The Study Focuses on the Influencing Factors of New Energy Consumption and Power Supply Security in the Beijing-Tianjin-Hebei Region under the Context of "Dual Carbon"

Tiejun Ci, Ziheng Liao*
College of Energy Power and Mechanical Engineering, North China Electric Power University, Baoding, China
**Corresponding Author*

Abstract: In the "double carbon" goal proposed at present, the power enterprises are looking for change and transformation, but each enterprise faces different environment. Since the complex influencing factors of new energy consumption and power security supply involve a wide range and complexity, it is necessary to explore a strong adaptive research method to sort out the influencing factors from the qualitative and quantitative perspectives. Based on the idea of system engineering, this paper takes State Grid Jibei Electric Power Co., LTD as an example, combined with the company's strategic objectives, analyzes various factors that affect the consumption of new energy and power security and supply in the northern Beijing-Tianjin-Hebei region under the "dual carbon" goal, establishes the relationship table of influencing factors, and then establishes the adjacency matrix and accessibility matrix in turn for hierarchical division. The construction of a structural model for new energy consumption and electric power security is based on this premise. Ultimately, the hierarchical distribution relationship among various elements can be comprehended through the hierarchical relationship diagram, enabling clear definition of the significance of influencing factors and proposing corresponding reform ideas.

Keywords: "Double Carbon" Target; New Energy Consumption; Power Supply Security; Influencing Factors; Systems Engineering; Ism

1. Introduction

In October 2022, the "Action Plan for Achieving Carbon Peak before 2030" was officially released, defining the relevant targets and specific tasks for China to achieve carbon peak and carbon neutrality [1]. In the context of "dual carbon", achieving large-scale consumption of clean energy and ensuring the security of power supply have become urgent challenges to be solved. As China's economic core and energy hub, the northern Beijing-Tianjin-Hebei region is rich in wind, solar and other renewable energy resources, which makes new energy power generation potential huge [2]. On the other hand, its power demand is huge, and the reliability and stability of the power supply is very high. Therefore, while promoting the development of new energy, we must fully consider the issue of power security and supply.

The influencing factors of new energy consumption and power security supply constitute a complexity that involves a wide range and intricate. Li established a contribution model of influencing factors of renewable energy consumption and analyzed the interaction between various factors [3]. Wang Wei analyzed the key factors affecting the consumption of new energy in Hunan province and quantified the reduction effect of new energy consumption through sensitivity analysis [4]. Li comprehensively considered a variety of key influencing factors and proved that the participation of new energy units in frequency modulation can improve the consumption capacity of new energy [5]. Xie believed that new energy consumption is a systematic engineering, which is closely related to power structure, power demand and other factors [6]. Shan analyzed the global energy and power shortage problem since 2021 and prospected the new situation of energy and power supply and demand. Combined with China's national conditions, he put forward the response strategy of China to ensure energy and power security from the aspects of energy supply, consumption and technology [7]. Shi analyzed the problems of unbalanced development of new energy consumption under active power distribution with examples, and proposed corresponding improvement measures [8].

Currently, extensive research has been conducted by scholars on the influencing factors of new energy consumption using various research methods. However, these studies have overlooked the impact of security supply on the new energy consumption system. Therefore, this paper aims to provide effective strategies and policy suggestions by taking State Grid Jibei Electric Power Co., LTD as an example and applying the ISM analysis method of system engineering to deeply study the multiple comprehensive factors of new energy consumption and power security supply in the Beijing-Tianjin-Hebei region. It is expected that this study will offer strong support for the energy transformation in the Beijing-Tianjin-Hebei region while also providing valuable experience and inspiration for similar issues.

