Research on hybrid transmission mode for HVDC with optimal thermal power and renewable energy combination

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Abstract. With the rapid development of renewable energy in Northwest China, curtailment phenomena is becoming more and more serve owing to lack of adjustment ability and enough transmission capacity. Based on the existing HVDC projects, exploring the hybrid transmission mode associated with thermal power and renewable power will be necessary and important. This paper has proposed a method on optimal thermal power and renewable energy combination for HVDC lines, based on multi-scheme comparison. Having established the mathematic model for electric power balance in time series mode, ten different schemes have been picked for figuring out the suitable one by test simulation. By the proposed related discriminated principle, including generation device utilization hours, renewable energy electricity proportion and curtailment level, the recommendation scheme has been found. The result has also validated the efficiency of the method.

1. Introduction

The Northwest China is abundant in wind, solar and coal resource, as shown in Figure 1 and Figure 2. Several large-scale wind power, solar power and coal-fired power bases have been planned and under construction, where is far from the load centres in Central East China and lack of electricity market space and flexibility resouces. Therefore, there is huge potential and necessity for coordinated development and hybrid transmission of multi energy resources [1-8].

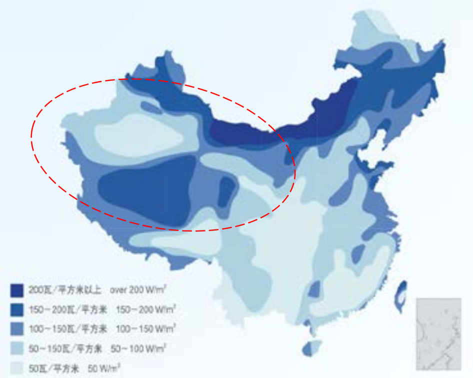

Figure 1. Distribution of wind energy resource.

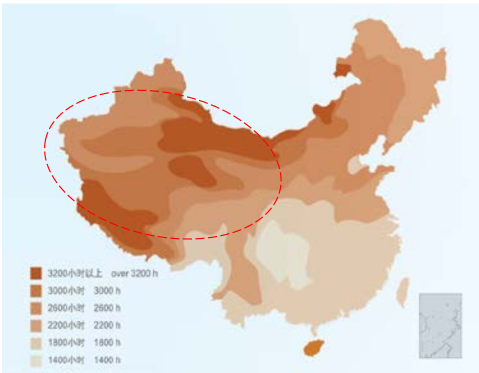

Figure 2. Distribution of solar energy resource.

By the end of 2016, wind power installed capacity in Northwest China has reached 43GW, and wind power installed capacity in Xinjiang, Gansu was 17.8GW and 12.8GW respectively.The capacity of grid-connection solar power was 77.4GW, 41.3% of the total grid-connected solar power capacity in Northwest China. Xinjiang has ranked No.1 in China for its 9.8 GW capacity. According to the 13th five year plan for renewable energy development, up to 2020, the capacity targets of wind and solar power will be separately 210GW and 150GW at least, in which Northwest China is able to take the percentage of 23.2%, 30%[9,10].

However, lack of enough network transmission lines and shortage of the peaking regulation resources are becoming the most important factors for new energy development, which have effect on new energy accommodation[1]. Northwest China was the first place with new energy curtailment phenomena, initial wind power curtailment happened in 2009 and initial solar power curtailment happened in 2012 in Gansu province. Owing to mismatching deployment of generation power resources and the electric power load centres, HVDC transmission channels，long in distance，large in capacity and high in voltage rank, could delivery much more power from Northwest China to Central East China, which is equal to enlarge power requirement for sending region[1,6]. It is important that the accommodation of new energy will gain benefit. How to figure out the arrangement of associated generation power sources, including thermal power, wind power and solar power, has become an essential problem. In this paper, according to traditional HVDC, a method on hybrid transmission mode for conventional power and renewable energy is proposed to find the suitable power source combination, in which curtailment ratio could be controlled under a reasonable level and the utilization hours also would be guaranteed for normal situation.

2. Research on hybrid transmission mode

2.1. The study background of hybrid transmission mode

Due to the intermittent and randomness of wind power and solar power, it is not economic, safe and feasible to make renewable energy power transmitted in large-scale by special transmission projects.

From the sending region, renewable energy power could be transmitted in a hybrid mode with thermal power according to one planning transmission curve, which can easily secure the system stable operation, and improve economic usage level of wind power, solar power, thermal power and transmission capacity. Especially, the installed capacity for wind power, solar power and thermal power should be optimized for a certain transmission capacity, as shown in Figure 3.

