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Research on the Economy of UHVDC Transmission under the Background of Global Energy Interconnect

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Abstract. As the main transmission modes of global energy interconnect, studies on the application scope of economic transmission of ultra-high voltage DC（UHVDC） is of great significance to the scientific planning of power grids. This paper analyses the development trend of global energy interconnect in light of the trend of renewable energy development. Based on the study of the calculation method of annual cost per unit capacity of UHVDC transmission, a calculation method for the application scope of economic transmission is proposed. The UHVDC transmission configuration scheme is studied, the factors that affect the transmission loss of UHVDC project is analysed. On the basis of the unit-capacity annual cost method, taking into account changes in the different distance and power price of the UHVDC project, the economic transmission scope of ±800kV and ±1100kV voltage levels are also analysed.

1. Introduction

The reverse distribution of global energy resources and their consumption makes it possible for transnational and transcontinental electricity transmission in the future [1]. The advantages of HVDC transmission including long distance, large capacity and low loss will play an important role in the construction of global energy interconnect [2]. UHVDC transmission has been widely used in China and enjoyed good economic and social benefits. The transnational and transcontinental DC network can not only greatly increase the transmission capacity and distance, but also reduce the transmission line circuit, line corridors and the overall investment in power grid construction. It has the advantages of isolating faults, resolving the frequency differences among countries and realizing long-distance transportation of new energy [3-5]. The UHV AC/DC economic evaluation model is established by combing the system reliability evaluation model [6]. However, the influence of UHVDC transmission configuration at different voltage levels on investment is not considered in detail in the economic analysis. The annual cost method is applied to compare and analyse the transmission economy of ± 800kV and ±1000kV UHVDC and half-wavelength [7], the economy of the conductor cross-section of UHVDC transmission lines is studied [8].

Taking the application scope of economic transmission of ±800kV and ±1100kV UHVDC as the research object, this paper compares and analyses the economy of each UHVDC transmission scheme by simulating transmission project configuration schemes at the two voltage levels that meet various transmission capacity and distance requirements. Then it analyses and proposes the application scope of economic transmission of the two levels. The research results are of great significance to the development planning of ultra-long-distance power interconnection.

2. Development trend of global energy Internet

The global energy internet is a strong globally interconnected smart grid with the UHV grid as its backbone network as well as a foundation platform for the large-scale development, transportation and use of clean energy around the world [1]. On November 4, 2016, the Paris Agreement officially entered into force, which marks the consensus and common action of all countries to accelerate clean development, combat climate change and promote the world energy transformation. The construction of global energy internet reflects the vision of innovative, coordinated, green, open and inclusive development of the world energy, representing broad prospects.

Wind energy, solar energy, and other renewable energy resources in the world are mainly concentrated in developing countries in Africa and Asia [9]. And most of the solar energy resource-rich regions also have abundant wind energy resources, such as North Africa, Mongolia, Central Asia, and the Midwest of U.S. The new energy resources in these regions are of relatively high quality with high power generation utilization hours and low investment cost, which have obvious advantages compared with the cost of renewable energy development in developed countries in Europe and other regions. It is estimated that the renewable energy installation in major sending end regions, such as China, India, Africa, and Latin America, will account for more than 50% of the world's total installed capacity by 2050. Costs of labor and building materials and taxes and fees are lower in these developing countries where the cost of investment in renewable energy systems is significantly lower than that of OECD and other developed countries. Currently, the cost difference of new energy investment among some regions can reach $1,000 /kW while the difference of average utilization hours of renewable energy between the sending and receiving ends is significant. The utilization rate of solar energy in North Africa and the Middle East, etc. is 800~1000h higher than that in northern and central Europe and eastern and central China in terms of the average radiation intensity. When taking into account the difference in investment level ($1,000/kW) and in utilization hours (1,000h), it is preliminarily estimated that the difference in LOCE of renewable energy between the sending and receiving ends can reach $0.05~0.15/kWh. Large-scale development and long-distance transmission of new energy resources can be realized by adopting UVHDC transmission mode[4-5].