2. Construction of Influencing Factors of new Energy Consumption and Power Supply Security

In terms of new energy supply and consumption, through different development and utilization of new energy, from the attributes, challenges, volume rate analysis and other aspects of analysis [9]. In terms of power security and supply, this paper analyzes the risk transmission mechanism of energy and power, analyzes the positioning of State Grid Jibei Electric Power Co., LTD, and makes countermeasures from the aspects of infrastructure construction, power market and enterprise operation. Based on the comprehensive completion of the strategic indicators of the State Grid Corporation, according to the characteristics of the Beijing-Tianjin-Hebei northern region, combined with the strategic goals of the North Hebei Electric Power Company and the new power system construction goals, the “new energy consumption system construction and power security guarantee” as a factor S_0; The development factors of State Grid Jibei Electric Power Co., LTD under the new power system are respectively recorded as: “supply storage side” S_4, “power enterprise side S_5”; See Table 1 for details.

Table 1. Strategic Indicators for New Energy Consumption and Security of Electricity Supply

Target	Dimension	Name of indicator	Factor number	Definitions/calculations
Supply side (source) S_1	Reliable power supply	New energy multi-site short circuit ratio	S_6	Rated short-circuit current/system reference short-circuit current at all new energy field station access points
		Online monitoring and fault diagnosis level	S_7	(Number of correctly diagnosed faults + number of unmonitored but manually detected faults) / number of faults actually occurring
	Coordination and optimization	Coal and new energy portfolio capacity	S_8	Percentage of thermal power units and new energy units
		Abandoned water, wind and light rate	S_9	Abandoned water, wind and photovoltaic power from centralized power stations / (actual power generation + abandoned photovoltaic power)
		Level of new energy grid-connected consumption technology	S_{10}	Overall development level, derived from the expert evaluation method
		Distributed Power Development Index	S_{11}	Observable and controllable level of distributed power supply at 10 kV and 380 V and below and its penetration rate
	Clean and Low Carbon	New Energy Consumption Index	S_{12}	(Non-fossil energy consumption/total primary energy consumption)
		New Energy Development	S_{13}	Short-circuit ratio, unit-level active support

		Index		capability and power prediction index improvement; market grid-connected new energy scale share
		Carbon emission reductions achieved	S_{14}	Total carbon emission reductions from clean energy generation, loss reduction, etc. during the statistical period
Grid side (net) S_2	Resilience	Severe weather conditions	S_{15}	Number of days near or below equipment design temperature/total number of days in a year
		Power system resilience	S_{16}	Grid capacity for prevention, resilience and rapid recovery from extreme events
		Level of grid security and control technology	S_{17}	Evaluate in terms of dynamic stability margin, voltage stability, transient stability margin, etc., and perform sample/Monte Carlo simulation
	Smart grid	Grid development level	S_{18}	Optimized resource allocation capacity of large grids and level of flexibility of distribution grids
		Smart device coverage	S_{19}	Coordinated measurement of secondary indicators such as smart inspection robot coverage, smart meter coverage, etc.
	Widespread interconnection	Extended coverage of large power grids	S_{20}	Proportion of extension of large power grids to townships and administrative villages
		New energy transmission capacity	S_{21}	Limit capacity of new energy to be sent out through transmission corridors
Load side (load) S3	Demand-side resource management	Electricity conservation promotion	S_{22}	Evaluated by staggered electricity consumption
		Comprehensive evaluation of demand response	S_{23}	Size, variety and responsiveness of demand response repositories
		Level of electrification of end-use energy	S_{24}	Port shore power, heavy trucks and other areas of electric energy substitution and V2G charging pile layout
	Intelligent Interaction	Power system informatization level	S_{25}	Scale of access to provincial smart energy platforms, level of ability to interact with grid scheduling
		Comprehensive energy business development index	S_{26}	(Value of comprehensive energy income/target value of income) x 60% + (Energy consumption per unit of GDP/target value of energy consumption per unit of GDP) x 40%
	Safe and reliable	Comprehensive power supply reliability	S_{27}	Reliability of power supply for urban and rural grids
		Information security protection capabilities	S_{28}	The ability of information network hardware and software and their system data not to be damaged or leaked
Energy storage side (storage) S_4	Technological developments	Level of development of multiple energy storage options	S_{29}	Comprehensive evaluation of the scale and mode of operation of pumped storage, grid-side energy storage, hydrogen energy storage and other modes in the north Hebei region
		Energy Storage System Safety	S_{30}	Statistics on the number of security incidents at energy storage plants
	Market development	Scale of Participating Subjects	S_{31}	Substantial layout and scale of capital investment in energy storage by market players
		Energy storage side policy support	S_{32}	Level of policy support related to the energy storage side
	Research	Load technology innovation input intensity	S_{33}	Characterize the intensity of investment in load technology innovation

