Research on New Energy and Thermal Power Proportion Comparison of UHVDC Generation Expansion Planning

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Abstract. Generation expansion planning of UHVDC plays a crucial role in optimizing resource utilization. A mixed delivery of wind, solar, and thermal power can help achieve multiple objectives such as to stabilize power supply, to raise renewable energy ratio, to reduce the wind and solar curtailment rate, while keeping the price acceptable. This paper considers 4 objectives of generation planning of UHVDC and formulates a model to simulate the operation and thus get the key indices that are used to choose from possible generation expansion planning options. We show the effect of the proposed method using a case study of the Xinjiang 3rd UHVDC channel.

1 Introduction

1.1 Motivation and aim

Generation resources and load are reverse-distributed in China. The northwest part of China is abundant in the wind, solar and coal power, and ultra-high voltage direct current (UHVDC) transmission lines are built to transmit the electrical power from northwest to the load centre in the east part. The ratio of power generators for UHV lines starting from the northwest area of China is quite different. For example, the “Hami-Zhengzhou” ±800kV UHVDC is equipped with 6600MW thermal power, 8000MW wind power, and 1250 MW solar power, while the “Zhundong-Wannan” ±1100kV UHVDC has 13200MW thermal power, 5200MW wind power, and 2500 MW solar power. To guarantee the economic and effectiveness in future operations, the proportion of different kinds of units must be carefully studied in the planning stage.

Relevant works related to generation planning of UHV lines are reviewed below. Ref [1] illustrates the necessity and feasibility of transmitting large-scale renewable power together with thermal power through UHVDC. An optimization method to determine the capacity of wind and thermal units is provided in [1,2]. Ref [3] focuses on the technical and economic analysis of UHVDC units. The proportion of generating units “Jiuquan-Hunan” UHVDC line is studied in [4], where three available options are proposed, and thermal unit equivalent hours and wind curtailment rates are compared. Ref [5] proposes a generation expansion planning model considering environmental policy and ESS facility. However, few papers have examined the multiple objectives together during UHVDC generation planning, and how to compare with available planning options is not provided.

In the practice of generation expansion planning, several available planning options are usually proposed. This paper illustrates how to make comparisons among those possible options considering multiple goals, and find out the best solution.

1.2 Contributions

Contributions of this paper are threefold:

1) To examine 4 objectives of the generation expansion planning of a UHVDC, namely power supply ability, renewable energy ratio, new energy curtailment rate and price of electricity.

2) To propose a simplified simulation model to estimate the operation statistics of generating units of UHVDC.

3) To carry out a case study of the Xinjiang 3rd UHVDC channel to find the optimal solution among available generation expansion planning options.

1.3 Paper organization

This paper is organized as follows. Section 2 describes the probable objectives during the UHVDC generation expansion planning procedure. An operation simulation model that considers the wind, solar, and thermal power is provided in section 3. A case study of a planned UHVDC starting from Xinjiang province is carried out in section 4. Conclusions are given in section 5.

2 Objectives of generation planning of UHVDC

Multiple objectives should be coordinated in the generation expansion planning of a UHVDC. To be specific, this paper examines the generating units of UHVDC from Xinjiang to Chongqing, also referred to as Xinjiang 3rd channel. In this paper we consider four objectives, including the power supply ability, the renewable energy ratio, the new energy curtailment rate, and the overall price of electricity.

Note that generally these objectives conflict with each other. They may not be optimized simultaneously. The weighted sum method [6] can be used to find the best solution.

2.1 Power supply ability sub-objective

To guarantee the power supply of the receiving area, the power flow of the UHVDC is usually kept stable, which does not vary with the wind and solar power among days. Thermal units can help stabilize the stochastic power output of wind and solar power. In this case, we measure the power supply ability according to the capacity of thermal units. The higher capacity of thermal units results in a stronger power supply ability.

2.2 Renewable energy ratio sub-objective

China is currently in the rapid procedure of energy transformation. The government has proposed the goal that non-fossil energy will account for 15% of primary energy consumption by 2020, and 20% by 2030. Renewable energy is green and abundant, and thus preferred. In 2019, the renewable portfolio standard (RPS) policy is carried out, which requires electric utilities to gradually increase the amount of renewable energy usage [7]. For UHVDC, the renewable energy ratio should exceed 30%.