3. Evaluation method of annual cost per unit capacity

3.1. Annual cost method of the transmission scheme

The annual cost of transmission capacity refers to the total cost to be paid each year for the transmission project to deliver the corresponding capacities after the project is completed and put into production, i.e. the total annual operating cost of the transmission project in essence. The annual cost method is one of the methods used for economic comparative analysis in electric power system planning that is applicable to the comparison of planning schemes with basically the same benefits or functions. In addition, this method can also be applied to the comparison of two planning schemes with different calculating periods. The universal annual cost calculation method is shown in equation (1).

$$A_C = \left[\sum_{t=1}^{n} (I + C' - S_v - W)_t (1+t)^{-t}\right]\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] \quad (1)$$

In the equation, I is total investment, C' is total annual operating cost, S_v is residual value of fixed assets recovered at the end of the calculating period, W is circulating fund at the end of the calculating period, i is benchmark return rate or discount rate of the power industry, n is calculation operating period, $(1+i)^{-t}$ is discount factor, $i(1+i)^n/[(1+i)^n-1]$ is capital recovery factor. In order to simplify the calculation of the annual cost, the costs shown in equation (1) can be simplified according to actual conditions.

Assuming that the total investment in the project is one-off and occurs in early the first year of the calculating period, i.e. t=0, the calculation component of annual investment in equation (1) can be approximated as:

$$\left[\sum_{t=1}^{n} I_t (1+i)^{-t}\right]\frac{i(1+i)^n}{(1+i)^n - 1} \approx I_0 \frac{i(1+i)^n}{(1+i)^n - 1} \quad (2)$$

Assuming that the annual operating cost occurs at the end of each year from the first year to the n year of the calculating period, and is equal in each year, as the S_v and W are small at the end of the calculating period, the two components in equation (1) can be ignored.

In conclusion, considering the above conditions, the annual cost formula can be simplified to equation (3). That is, the simplified equation indicates that the annual cost is the sum of annual equal investment cost and annual equal operating cost.

$$A_c = I_0 * i(1+i)^n/[(1+i)^n-1] + C' \quad (3)$$

3.2. Method of annual cost per unit capacity of transmission schemes

In order to compare the ±800kV and ±1100kV transmission schemes under various demands, the unit-capacity annual cost method is adopted to analyse the economy of each transmission scheme at the two voltage levels to compare their economic transmission scope under different distances.

To sum up, the calculation formula of the unit-capacity annual cost method of DC transmission at different voltage levels is shown in equation (4).

$$Unit\ A_C = A_C\ /\ HVDC\ capacity \quad (4)$$

In the equation, the annual cost A_C equals to the sum of annual investment value, operation and maintenance cost and line loss cost. Among them, the annual investment value is calculated according to equation (2). The operation and maintenance cost equals to the product of the original value of fixed assets and the operation and maintenance rate, the original value of fixed assets can be approximated to the project investment I_0 shown in equation (2) in actual calculation.

4. DC transmission configuration scheme

In view of the large demand for transnational and intercontinental networking under the background of global energy internet, the long-distance network of over 1000km is mainly adopted. ±800kV and ±1100kV UHVDC transmission schemes have obvious advantages.

4.1. Transmission line investment estimation

The paper puts forward the UHVDC line cost method based on the integrated calculation of the investment, construction and planning data of ± 800kV and ± 1100kV DC projects. As the annual operating hour of the UHVDC project is 6,000h, the annual cost of different conductor models at ±800kV and ±1100kV is compared when the power price is 0.060$/kWh and the transmission distance is 3,500 km. The results show that the total annual cost of the 8×1,250mm^2 wire is the lowest under the above conditions.

4.2. Converter station investment estimation

The unit capacity investment of ±800kV and ±1100kV DC station is calculated based on previous engineering budgetary estimations and the analysis of the cost structure of converter station. The specific indexes are shown in Table 1 and Table 2.

Tab.1 The integrated unit cost of various cross-section conductors at different voltage levels.

Serial No.	Voltage level kV	Line models mm^2	Integrated cost ($ /km)
1	±800	8×1,000	714,925
2		8×1,250	794,030
3		8×1,660	1,010,448
4	±1100	8×1,250	1,282,090
5		8×1,660	1,708,955

Tab.2 Investment estimation of UHVDC converter stations at different voltage levels

Current (A)	**Voltage (kV)**	**Main connection mode**	**Transmission capacity (MW)**	**Total investment of the converter station (million $)**
5,000	±800	Double 12-pulse	8,000	1,825.4
6,250	±800	Double 12-pulse	10,000	1,914.9
4,545	±1100	Double 12-pulse	10,000	2,122.4
5,500	±1100	Double 12-pulse	12,000	2,419.4

5. Economic DC transmission distance of er stations at diff

5.1. Calculation parameters of the annual cost

The calculation of the annual cost of each UHVDC transmission scheme adopts the following parameters, of which the data value refers to the existing related Chinese engineering experience. The specific indexes are shown in Table 3.