	and development investment	Emerging load development	S_{34}	Extent of Emerging Load Expansion
Power enterprise side S_5	Innovation Leadership	Digital Development Index	S_{35}	Ratio of the number (type) of transactions conducted online to the number (type) of transactions that should be conducted online
		Science, technology and innovation investment intensity	S_{36}	Indicates the intensity of factor inputs in science, technology and innovation
		Talent-equivalent density	S_{37}	Percentage of the highest converted value cumulative/number of permanent employees after converting the coefficients of education, title, skill level, etc. of permanent employees
	Organization and leadership	Organizational construction level	S_{38}	Secondary indicators measuring the results of enterprise reform and development, the completeness of the governance system and risk management and control
		Company management level	S_{39}	Degree of company-wide coordination

3. Analysis of Influencing Factors of New Energy Consumption and Power Supply Security

(1) Subordination relationship

According to the hierarchy of the factor construction process, there is a directly related subordination relationship between factors, such as S_1, S_2, S_3, S_4, S_5 are subordinate to S_0. Factors at the latter level will have an effect on the factors at the former level to which they are subordinate. The subordination between factors is the same as in Table 1.

(2) Other relationships

Analyze the relationships, other than subordination, that each factor has with other factors. The specific analyses are as follows:

S_6 can be directly influenced by the following factors: S_{13} (reason: the new energy field station-level short circuit ratio is one of the qualitative evaluation factors of new energy development); S_7: S_6, S_{16}, S_{18} (strong monitoring and fault diagnosis will safeguard the new energy power supply and help to prevent the risk of the power system and support the development of the smart distribution grid); S_8: S_9, S_{13} (the water abandonment wind and landscape rate can measure the coal and new energy Combined capacity); S_{10}: S_9, S_{12}, S_{13}, S_{18}, S_{21} (new energy grid consumption technology affects the transmission capacity of the new energy outgoing cross-section, if insufficient will lead to increased waste, hindering the consumption of new energy, and vice versa can improve the optimization of resource allocation capacity of the power grid, the flexibility and intelligence of the distribution network); S_{11}: S_9, S_{14} (distributed power supply can regulate the peak of the electric power, stable power supply to reduce waste, and a high transmission rate represents an increase in the low-carbon level and thus affects carbon emissions); S_{12}: S_{14} (new energy consumption is positively correlated with the amount of carbon emission reduction achieved); S_{13}: S_{12} (new energy development supports new energy consumption); S_{15}: S_{16} (bad regional weather conditions are closely related to the power system's ability to withstand risks); S_{17}: S_{10}, S_{16}, S_{27}, S_{30} (grid security and control technology is an important component of new energy grid-connected consumption, which will provide support for the power system's ability to resist risks, while the security of the energy storage system requires the improvement of multi-layer security protection technology); S_{19}: S_7 (real-time monitoring of equipment operation, timely detection and resolution of faults, and a high degree of integration of the collected data to facilitate the diagnosis); S_{20}: S_{18} (the extension of the coverage of the large grid is an important factor in evaluating smart grid development); S_{22}: S_9, S_{12} (peak power consumption reduces the rate of water and wind abandonment and light abandonment, and the promotion of power conservation promotes new energy consumption); S_{23}: S_{10}, S_{24}, S_{26} (the scale, type and speed of demand response affects the level of new energy consumption on the grid and the electrification of end-use energy, and it is also one of the indicators affecting the development of energy service business); S_{25}: S_{10} (The interaction between energy management platforms and grid scheduling can improve the technical level of new energy grid-connected consumption); S_{28}: S_{16} (information security protection capability improves the risk-resistant capability of the power system); S_{30}: S_{16} (the security of the energy storage system is one of the indicators affecting the risk-resistant capability of the power system); S_{32}: S_{29}, S_{31} (the policy supports the development of energy storage, and promotes the field main body's substantial layout and capital investment in energy storage); S_{33}: S_{29}, S_{34}(load technology innovation investment to support energy storage development can promote emerging load development); S_{35}: S_{23}, S_{25} (online processing of business allows for faster response and provides a vehicle for power system informatization); S_{36}: S_{7}, S_{10}, S_{17}, S_{18}, S_{23}, S_{33}, S_{35}, S_{37} (science and technology innovation investment to promote technological development and promote the corresponding capacity improvement); S_{38}: S_{39} (reorganization of the company's internal affairs, which in turn improves the degree of coordination and organization building up and down the company).

