

# Operational adaptability evaluation index system of pumped storage in UHV receiving-end grids

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**Abstract.** Pumped storage is an effective solution to deal with the emergency reserve shortage, renewable energy accommodating and peak-shaving problems in ultra-high voltage (UHV) transmission receiving-end grids. However, governments and public opinion in China tend to evaluate the operational effectiveness of pumped storage using annual utilization hour, which may result in unreasonable and unnecessary dispatch of pumped storage. This paper built an operational adaptability evaluation index system for pumped storage in UHV-receiving end grids from three aspects: security insurance, peak-shaving and renewable energy accommodating, which can provide a comprehensive and objective way to evaluate the operational performance of a pumped storage station.

## 1. Introduction

Recently, the rapid development of renewable energy and large-scale UHV DC transmission have brought significant changes to the basic structure of power grids in China. Peak-shaving, accommodating renewable energy, emergency reserve, frequency control and active power control in UHV receiving-end grids are becoming more and more serious problems. Pumped storage is an effective way to deal with these problems due to its excellent technical and economical characteristics. However, there are no official rules or evaluation systems to evaluate the actual operation of pumped storage in China. Government and public opinions tend to using annual utilization hour to see whether the operation a pumped storage has achieved its full potential. This may result in unnecessary or unreasonable dispatch of pumped storage. For instance, a station that is intended to provide emergency reserve may be frequently dispatched to generating power and would fail to provide enough reserve when needed.

In this paper, the main functions of pumped storage in UHV receiving-end grids are classified into three categories: security insurance, peak-shaving and renewable energy accommodating. An operational adaptability evaluation index system is built considering these functions, which can provide a comprehensive and objective perspective to evaluate the performance of pumped storage.

## 2. Main Principle and Framework of the Evaluation Index System

### 2.1. Main Principle

Pumped storage station is intended to serve the entire power system, which means its operational adaptability evaluation index system should also consider the characteristics of the whole power system.



Therefore, the evaluation indexes in this paper are chosen according to the following principles :

- **Scientific principle:** the evaluation index should be built under theoretical basis, which could reflect the connotations of the functions of pumped storage.
- **Feasible principle:** the evaluation index system aims to evaluate the operational performance of pumped storage, therefore the index should be feasible, especially the required data should be easy to get. Indexes that are unable to get should not be included.
- **Representative principle:** the evaluation index should be representative, which means the evaluation system should be able to reflect all the aspects of the operation of pumped storage.
- **Comparable principle:** the evaluation index should be comparable, which means it should be applicable to different pumped storage stations and the result should be comparable.

### 2.2. Framework

The evaluation index system consist of 4 criteria layers, including overall performance, security insurance, peak-shaving and renewable energy accommodating, and 18 evaluation factors shown as the figure below.