Tab.3 Relevant calculation parameters of the annual cost of UHVDC transmission

Relevant parameters	Value
Substation maintenance rate	2.0%
Line maintenance rate	1.5%
Thermal power operation rate	3.5%
Power transmission hours/loss hours	6,000/4,200
Sending-end power price（$/kWh）	0.04, 0.1
Project service life（h）	30
Rate of return	8.0%

5.2. Calculation of the UHVDC transmission loss

The paper focuses on the economy of ±800kV and ±1100kV UHVDC with different transmission capacities at various distances. Scheme 1 is ±800kV with the capacity of 8000MW, Scheme 2 is ±800kV with the capacity of 10000MW, Scheme 3 is ±1100kV with the capacity of 10000MW, Scheme 4 is ±1100kV with the capacity of 12000MW.

The devices of the converter station are various with different loss mechanisms and the loss of the converter station is normally about 0.5-1% of its rated power. The paper takes 0.75% and the total loss of the two voltage source converter stations is 1.5%.

The power loss of UHVDC transmission line at different distances is calculated according to the basic configuration of ±800kV and ±1100kV UHVDC transmission and the total loss of each scheme is obtained. With the increase of transmission distance, the power loss of each scheme also increases.

5.3. Annual cost calculation at various transmission distances

5.3.1. The annual utilization hour is 6,000h while the sending-end power price is 0.04$/kWh

At various distances, the annual cost per unit capacity of scheme 2 is the lowest as a whole. Scheme 1 and Scheme 3 are intersected at the point of about 1,500km. When the transmission distance is ＜1,500km, the Scheme 3 is slightly lower, When the distance is ⩾1,500km, Scheme 1 is slightly lower. The specific result is shown in Fig. 1.

5.3.2. The annual utilization hour is 6,000h while the sending-end power price is 0.1$/kWh

At various distances, the annual cost per unit capacity of Scheme 4 is the lowest as a whole. Scheme 2 and Scheme 3 are intersected at the point of about 3,500km in terms of the annual cost per unit capacity. When the distance is ＜3,500km, the annual cost per unit capacity of Scheme 2 is lower. When the distance is ⩾3,500km, the annual cost per unit capacity of Scheme 3 is lower. The specific result is shown in Fig. 2.

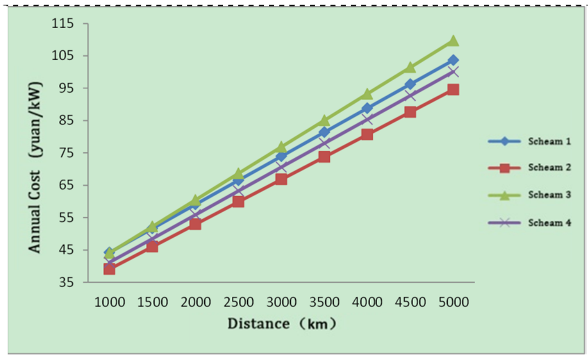

Figure 1. UHVDC transmission annual cost per unit capacity for 0.04$/kWh

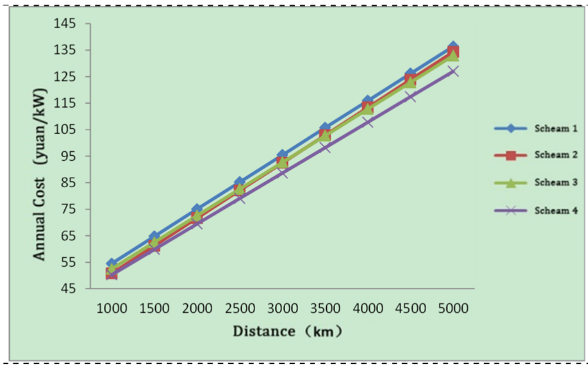

Figure 2. UHVDC transmission annual cost per unit capacity for 0.1$/kWh

6. Conclusion

This study can provide a preliminary reference for the selection of UHVDC voltage levels in the global energy interconnect planning. The unit-capacity annual cost of UHVDC transmission scheme is influenced by many factors such as project investment, operating hours, and the sending-end power price. In the study, the construction of converter station and the terrain conditions of the transmission route are assumed. However, in actual project, all factors will affect the annual cost per unit capacity. In view of the long transmission distance UHVDC and the complicated conditions along the route, it is necessary to conduct in-depth research in the design stage in accordance with the actual situation of the project to determine the UHVDC scheme.

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