ISSN: 2414-1895 DOI: 10.6919/ICJE.202107_7(7).0053

Research Status and Prospects of Key Technologies for Comprehensive Evaluation of Regional Integrated Energy Systems

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Abstract

As an important carrier of smart energy in the adjustment of China's energy structure, regional integrated energy has received extensive attention from academia and industry. Comprehensive evaluation technology is an important means to comprehensively evaluate the development level of the energy system, which mainly involves two aspects: indicator structure and evaluation methods. However, related research work is relatively lacking at present. For this reason, this article separately elaborates the research status of the index system construction and the comprehensive evaluation method and puts forward the problems and shortcomings in the current evaluation method. On this basis, based on the new data processing technology-multi-source data fusion technology, combined with the development status of the regionally integrated energy system, the development prospects of integrated energy evaluation techniques are discussed in-depth, and the future research focus and development direction of this field is proposed. To provide reference and new ideas for evaluation research and engineering project development, to promote the rapid development of my country's comprehensive energy technology.

Keywords

Comprehensive Evaluation; Integrated Energy System; Multi-source Data Fusion; Energy Interconnection; Economic Benefit.

1. Introduction

Energy is the foundation of human civilization. However, due to the dual dilemma of rapid consumption of traditional petrochemical resources and increasing environmental pollution, comprehensive energy technologies with the power system as the core have been born. In recent years, the theoretical research and engineering construction of the integrated energy system have received extensive attention from scholars in the energy field at home and abroad, becoming a trend and also an important development direction for my country's current energy structure adjustment. The regionally integrated energy system is the product of the deep integration of information and communication technology and energy system. It refers to the realization of complementary advantages and renewable energy in a wide area by coupling power, transportation, natural gas, heating, and cooling systems based on traditional energy supply networks. Sharing and efficient use within the scope[1]. Realize the organic coordination and optimization of energy supply, transmission and distribution, coupling, storage, consumption, and other links, and then form an integrated system of energy production, supply, and marketing, and provide high-quality, safe, and efficient energy services[2].

ISSN: 2414-1895 DOI: 10.6919/ICJE.202107_7(7).0053

The integrated energy system can effectively improve the comprehensive utilization efficiency of energy, realize the sustainable supply of social energy, accelerate the intensity and progress of renewable energy development, and improve the flexibility, economy, safety and self-healing ability of the social energy supply system. Realizing the interconnection, conversion and utilization, and coordinated optimization of multiple energy sources of electric cooling and heating can effectively improve energy utilization efficiency, reduce environmental pollution, and promote the transformation of energy utilization from traditional extensive to intensive and sustainable. This system is especially suitable for the operation optimization of the energy system at the park (community) and town level and is one of the important means to deal with the problems of high energy consumption and high pollution in the process of urbanization in China[3].

As the physical carrier of the energy Internet, the integrated energy system is not only a research and development direction that has received much attention in the energy field, but also an important goal of my country's energy industry structure adjustment. However, due to the complexity of its multi-energy synergy, it needs to be evaluated reasonably[4]. As more and more integrated energy system engineering projects in our country are put into operation, it is necessary to evaluate integrated energy system engineering so that the evaluation link can provide timely and effective feedback information on the operation of integrated energy system engineering, and give guidance to the construction of integrated energy system engineering The role of guidance is to form a good development mechanism for the construction of integrated energy systems to guide planning and scheduling. As a research hotspot in recent years-integrated energy, needs to be comprehensively evaluated in the process of planning, construction, and putting into use, just like the power grid. To make these projects play the greatest role in the development of my country's integrated energy, the assessment of integrated energy is indispensable. Therefore, this article will specifically sort out the existing comprehensive energy evaluation index and evaluation methods, and propose the research focus and development direction of the future comprehensive energy evaluation research.

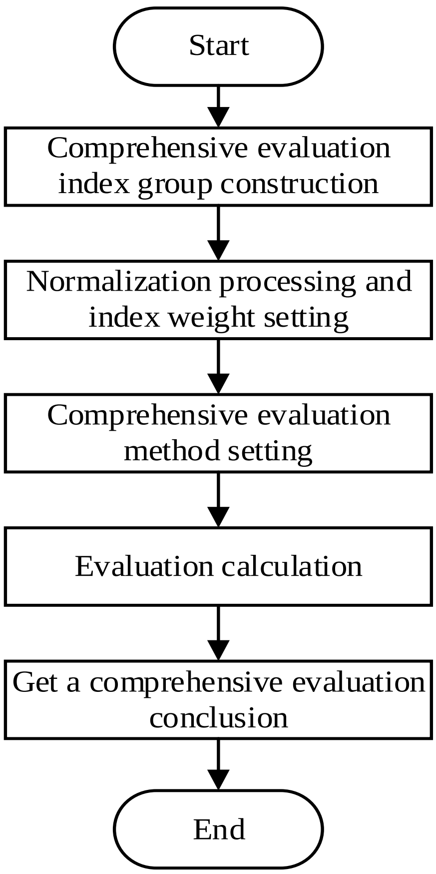

Figure 1. Comprehensive evaluation flow chart

ISSN: 2414-1895 DOI: 10.6919/ICJE.202107_7(7).0053

2. Basic process of regional comprehensive energy comprehensive evaluation

At present, the detailed steps of the evaluation process are similar, and the basic process is carried out around core modules such as indicator clusters, data processing, and selection of evaluation methods. Therefore, the comprehensive evaluation process of the regionally integrated energy system is shown in Figure 1.

3. Research status of evaluation index

The selection of index is the first step in the evaluation work, and the quality of the selection determines the quality of the evaluation results from a certain perspective. As the most important key link in the evaluation process, it is an important bridge linking evaluation objectives and evaluation methods. Only by establishing a scientific and reasonable comprehensive evaluation index system can the credibility of the evaluation results be guaranteed.