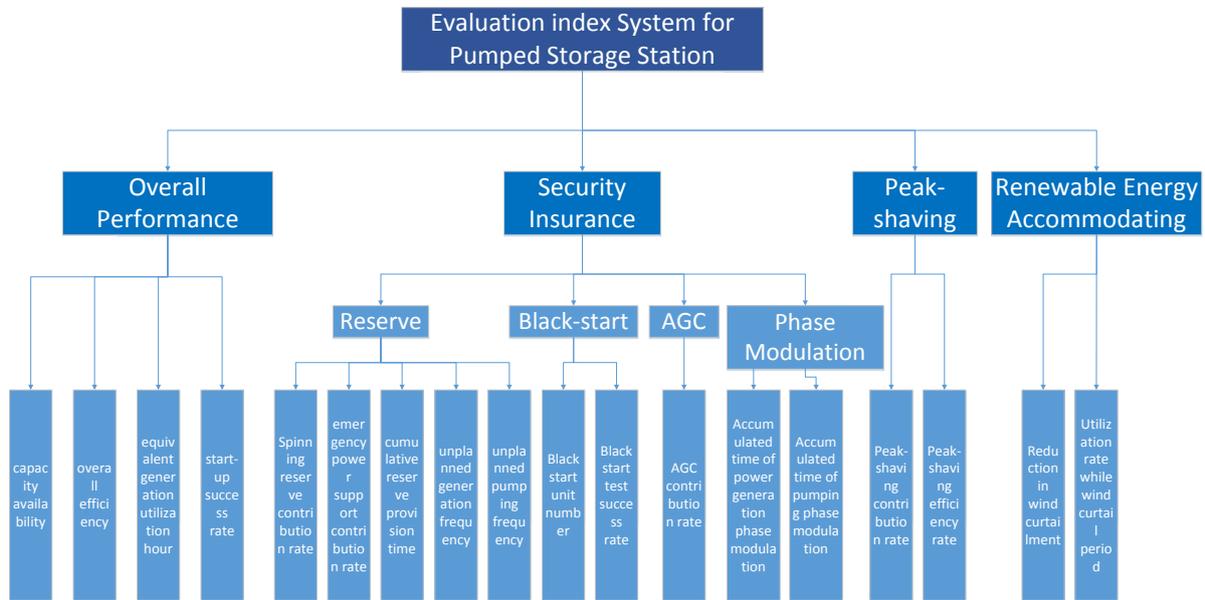


Figure 1. Framework of the evaluation index system

## 3. The Operational Adaptability Evaluation Index System for Pumped Storage Station

### 3.1. Overall Performance Criteria

The overall performance criteria layer consist of 4 evaluation factors, including capacity availability, overall efficiency, equivalent generation utilization hour and start-up success rate. The first two factors aims to evaluate the operation and maintenance status of the pumped storage station, the other two factors aims to evaluate how often and how well the station is used by the system operator.

Capacity availability is intended to evaluate the unavailable capacity caused by overhaul and malfunction. It can be calculated by

$$CF = 1 - \frac{CU \times T_U}{CR \times T}$$

Where  $CF$  refers to capacity availability;  $CU$  refers to unavailable capacity;  $T_U$  refers to time of duration of unavailable capacity;  $CR$  refers to the rated capacity;  $T$  refers to the overall time period.

Overall efficiency is intended to evaluate the losses caused by pumping and generating of a pumped storage station. It is the ratio of the electricity generated by the station to the electricity consumed by the station.

$$OR = \frac{EG}{EP}$$

Where  $EG$  refers to the electricity generated by the station during the evaluation time period;  $EP$  refers to the electricity consumed by the station to pump water during the evaluation time period.

Equivalent generation utilization hour provide an intuitional perspective of how often the station is deployed by the system operator.

$$EH = \frac{EG}{CR}$$

Where  $EH$  refers to the equivalent generation utilization hour.

Start-up success rate represents the operation and maintenance level of the pumped storage station, which is most concerned by the system operator.

$$SR = \frac{SS}{SS + FS}$$

Where  $SR$  refers to the start-up success rate;  $SS$  refers to the number of times that the pumped storage unit is successfully started;  $FS$  refers to the number of times that the pumped storage unit is fail to start.

### 3.2. Security Insurance Criteria

The security insurance criteria consist of 4 secondary layers with 10 evaluation factors in total. The secondary layers are reserve, black-start, AGC frequency adjustment and phase modulation.

**3.2.1. Reserve.** There are five evaluation indexes to evaluate the reserve service provided by the pumped storage station, including the spinning reserve contribution rate, the cumulative reserve provision time, the emergency power support contribution rate, the unplanned generation frequency and the unplanned pumping frequency. The first one assesses the ability of the pumped storage station to provide spinning reserve capacity and the contribution to the reduction of the reserve capacity of the grid; the latter four indicators evaluate the actual performance of the reserve service provided by the pumped storage station from the standpoint of spinning reserve.

Spinning reserve contribution rate is used to measure the proportion of reserve capacity provided by the pumped storage station to the reserve capacity required by the whole system, which can be calculated by:

$$\alpha = \frac{\int_T (P_R - p(t))dt}{\int_T R(t)dt}$$

Where  $\alpha$  is spinning reserve contribution rate;  $T$  is the evaluation time period;  $P_R$  is the rated power of pumped storage;  $R$  is the spinning reserve of the whole system.

The emergency power support contribution rate represents the ratio of the emergency active power the station can provide to the emergency power gap when a large capacity loss occurs.

The cumulative reserve provision time represents the actual cumulative time that the pumped storage provided spinning reserve, which can be drawn from the historical operation statistic data.