Based on the subordination and other relationships, a relationship table of influencing factors was established, as shown in Table 2.

Table 2. Relationship of Influencing Factors

Factor S_i	Direct impact factor S_i	Factor S_i	Direct impact factor Si	Factor S_i	Direct impact factor Si
0	—	14	1	28	3、16
1	0	15	2、16	29	4
2	0	16	2	30	4、16
3	0	17	2、10、16、27、30	31	4
4	0	18	2	32	4、29、31
5	0	19	2、7	33	4、29、34
6	1、13	20	2、18	34	4
7	1、6、16、18	21	2	35	5、25
8	1、9、13	22	3、9、12	36	5、7、10、17、18、23、33、35、37
9	1	23	3、10、24、26	37	5
10	1、9、11、12、13、18、21	24	3	38	5、39
11	1、9、14	25	3、10		
12	1、14	26	3	39	5
13	1、12	27	3		

4. Modeling the Explanatory Structure

According to Table 2, an adjacency matrix is created, and two factors are marked 1 in the matrix if they are in a direct influence relationship. Figure 1 shows part of the adjacency matrix. In the row of S_0, since S_0 has no direct influence, the row is marked 0. For S_1, its direct influence is only S_0, so the column of S_0 is marked 1, and the others are marked 0. Repeat the above steps until S_{39}.

	S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32	S33	S34	S35	S36	S37	S38	S39
S0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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S39	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 1. Partial Presentation of the Adjacency Matrix

Using the method of continuous multiplication to find the reachable matrix, first of all, the adjacency matrix and the unit matrix are added to get the multiplication matrix, and then the Boolean product (Boolean Product) operation is performed on the multiplication matrix, according to the characteristics of Boolean matrices, the last is no longer change that is the reachable matrix, the specific algorithm: $(A+I)^{(K-1)} \neq (A+I)^{K} = (A+I)^{(K+1)} = R$, in which A is the original adjacency matrix, I is the unit matrix, and R is the reachable matrix [10].

Then, to divide the hierarchical relation of the reachable matrix, it is necessary to find the following factors: (1) Reachable set $R(S_i)$: the set formed by the factors that can be reached by the factor S_i in the reachable matrix; (2) The antecedent set $Q(S_i)$: the set composed of the factors of the reachable factor S_i in the reachable matrix; (3) Common set $A(S_i)$: The intersection of factor S_i in reachable set and antecedent set.

Table 3. Examples of Reachable Sets, Antecedent Sets, and Common Sets of Influencing Factor.

S_i	Reachable set (S_i)	The antecedent set $Q(S_i)$	Common set $A(S_i)$
0	1	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40	1
……			
39	1,6,40	39,40	40

Since the above operations are only mathematical operations, no correlation analysis is involved. Therefore, SPSSAU software is used to calculate the reachable matrix from the adjacency matrix and the hierarchy is divided. The reachability set, antecedent set and common set of influencing factors are shown in Table 3. The specific results are as follows:

(1) Region division

The termination set $E(S)=\{S_i|S_i \in S, C(S_i)=R(S_i), i=1,2,......,n\}$ is derived from the termination set defining equation $E(S)=\{0\}$. There is only one factor in the termination set and the set of factors S is indivisible.