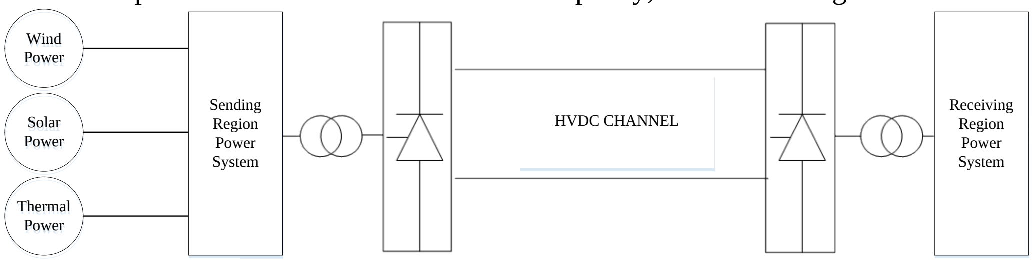

Figure 3. Structure of hybrid transmission mode of HVDC.

2.2. Research principles

1) DC transmission project: the power transmission should meet the scheduled curve, and keep operating smoothly.

2) Wind & solar power:the curtailment percentage of wind and solar power are less than 5%, and the wind and solar power generation electricity ratio is not less than 20%.

3) Thermal power: the annual full load hours of thermal power units is not less than 4000h in sending region.

4) Economy: the price in receiving region should have price competency.

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5) Overall assessment: the optimal scheme meet all the above mentioned principles, which should improve wind & solar power transmission electricity ratio.

2.3. The model of hybrid transmission mode

Objective function of hybrid transmission：

$$\max \sum_{i=1}^{N} P_{W\&S,\ real,\ i} \tag{1}$$

In which, the maximum sum of the wind power and solar power is chosen as the research object.

For one special time slice i, the formulas for corresponding accessible capacity, real output power, surplus electricity of wind and solar power, and real output of thermal power unit are as following:

$$P_{W\&S,admissible,i} = P_{Tr,i} - P_{Tr,\min} \tag{2}$$

$$P_{W\&S,real,i} = \min(P_{W\&S,admissible,i}, P_{W\&S,predict,i}) \tag{3}$$

$$P_{W\&S,surplus,i} = P_{W\&S,predict,i} - P_{W\&S,real,i} \tag{4}$$

$$P_{Ther,i} = \min(P_{Tr,i} - P_{W\&S,real,i}, P_{Ther}) \tag{5}$$

Where,

$P_{Tr,i}$, represent the operation value of HVDC channel at i time according to the predetermined curve;

$P_{W\&S,admissible,i}$,represent the admissible space for HVDC channel to accept the new energy at i time by the subtract the minimum operation power $P_{Tr,\min}$ from $P_{Tr,i}$;

$P_{W\&S,real,i}$, represent the real accepted new energy power by the HVDC channel at i time;

$P_{W\&S,surplus,i}$, represent the curtailment of new energy power constrained by the accepted space which determined by the HVDC channel at i time;

$P_{Ther,i}$,represent the thermal power units output level at i time;

In a summary, according to the planned transmission curve, the output of power sources in sending region should guarantee that the DC power is equal to the curve value. The admissible wind and solar power are determined by the transmission curve and the minimum stable level of thermal units. In this procedure, the capacities of thermal power, wind power and solar power are considered as variables, figured out by combining with some optimal algorithms. In China, for one HVDC projects, the associated power generation types and capacities will be given as a guiding line. For instance, the HVDC project from Hami in Xinjiang to Zhengzhou in Henan with voltage rank ±800kV and capacity 8GW has associated power sources in three different types, in which there are 6.6GW thermal power, 8GW wind power and 1.25GW solar power. As a result, it is not an optimal combination for normal operation of HVDC project and related power source units.

The simulation needs a whole time scale, usually as a year, in which wind power and solar power output data is determined by the local wind and solar resources characteristic. As to the traditional thermal power, the adjustment capacity is finally by the rated capacity and minimum technical output level for each unit. For one combination of thermal, wind and solar power capacity, at each i time the formula (2) to (5) will be used to calculate corresponding power curtailment of wind and solar power. Finally, the total curtailment electricity could be found and curtailment ratio for wind and solar power also could be gained, which is able to be compared with the some specified reference level(such as 5%) and then be determined whether to go into the next loop or not.

2.4. The key output parameters for renewable energy power

Guaranteed Capacity: after ordering the wind power outputs from largest to smallest at load peaking time, the guaranteed capacity is defined as minimum wind power output with the certain guarantee rate(95%),as shown in Figure 4.

Effective Output: after ordering the wind power outputs from smallest to largest at load valley time, the effective output is defined as maximum wind power output with the certain guarantee rate(95%), as shown in Figure 5.