The unplanned generation frequency and the unplanned pumping frequency indicate unplanned unit start-up due to emergencies during the evaluation period and are derived from historical operation statistic data.

3.2.2. *Black-start.* The black start function of the pumped storage power station needs to be certified by the grid dispatching authority in the region. The black start performance of the power plant is evaluated from the following two aspects:

- Black start unit number, that is, number of units certified by the dispatching authority.
- Black start test success rate, that is, the success rate of each black-start unit through the black start test.

3.2.3. *AGC frequency adjustment.* The AGC function of the pumped storage power station is evaluated by the AGC contribution rate index. AGC contribution rate represents the AGC power consumption of all units in the power station that accounting for the whole network AGC theoretical requirement for the corresponding time, which could evaluate the actual AGC performance of the power station. It can be calculated by:

$$\rho = \frac{\int_{t_1}^{t_2} p_1(\Delta f, t) dt}{\int_{t_1}^{t_2} p_{system}(\Delta f, t) dt}$$

Where  $\rho$  is the AGC contribution rate;  $t_1-t_2$  is the AGC responding time, which is usually 60 seconds;  $p_1(\Delta f, t)$  is the AGC characteristic of the pumped storage, and  $p_{system}(\Delta f, t)$  is the AGC characteristic of the whole system.

3.2.4. *Phase Modulation.* The evaluation index of phase modulation function of pumped storage power station includes the accumulated time of power generation phase modulation and the accumulated time of pumping phase modulation.

Accumulated time of power generation phase modulation = power generation phase modulation cumulative hours during the evaluation period.

Accumulated time of pumping phase modulation = pumping phase modulation cumulative hours during the evaluation period.

### 3.3. *Peak-shaving Criteria*

This paper investigates the peak-shaving criteria of pumped storage power station using two evaluation factors, peak-shaving contribution rate and peak-shaving efficiency rate. The first one is to evaluate the inherent peak-shaving capability of pumped storage; the second evaluation factor is to assess the actual performance of the pumped storage during operation period.

Peak-shaving contribution rate represents how much the construction of pumped storage power station can relieve the peak-shave pressure of the system. It is the ratio of the double installed capacity of the pumped storage to the system peak-valley difference:

$$PC = \frac{2 \times CR}{PV}$$

Where  $PC$  is the peak-shaving contribution rate;  $PV$  is the system peak-valley difference.

Peak-shaving efficiency rate is used to evaluate the performance of the pumped storage for peak-shaving during the evaluation period. It is expressed as the absolute value of the correlation coefficient between the power output curve and the load curve:

$$\beta = \left| \frac{\sum (P - \bar{P})(L - \bar{L})}{\sqrt{\sum (P - \bar{P})^2 \sum (L - \bar{L})^2}} \right|$$

where  $\beta$  is the peak-shaving efficiency rate;  $P$  is the output curve of the pumped storage;  $\bar{P}$  is the average power output of the pumped storage;  $L$  is the load curve;  $\bar{L}$  is the average load of the load curve.

### 3.4. Renewable Energy Accommodating Criteria

When evaluating the performance of a pumped storage to accommodate renewable energy, this paper uses two evaluation factors, which are the reduction in wind curtailment, and utilization rate while wind curtail period.

Reduction in wind curtailment refers to the reduced amount of wind curtailment due to the construction of the pumped storage. It can be represented by the electricity used to pump water during wind curtailment period.

Utilization rate while wind curtail period represents whether the pumped storage is fully utilized during wind curtailment period. It can be calculated by:

$$\eta = \frac{\sum_{T'} P_{T'}}{\sum_{T'} P_R}$$

Where  $\eta$  is the utilization rate while wind curtail period;  $T'$  is wind curtailment period;  $P_{T'}$  is the pumping output during wind curtail period;  $P_R$  is the rated pumping rate of the pumped storage station.

## 4. Conclusion

This paper proposed an operational adaptability evaluation index system for pumped storage station in UHV receiving-end grids. The evaluation index system consist of 4 criteria layers, including overall performance, security insurance, peak-shaving and renewable energy accommodating, and 18 evaluation factors, which could comprehensively and scientifically assess the operation of the pumped storage and guide its operation and management.

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