2.3 New energy curtailment rate sub-objective

The new energy consumption rate is a key index to reflect the usage efficiency of new energy. Due to the low level of local load, lack of power system flexibility in Xinjiang and the imbalance of new energy units and the transmission grid, the wind and solar curtailment rate is high especially in Xinjiang since 2015. Hence, the new energy curtailment rate should be kept within a reasonable level for new generators for UHVDC. Also, a lower curtailment rate usually means more profit for GenCos.

2.4 Price of electricity sub-objective

The price of electricity determines whether the UHVDC project is economic. The average electricity price including the transmission price should be no higher than the local benchmark electricity price in Chongqing (the receiving province), and it should meet the agreement signed by both sides.

3 Model formulation

To compare with available generation plan options, a simulation model to examine the operation status is formulated below. t is the index for time periods from 1 to N, where N = 8760 for the hours in one year. Superscripts W, S, and I indicate wind, solar and thermal units separately. The capacity of units in each available planning option is regarded as given data.

3.1 Variables

Variables include the power output of wind, solar, and thermal units at time t, i.e. $P^{\mathrm{W}}(t)$, $P^{\mathrm{S}}(t)$, $P^{\mathrm{I}}(t)$, wind spillage power at time t, $P^{\mathrm{WC}}(t)$, solar spillage power at time t, $P^{\mathrm{SC}}(t)$, and the power supply from the main grid at time t, $S(t)$.

3.2 Objective function

The objective function is to minimize the wind and solar power curtailment and to minimize the power supply from the main grid.

$$\min \sum_{t=1}^{N} \left(P^{\mathrm{WC}}(t) + P^{\mathrm{SC}}(t) + S(t) \right) \quad (1)$$

3.3 Constraints

Constraints of the proposed formulation is as follows.

$$P^{\mathrm{I}}(t)+P^{\mathrm{W}}(t)+P^{\mathrm{S}}(t)+S(t)=P^{\mathrm{T}}(t), \quad \forall t \quad (2)$$

$$P^{\min} \le P^{\mathrm{I}}(t) \le P^{\max}, \quad \forall t \quad (3)$$

$$0 \le P^{\mathrm{W}}(t) \le W \times k^{W}(t), \quad \forall t \quad (4)$$

$$0 \le P^{\mathrm{S}}(t) \le S \times k^{S}(t), \quad \forall t \quad (5)$$

$$-L^{-} \le P^{\mathrm{I}}(\mathrm{t})\text{-}P^{\mathrm{I}}(\mathrm{t}\text{-}1) \le L^{+}, \quad \forall t \quad (6)$$

$$P^{\mathrm{W}}(t)+P^{\mathrm{WC}}(t)=W \times k^{W}(t), \quad \forall t \quad (7)$$

$$P^{\mathrm{S}}(t)+P^{\mathrm{SC}}(t)=S \times k^{S}(t), \quad \forall t \quad (8)$$

Eq. (2) is the power balance. Eqs. (3)-(5) limits the power output range for thermal, wind and solar units, where $k^{W}(t)$ and $k^{S}(t)$ are the power output curve factor of wind and solar units, W and S are the capacities of wind and solar for each available plan. Eq. (6) constraints the ramping limits for thermal units. Wind power spillage and solar power spillage are illustrated in Eqs. (7) and (8).

4 Case study

In this section, we use a UHVDC in China from Xinjiang to Chongqing to express the proposed method. This UHVDC is still under planning, and is subject to change. The specific figures should be based on actual results.

4.1 Data

The power flow of the UHVDC is shown in Fig. 1, with 5525 equivalent utilization hours per year. Since the sending end of the UHVDC is rich in coal, wind and solar energy resources, we consider a mix of thermal, wind and solar power, and storage may be used if needed. Considering the load requirements and the constraints of the UHVDC operation, we propose three possible options for generation expansion planning. The capacities of each power source are shown in Table 1.

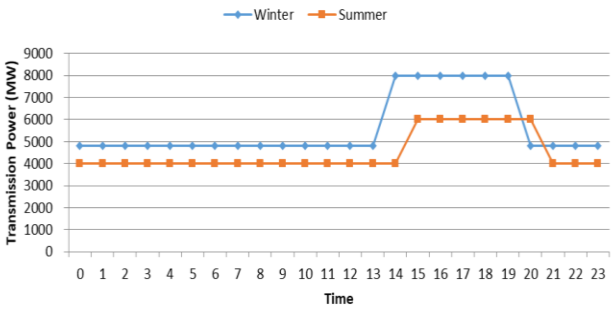

Fig. 1. Transmission power of Xinjiang 3rd channel.

