [14].

The most important issues of water electrolysis are the cost of electrical power and energy conversion efficiency. About 80% of the total cost of hydrogen production is electricity [15]. The other factors have little impact on hydrogen production cost. At present, the results of commercial application show that the alkaline cell and hydrogen PEM electrolyzer have high stability and reliability. Typical electrolyzer consumes up to 50 kW h for purpose of generating 1 kg of hydrogen [16]. The efficiency of water electrolysis is 67% in 2009, lower than the goal of US department of energy, 69% in 2014 [15]. The efficiencies of both thermochemical and photo catalytic hydrogen production methods are too low to be economically competitive [17].

There are two main ways of hydrogen application. Hydrogen can be used as the fuel for fuel cells which will relieve the contradictions between the increasing use of motor vehicles and energy consumption. It is very important for energy saving and transformation of economic development pattern in China. The share of renewable energy has begun to play a role in Chinese energy structure [18]. Li has proved that hydrogen fuel cells can be a better transportation energy compared with other fuels [19]. The application of hydrogen will accelerate China's economy growth with the development of hydrogen fuel cell technology and hydrogen storage devices in recent years [20]. For developed countries, US department of energy has established a national hydrogen storage project, which is expected to make big improvement of hydrogen storage system in 2015, such as system gravimetric capacity, storage system cost, charging rates and safety in 2015 [21]. Economic benefits can be achieved by hydrogen storage for wind parks in a recent research in German [22]. As the important link between the "low-carbon production and highly efficient storage" [23], the proposed approach can promote the sustainable utilization of China's energy as well as accord with the development direction of energy utilization in the future. Another way is to convert hydrogen into electricity. The electricity can be used for natural disaster relief, emergency power or directly supplying