ATLANTIS PRESS

Advances in Engineering Research, volume 86

2nd International Conference on Electrical, Automation and Mechanical Engineering (EAME 2017)

Relevancy Analysis of UHVDC Power Transmission and Provincial Power Source Construction

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***Abstract*—The rapid development of UHVDC power transmission makes the proportion of external power accepted by provinces increase significantly. This paper aims at analyzing the relevancy of UHVDC power transmission and provincial power source construction from two aspects of reliability and environmental protection, as well as finding the relevancy characteristics. Firstly, we establish the evaluation index system for power source construction and UHVDC power transmission. Secondly, we establish the correlation model based on the grey correlation analysis algorithm, and solve models by using Matlab software programming. Last, we take a province and an ± 800kV UHVDC power transmission engineering for example to conduct a case study. According to evaluation index system and data mining, the research calculates grey correlation value of the UHVDC power transmission and power source construction system, and qualitatively and quantitatively analyses the relevancy characteristics between the above two systems. The result reveals the inner relevancy and dominant factors between the ± 800kV UHVDC power transmission and provincial power source construction.**

Keywords-UHVDC; power source construction; evaluation index; relevancy analysis

I. INTRODUCTION

The UHVDC power transmission in China is developing rapidly and has a significant impact on power construction. The level of power construction also affects the safety and reliability of the UHVDC power transmission system. Along with the process of electric power system reform and the implementation of the national energy strategy, the effect of reliable power supply and environmental protection on power generation, power source construction and even power layout will be more and more highlighted. In this context, in order to coordinate UHVDC power transmission and power source construction in the province, the paper establishes the correlation model based on grey correlation analysis and solves models by using Matlab software programming. The research content can provide the basis and foundation of internal power dissolution together with external power, power source planning and construction in the province.

There have been studies conducted on power sources construction over many years. The most important thing of traditional power planning is constructing the objective function and constraint condition [1]. When the objective function and constraint condition was constructed, authors use different artificial intelligent algorithms to solve this nonlinear programming problem in [2-5]. The research on reliability analysis of UHVDC transmission systems also has been going on for a long time. Markov theory has been put forward to calculate the reliability of UHVDC transmission system in [6], and the paper[7] presents another method called state space method to calculate it. The evaluation indexes of UHVDC transmission system was discussed in [8-10]. The effects of different components on the overall reliability of UHVDC system are investigated in [11]. However, there are very few researchers pay their attention to combine the power sources construction with UHVDC transmission system, and analyze the relevancy between them. When a province has more and more landing point of UHVDC transmission project, the power sources construction must be influenced.

In this paper, the evaluation index systems of UHVDC transmission reliability and power sources construction were established in section II. The evaluation index system selected the most representative indexes to reflect the safety, adequacy and environment of power sources construction and UHVDC transmission. According to the grey correlation analysis algorithm, the correlation model was established in section III. The model comprised 6 parts: form characteristic sequence, make indexes being dimensionless, calculate the maximum and minimum range, calculate grey relational coefficient, calculate grey relational degree and classify grey relational degree. A province which has landing point of ± 800kV UHVDC transmission engineering was taken for example in section IV.

II. ESTABLISHMENT OF EVALUATION INDEX SYSTEM

A. *The Evaluation Index System of Power Sources Construction*

The evaluation index system collectively contained 16 indexes, which were divided into three levels (Table 1). First-level index is system level index, it reflects the whole situation of power sources construction. This index consists of three second-level indications: safety index, adequacy index and environment index. Further more, safety index consists of 5 third-level indexes: N-1 pass rate, N-2 pass rate, short-circuit current, the percentage of transmission capacity from other provinces and reactive power compensation. Adequacy index consists of 7 third-level indexes: installed capacity, maximum load, the percentage of conventional hydropower, the percentage of pumped-storage power, the percentage of wind power, the percentage of thermal power and the percentage of Photovoltaic power. Environment index consists of 4 third-level indexes: the percentage of renewable energy, the weight of saving standard coal, CO_2 emission reduction and SO_2 emission reduction.

TABLE I. THE INDEX SYSTEM OF POWER SOURCES CONSTRUCTION

First-level Index	Second-level Index	Third-level Index
The Evaluation Index of Power Sources Construction	Safety Index	N-1 pass rate
		N-2 pass rate
		Short-circuit Current
		The Percentage of Transmission Capacity from other Provinces
		Reactive Power Compensation
	Adequacy Index	Installed Capacity
		Maximum Load
		The Percentage of Conventional Hydropower
		The Percentage of Pumped-storage Power
		The Percentage of Thermal Power
		The Percentage of Wind Power
		The Percentage of Photovoltaic Power
	Environment Index	The Percentage of Renewable Energy
		The Weight of Saving Standard Coal
		CO_2 Emission Reduction
		SO_2 Emission Reduction

B. The Evaluation Index System of UHVDC Transmission Reliability

TABLE II. THE EVALUATION INDEX SYSTEM OF UHVDC TRANSMISSION RELIABILITY

The Evaluation Index System of UHVDC Transmission Reliability	Energy Availability
	Forced Energy Unavailability
	Scheduled Energy Unavailability
	Monopole Forced Outage Times
	Bipolar Forced Outage Times

The evaluation index system of UHVDC transmission reliability consists of 5 indexes: energy availability, forced energy unavailability, scheduled energy unavailability, monopole forced outage times, bipolar forced outage times(Table 2).