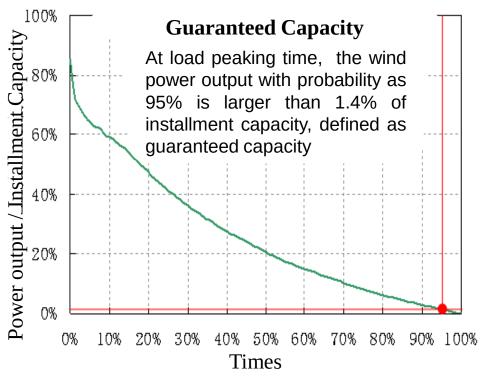

Figure 4. Concept of guaranteed capacity.

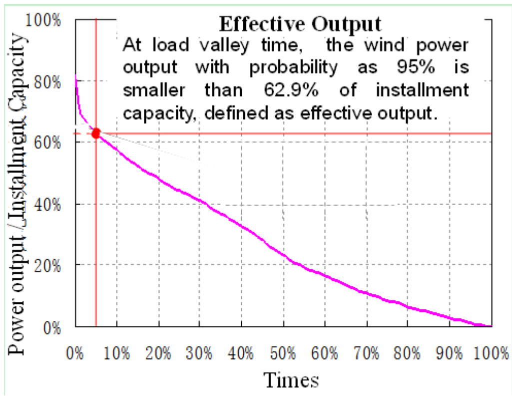

Figure 5. Concept of effective output.

2.5. The daily and yearly transmission curves of HVDC line

In order to keep the steady operation of HVDC line, the operation curve always could be preset as some steps. In China, the existing HVDC lines' choice is two steps daily mode, in which the peaking time longs for 14 hours and the valley time will be 10 hours. It is the reason for the daily curve shape that the input electric power for receiving region will participate in the daily peaking regulation. As shown in Figure 6, the daily operation curve has three steps, corresponding to the valley load, midday peaking load and night peaking load. Obviously, the chosen operation mode will be better for electric power balance of receiving region system than the single line mode without any steps. From the whole year vision, the maximum transmitted power of HVDC line will follow the change of yearly load curve of the receiving region, as illustrated in Figure 7.

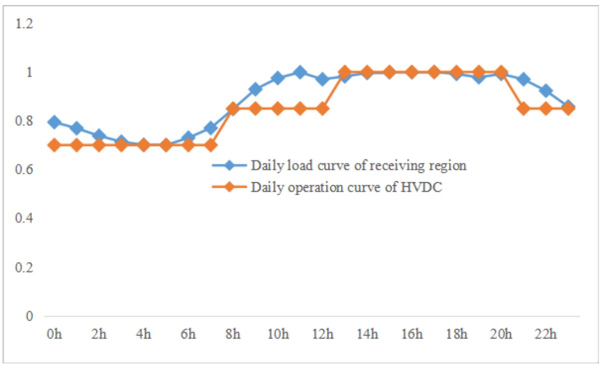

Figure 6. Illustration of daily operation curve of DC and load curve of receiving region.

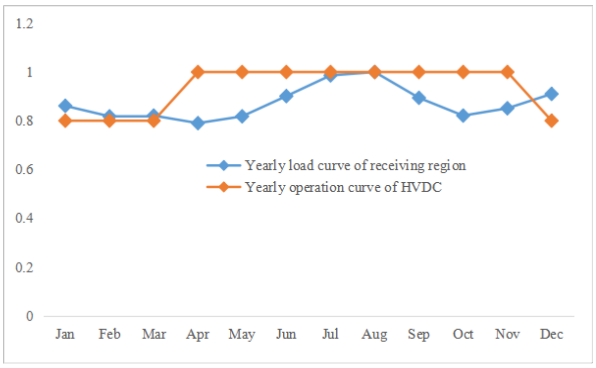

Figure 7. Illustration of yearly operationcurve of DC and load curve of receiving region.

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3. Test example simulation and simulation

3.1. Boundary conditions for typical HVDC project

1)The station service power consumption rate is set as 7%, and the minimum stable level of thermal power unit is set as 40%.

2)The capacity of HVDC project is 8000MW, and the annual utilization hours is 5000h.

3)The two segments transmission curve is adopted by HVDC project. The transmission power are 100% at peak time, lasting for 14h/day(8:00-22:00); and power at valley time is 40% of rated capacity, lasting for 10h/day(0:00-8:00, 22:00-24:00).

4)The feed-in traffic in sending and receiving regions are set as 0.25 and 0.4392 RMB/kWh respectively.