Table 1. Supporting power options of the studied UHVDC (MW).

Generation type	Option 1	Option 2	Option 3
Thermal power	6600	5940	5280
Wind power	2800	4200	5500
Solar power	1400	2100	2750
Storage	0	0	500
Total	10800	12240	14030

4.2 Comparison analysis

The key indices of the simulation results using the proposed model are shown in Table 2. Option 1 has the highest thermal capacity ratio and thermal energy ratio, the lowest new energy curtailment rate, but the lowest new energy ratio. Option 3 takes the opposite. It has the the highest new energy ratio, but the lowest thermal capacity ratio, thermal energy ratio, and the highest new energy curtailment rate. Indices of option 2 are moderate, which are between option 1 and option 3.

Table 2. Power supply structure and new energy consumption.

	Option 1	Option 2	Option 3
Thermal capacity ratio (Power supply ability)	61.1%	48.5%	37.6%
Thermal energy ratio	78.6%	70.0%	63.3%
New energy ratio	21.4%	30.0%	36.7%
New energy curtailment rate	1.2%	7.6%	13.7%

Since the capacity of thermal units is lower than the maximum transmission power, in some occasions the power supported by Xinjiang's main grid is required, considering the variation of new energy power output. Relevant results of the energy supported are shown in Table 3. In general, energy supply in option 1 is lowest, and that in option 3 is highest.

The results of electricity price analysis are shown in Table 4. In this case, the price of thermal units (0.256 yuan/kWh) is the lowest among all the power sources. The higher the thermal power capacity, the lower the total price. The price in option 1 is 0.263 yuan/kWh. The price in option 2 is 0.265 yuan/kWh, which is a little bit higher than that in option 1. The price in option 3 is 0.271 yuan/kWh, with an added price 0.004 yuan/kWh by storage.

Table 3. Energy supported by Xinjiang's main grid (GWh).

Power from the main grid	Option 1		Option 2		Option 3	
	Energy	Percentage	Energy	Percentage	Energy	Percentage
$P \leq 1000MW$	214	47.3%	168	24.61%	118	15.3%
$1000MW \leq P \leq 2000MW$	239	52.7%	429	63.05%	322	41.8%
$2000MW \leq P \leq 3000MW$	0	0.0%	84	12.34%	330	42.9%

Table 4. Electricity price analysis.

	Option 1		Option 2		Option 3	
	Energy (GWh)	Price (yuan/kWh)	Energy (GWh)	Price (yuan/kWh)	Energy (GWh)	Price (yuan/kWh)
Thermal power	34.42	0.256	30.65	0.256	27.62	0.256
Wind power	7.17	0.28	9.81	0.28	12.27	0.28
Solar power	2.16	0.31	3.06	0.31	3.59	0.31
Main grid power	0.45	0.28	0.68	0.28	0.77	0.28
Price without storage	--	0.263	--	0.265	--	0.267
Storage	--	0	--	0	--	0.004
Price with storage	--	0.263	--	0.265	--	0.271

Table 5. Evaluation of the available options.

	Option 1		Option 2		Option 3	
	Value	Score	Value	Score	Value	Score
Power supply ability	660	16	596	15	528	13
Renewable energy ratio	21.3%	2	30.0%	15	36.5%	24
New energy consumption	2.1%	20	9.4%	16	15.3%	10
Electricity price	0.263	27	0.265	25	0.271	19
Total	--	65	--	71	--	67

4.3 Results

A comprehensive scoring method considering the four sub-objectives are used to evaluate the available options. The price and renewable energy ratio sub-objectives account for 30 points each, and the NE consumption and power supply ability sub-objectives account for 20 points each. The figures of total points and scoring standard are consistent with the orientation of current national policy in China, and the score for each sub-objective is piecewise-linear to its index value. Detailed scoring standards are omitted here due to the length limitation. The results of the scoring are shown in Table 5. Among the three options, option 2 has the highest score and thus recommended in this project.

5 Conclusion

The proportion of different kinds of generating units must be carefully studied in the planning stage. This paper proposes 4 objectives of generation planning of UHVDC, which are power supply ability, renewable energy ratio, new energy curtailment and price of electricity. A simple model is proposed to simulate the operation status of the units. Three available options of the generation sources of the Xinjiang 3rd UHVDC channel are compared. Under the given standard, the combination of 5940MW thermal units, 4200MW wind units, and 2100MW solar units is recommended.

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