III. GREY CORRELATION MODEL OF POWER SOURCES CONSTRUCTION AND UHVDC TRANSMISSION RELIABILITY

Before you begin to format your paper, first write and save the content as a separate text file. Keep your text and graphic files separate until after the text has been formatted and styled. Do not use hard tabs, and limit use of hard returns to only one return at the end of a paragraph. Do not add any kind of pagination anywhere in the paper. Do not number text heads-the template will do that for you. The correlation model based on the grey correlation analysis algorithm was established to analysis the correlation between power sources construction and UHVDC transmission reliability.

A. Characteristic Sequence Forming

Suppose there are n indexes, and m characteristic data of each index. As in (1), a n*m characteristic sequence is formed to reflect the behavior characteristics of power sources construction system and UHVDC transmission reliability system. Two sequences are 16 indexes of power sources construction ($X_i(i=1,2,...,16)$) and 5 indexes of UHVDC transmission reliability ($Y_i(j=1,2,3,4,5)$). The sequence of power sources construction was selected as reference sequence.

$$(X_0, X_1, X_2, \ldots, X_m) = \begin{pmatrix} x_0(1) & x_1(1) & \ldots & x_m(1) \\ x_0(2) & x_1(2) & \ldots & x_m(2) \\ \ldots & \ldots & \ldots & \ldots \\ x_0(n) & x_1(n) & \ldots & x_m(n) \end{pmatrix} \quad (1)$$

B. Make Indexes Being Dimensionless

The dimension of two sequences (Xi and Yj) were eliminated by equalization operator. For all the data of original data sequence are removed with mean value of each sequence to form a new sequence which dimension is 1, as in (2).

$$X_i' = \frac{\overline{X}}{X_i},\ Y_j' = \frac{\overline{Y}}{Y_j} \quad (2)$$

where, $\overline{X}$ is the mean value of $x_i(k)$;

$\overline{Y}$ is the mean value of $y_j(k)$.

C. Calculate the Range

The difference sequences($\Delta_i(k)$) is the absolute difference between dimensionless sequences($X_i^{'}(k)$ and $Y_j^{'}(k)$) and the corresponding element of reference sequence($X_0^{'}(k)$), as in (3). The maximum value of all elements of difference sequence is the maximum range, as in (4). The minimum value of all elements of difference sequence is the minimum range, as in (5).

$$\Delta_i(k) = \left| x_0'(k) - x_i'(k) \right| \tag{3}$$

$$MX = \max_i \max_k \left| x_i'(k) - y_j'(k) \right| \tag{4}$$

$$MN = \min_i \min_k \left| x_i'(k) - y_j'(k) \right| \tag{5}$$

D. Calculate Grey Relational Coefficient

Grey relational coefficient is the correlation degree between the element of reference sequence and the element of relation sequence, as in (6).

$$R_{ij}(k) = \frac{MX + \xi \cdot MN}{\Delta_i(k) + \xi \cdot MN} \tag{6}$$

where, ξ is resolution coefficient (usually 0.5);

MX is maximum range;

MN is minimum range.

E. Calculate Grey Relational Degree

Grey relational degree is not equal to grey relational coefficient, it is not the correlation degree of two elements but two systems, as in (7).

$$\gamma_{ij} = \frac{1}{n} \sum_{k=1}^{n} R_{ij}(k) \tag{7}$$

F. Grey Relational Degree Classification

The relational degree value is between 0 and 1, the greater value reflects the stronger correlation between two systems, and vice versa. According to the relational value, the relationship between two systems can be divided into weak correlation, moderate correlation, strong correlation and great correlation (Table 3).

TABLE III. GREY RELATIONAL DEGREE CLASSIFICATION

Value	Classification
$0 < \gamma \le 0.35$	weak correlation
$0.35 < \gamma \le 0.65$	moderate correlation
$0.65 < \gamma \le 0.85$	strong correlation
$0.85 < \gamma \le 1$	great correlation

IV. ANALYSIS OF EXAMPLE

Hami-Zhengzhou ±800kV UHVDC transmission project was taken as an example to verify the grey correlation model. The data of each indexes of power sources construction in Henan province were collected in Table 4, and the data of each indexes of Hami-Zhengzhou UHVDC transmission system reliability were collected in Table 5.