5)The associative thermal power units are 9240MW, in which one unit would be taken as reserve unit.

6)The curtailment ratios of wind power and solar power are about 5%.

3.2. The basic flowchart of searching optimal power generation combination

Step1: given an initial combination of power generation as a scheme, in which the capacity of thermal power, wind power and solar power generation could be pointed out as initial values.

Step2: according to daily and yearly operation curves of HVDC, the per-unit value of wind power and solar power, and minimum technical output level of thermal power, the curtailment of renewable energy could be figured out. If curtailment ratio is higher than the specified value (3.1-6)), the procedure should change to Step1, and the renewable energy capacity also should be reduced; else go into Step3.

Step3: Utilization hours of power generations and HVDC transmission line should be calculated by the yearly data collection. If HVDC utilization hour is lower than the specified value (3.1-2)), the procedure should change to Step1, and the renewable energy capacity also should be reduced; else go into Step4.

Step4: If HVDC utilization hour is near the specified value (3.1-2)), the bigger wind and solar power generation electricity ratio, the higher the scheme priority.

3.3. The index comparison of different power source portfolio

In this paper, ten schemes have been picked for analyzation and comparison as shown in Table 1, and the related indexes mainly include fours aspects such as generation device utilization hours, renewable energy power curtailment ratio, and renewable energy electricity proportion in HVDC and electricity price competitiveness.

The above ten schemes are verified by the previous mentioned principles. As a result, only scheme 1 and 2 are feasible according to wind and solar power curtailment ratio as 5%.

For scheme NO.2, the solar power capacity increases from 2000MW to 4000MW, and curtailment ratios of wind power and solar power are 2.1%,1.4% respectively, the total wind and solar power electricity ratio takes 24.8%, higher than 20.1% in Scheme NO. 1. Therefore, the recommended one is scheme NO.2. In this study HVDC transmission price (including net loss) is figured out as 0.0884RMB/kWh. The electricity price difference between sending and receiving regions is fixed as 0.1008RMB/kWh for all schemes, because the feed-in tariff in sending region is set as the local thermal power benchmark price.

If there is an appropriate relaxation of the proportion of solar power curtailment constraints, the scheme NO.3 will be another candidate one, in which the curtailment ratio is 7.4% higher than 5% specified by the above mentioned principle 2). According to scheme 3, the installed capacity of solar power is 2GW more than scheme 2 more than, the wind and solar power electricity proportion has accounted for 28.5%, and the utilization hours of thermal power, wind power and solar power are within the reference range .Therefore, under the same price competition conditions, with the more relaxed policy on proportion of abandoned solar power, the scheme NO.3 can also be adsorbed as a recommended scheme.

Table 1. Index comparison of different power source portfolio.

No.	Power source capacity（MW）			Utilization hours（h）			Curtailment ratio（%）		Ratio（%）
	Thermal Power	Wind power	Solar power	Thermal Power	Wind power	Solar power	Wind power	Solar power	Wind & Solar generation
1	9240	4000	2000	5351	2169	1399	1.4	0.1	20.1
2	9240	4000	4000	5041	2153	1380	2.1	1.4	24.8
3	9240	4000	6000	4801	2103	1297	4.4	7.4	28.5
4	9240	4000	8000	4671	2044	1141	7.1	18.5	30.5
5	9240	4000	10000	4607	1989	990	9.6	29.3	31.5
6	9240	6000	2000	4962	2007	1383	8.8	1.2	25.9
7	9240	6000	4000	4693	1962	1337	10.8	4.5	30
8	9240	6000	6000	4487	1908	1239	13.3	11.5	33.2
9	9240	6000	8000	4381	1849	1088	16	22.3	34.8
10	9240	6000	10000	4329	1800	944	18.2	32.5	35.7

4. Conclusions

A new method on hybrid transmission mode for HVDC with optimal thermal power and renewable energy combination has been proposed, which could figure out the power sources combination satisfied with the related principles. As a result, with the constant power mode for one typical HVDC project, the recommended hybrid transmission power sources portfolio is as following: wind power 4000MW, solar power 4000MW, and thermal power 9240MW. What needs to be pointed out is that this method could be spread to other similar HVDC projects. The existing operation curve for HVDC line mainly considers the peaking regulation in receiving regions, but not follows to sending regions' renewable energy output characteristic. In other words, the pressure of peaking regulation will put more in sending regions power system. Therefore, future operation curve making will synchronously take into account of the sending and receiving regions' adjustment capacity balance. In an additional, the trans-provincial integration and transmission of wind power and solar power are not recommended in Northwest China. The existing and under construction UHVDC lines should take consideration of accommodation of local renewable energy.

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