(2) Classification

The highest level factor of the system's factor set is the termination set factor of the system, and the first level is obtained as:

$L_1=E(S)=\{0\}$;

After removing the highest level factors, the remaining factors S - L_1 are divided according to the principle of $C(S_i)=R(S_i)$, and the second level is obtained as:

$L_2=\{1,2,3,4,5\}$;

And so on until the lowest level of factor set is determined. Get the levels as:

$L_3=\{9, 14, 16, 18, 21, 24, 26, 27, 29, 31, 34, 37, 39\}$;

$L_4=\{11, 12, 15, 20, 28, 30, 32, 33, 38\}$;

$L_5=\{13, 22\}$; L6= {6, 8, 10} ; L7= {7, 25};

L8= {36} ;

The reachability matrix is rearranged according to the order of hierarchical structure, removing the strongly connected factors, the cross-level binary relationship between factors and its own reachable binary relationship, and drawing a multilevel recursive directed graph according to the binary relationship to construct the explanatory structure model. The purpose of hierarchical decomposition is to understand the hierarchical distribution relationship of each element; the top layer indicates the ultimate goal of the system, and the lower layers are the causes of the upper layer; the bottom layer indicates the causes of the initial point of the system, and the upper layers are the results of the lower layer [11]. The hierarchical relationship of the factors affecting new energy consumption and power security supply of State Grid Jibei Electric Power Co., LTD in the context of "double carbon" is shown in Figure 2. The lower the level of the factors, the greater the impact on the realization of strategic objectives. The intensity of scientific and technological innovation investment is located in the deepest level, which has the greatest influence; the four factors of grid security and control technology level, comprehensive level of demand response, coverage rate of intelligent equipment, and digitalization development index are in the second deepest level, which have greater influence.

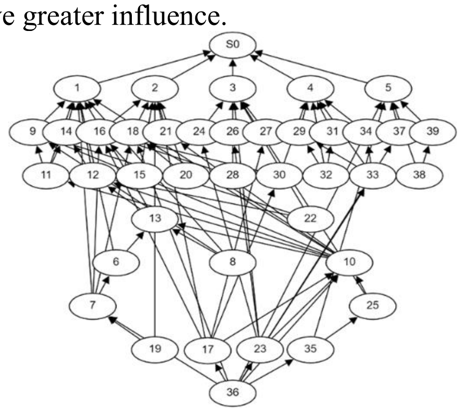

Figure 2. Schematic Diagram of Hierarchical Relationships

5. Conclusion

Through the analysis of ISM technology, State Grid Jibei Electric Power Co., LTD needs to increase the intensity of investment in scientific and technological innovation, further improve power technology to adapt to the current era environment, which also increases the company's investment in intelligent equipment and safety and control technology to cope with the transformation and development of new energy supply and consumption system, improve the level of online monitoring and fault diagnosis, and then improve the anti-risk ability of power system. Therefore, it is necessary to focus on the construction of updating system equipment, improve the level of information integration, to achieve the “double carbon” goal, we must change the construction ideas, improve the ability to cope with power security and supply, improve the combination of coal and new energy on the power side, and give full play to the supporting role of thermal power; On the power grid side, the traditional power grid is built as the core, and cutting-edge sensor technology, communication technology, IT technology, computer science and automation control technology are deeply integrated with the physical power grid to create an intelligent power grid system; On the demand side, improve the comprehensive ability of demand response and the level of digitization; On the load side, increase the investment intensity of load technology innovation and tap the potential of new load technology. Through these measures to achieve a high degree of information and automation of the power system, optimize the ability of resource allocation and anti-risk ability, and then improve the capacity of new energy supply and consumption, to ensure the safety of energy and power supply.

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