TABLE IV. THE DATA OF EVALUATION INDEX SYSTEM OF POWER SOURCES CONSTRUCTION IN HENAN PROVINCE

Indexes	2010	2011	2012	2013	2014	2015
N-1 pass rate(%)	100.0	100.0	100.0	100.0	100.0	100.0
N-2 pass rate(%)	94.6	94.6	95.0	96.0	96.0	96.5
Short-circuit Curren(kA)	-	-	-	-	48.21	49.59
The Percentage of Transmission Capacity from other Provinces(%)	3.0	2.3	5.5	3.0	8.3	10.9
Reactive Power Compensation(Mvar)	28842	41131	39260	52012	53229	55413
Installed Capacity(MW)	50560	53240	57647	60520	61960	67436
Maximum Load(MW)	37500	43530	46710	50550	52003	53500
The Percentage of Conventional Hydropowe(%)	5.19	4.93	4.56	4.34	4.27	3.95
The Percentage of Pumped-storage Power(%)	2.02	2.48	2.29	2.18	2.13	1.96
The Percentage of Thermal Power(%)	89.24	88.67	89.31	89.54	88.56	88.34
The Percentage of Wind Power(%)	0.10	0.20	0.27	0.44	0.70	1.35
The Percentage of Photovoltaic Power(%)	-	0.003	0.007	0.03	0.32	0.61
The Percentage of Renewable Energy(%)	7.31	7.62	7.11	7.01	7.43	7.87
The Weight of Saving Standard Coal（ton）	3895 905	4628 515	5971 783	4864 794	4919 997	5008 357
CO_2 Emission Reduction（ton）	9614400	11422350	14737295	12005445	12141675	12359733
SO_2 Emission Reduction（ton）	289300	343702	443449	361247	365346	371908

TABLE V. THE DATA OF EVALUATION INDEX SYSTEM OF ±800KV UHVDC TRANSMISSION SYSTEM

Year	Energy Availability(%)	Forced Energy Unavailability(%)	Scheduled Energy Unavailability(%)	Monopole Forced Outage Times	Bipolar Forced Outage Times
2014	94.49	0	5.51	0	0
2015	95.53	0.14	4.33	1	0

A. Relevancy Analysis of Power Sources Construction and Each Indexes of UHVDC Transmission System

The grey correlation model was used to calculate the relational degree of power sources construction and each indexes of UHVDC transmission system in Table 6.

TABLE VI. THE RELATIONAL DEGREE OF POWER SOURCES CONSTRUCTION AND EACH INDEXES OF UHVDC TRANSMISSION SYSTEM

Indexes of UHVDC Transmission Reliability	Y_1	Y_2	Y_3	Y_4	Y_5
Relational Degree	0.848	0.850	0.673	0.848	0.780

In these five indexes, forced energy unavailability (Y2) has a great correlation with power sources construction, and other indexes have a strong correlation with power sources construction.

B. Relevancy Analysis of UHVDC Transmission System and Each Indexes of Power Sources Construction

In the same way, the relational degree of UHVDC transmission system and each indexes of power sources construction in Table 7.

TABLE VII. THE RELATIONAL DEGREE OF UHVDC TRANSMISSION SYSTEM AND EACH INDEXES OF POWER SOURCES CONSTRUCTION

Indexes	X_{11}	X_{12}	X_{13}	X_{14}
Relational Degree	0.857	0.803	0.801	0.780
Indexes	X_{15}	X_{21}	X_{22}	X_{23}
Relational Degree	0.890	0.678	0.679	0.871
Indexes	X_{24}	X_{25}	X_{26}	X_{27}
Relational Degree	0.871	0.871	0.871	0.871
Indexes	X_{31}	X_{32}	X_{33}	X_{34}
Relational Degree	0.670	0.745	0.893	0.894

In these 16 indexes, SO_2 emission reduction (X34), CO_2 emission reduction (X33), reactive power compensation (X15), the percentage of conventional hydropower(X23) and N-1 pass rate(X11) have a great correlation with UHVDC transmission system. N-2 pass rate(X12), short-circuit current (X13), the percentage of transmission capacity from other provinces(X14), the weight of saving standard coal(X32), maximum load(X22) and installed capacity(X31) have a strong correlation with UHVDC transmission system.

V. CONCLUSION

This paper analyzed the relevancy between power source construction and UHVDC transmission reliability and found the relevancy characteristics of these two system. Frist of all, the paper established the evaluation index system of UHVDC transmission reliability and power sources construction. The evaluation index system of power sources construction comprised 1 first-level index, 3 second-level indexes and 16 third-level indexes. The evaluation index system of UHVDC transmission reliability consisted of 5 indexes. Subsequently, the correlation model was established based on the grey correlation analysis algorithm, and the models were solved by using Matlab software programming. Finally, a province which has landing point of ± 800kV UHVDC transmission engineering was taken for example to conduct a case study. According to evaluation index system and data mining, relational degree value of the UHVDC power transmission and power source construction system were calculated, and the relevancy characteristics between the above two systems were analyzed quantitatively.

ACKNOWLEDGMENT

This research was supported by North China Electric Power University and State Grid Henan Economic Research Institute.

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