The comprehensive energy assessment index mainly includes four dimensions: technical index, economic index, environmental index and social index. To this end, this article will summarize the current research status of the research index from the four dimensions of technology, economy, environmental protection and sociality.

3.1 Technical dimension

Compared with several other dimensions, the relevant technical index are relatively mature, mainly including energy supply reliability index, energy conversion efficiency index, network loss index and other directions. Reliability of energy supply is mainly used to evaluate the ability of the regionally integrated energy system to work normally and continuously supply energy. The literature [5] uses the "system average duration of disability SAIDICAIDI" and "user's average duration of disability CAIDI" to reflect the system Operational reliability. Literature [6] uses "system average failure time", "system energy supply reliability rate", and "system energy failure rate" as evaluation index to reflect system reliability. The network loss index is used to reflect the energy lost in the energy transmission link of the regional energy Internet, and it is also one of the factors that affect the comprehensive utilization efficiency of the regional energy Internet. It mainly includes the loss of the distribution network, the heat loss rate of the pipe network, and the natural gas transmission difference. Literature [7] sets the line loss rate and network comprehensive loss to reflect the comprehensive energy system network loss. Literature [8] uses the failure rate of 10KV overhead lines, the failure rate of switchgear, and the failure rate of distribution transformers to reflect the safety level of system operation

The following mainly describes the two directions of the energy supply reliability index and the energy conversion efficiency in the technical indexes. The mean time between system failures and outages is an important indicator for evaluating operational reliability. The numerical relationship is shown in formula (1) and formula (2).

$$T_{CAIDI} = \frac{T_{user}}{n_f} \tag{1}$$

$$T_{SAIDI} = \frac{T_{user}}{n_{user}} \tag{2}$$

Where: T_{CAIDI} is the average power outage time per household; T_{SAIDI} is the average duration of power outages in the system; T_{user} is the total duration of power outages for users; n_{user} is the total number of users; n_f is the total number of power outages for users.

The overall operating efficiency of the energy link is an important basis for whether the overall comprehensive energy structure is reasonable. Literature [9] uses the energy conversion efficiency coefficient to characterize the level of this level.

$$I_{ECEC} = \frac{Q_C\lambda_C+Q_H\lambda_C+E\lambda_e}{\sum(W_{HVAC_i}\lambda_i)} \tag{3}$$

Where: Q_H, Q_C, and E are the annual heat and cold consumption of the energy system and the output power of the cogeneration unit.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202107_7(7).0053

3.2 Economic dimension

Considering all aspects of the country, the assessment of the economic benefits of the integrated energy system at home and abroad is mostly consistent. That is, the economic index centered on the integrated energy system. It is mainly divided into two categories, investment-effective financial index, and equipment economic index that reflect the economic operation of the system. The evaluation of economic benefits of integrated energy systems in foreign countries mostly uses traditional evaluation index. The details are shown in Table 1.

Table 1. Economic index combing

Investment efficiency	System equipment economy
Equipment investment cost	Equipment utilization[10]
Net present value (NPV)	Device service life
Payback period (PP)	Cost savings in equipment operation
Cost-benefit ratio (IRR)	Equipment operation and maintenance costs

Judging from the existing research results, domestic and foreign researches have been carried out on the comprehensive energy system benefits evaluation index system, but the comprehensive energy benefit evaluation index system and its evaluation criteria that can be applied to actual engineering evaluation have not yet been fully established.

3.3 Environmental protection dimension

The environmental protection index is used to reflect the contribution of the integrated energy system to the reduction of pollutant emissions and the reduction of carbon emissions. Among them, the environmental protection settings mainly include carbon dioxide emissions, pollutant emission reductions, and solid waste emissions. The following mainly describes the calculation instructions of carbon dioxide CO_2 emissions.

Literature[10] defines and explains the carbon dioxide emissions of a certain park, and its mathematical calculation is formula (4):

$$\begin{cases} C_{\mathrm{EC}} = \dfrac{E_{\mathrm{buy}}}{\eta_T^P} C_{\mathrm{Eu}} + \dfrac{Q_{\mathrm{heat\,,\,load}}}{\eta_T^Q} C_{\mathrm{Ef}} \\ C_{\mathrm{ES}} = \dfrac{E_{\mathrm{chiller}} + E_{\mathrm{power\ load}}}{\eta_S^P} C_{\mathrm{Eu}} + \dfrac{Q_{\mathrm{heat\,,\,load}}}{\eta_S^Q} C_{\mathrm{Ef}} \\ \Delta C_E = \dfrac{1}{2.49}(C_{\mathrm{ES}} - C_{\mathrm{EC}}) \end{cases} \tag{4}$$

Where: C_{EC} and C_{ES} are the carbon dioxide emissions of the combined cooling, heating and power supply and sub-supply systems, respectively. E_{buy} is the electricity purchased by the cogeneration system from external public networks. $Q_{heat\ load}$ is the heat load. $E_{chiller}$ requires electricity for the cooling load of the sub-supply system. $E_{power\ load}$ is the electric power required by the electric load of the sub-supply system. C_{Ef} is the unit carbon dioxide emissions of fuel.

3.4 Social dimension

The sociality is mainly reflected in the user's satisfaction with the system. Representative index include the predicted percentage of dissatisfied people (PPD) index, indoor air quality satisfaction, user expense intensity, and user satisfaction index. The following is about the user cost CES and the user-side satisfaction index *CSAT*.

CES (Customer Effort Score) is used to describe how difficult it is for users to evaluate service to solve problems. The main options for customers include: very simple, simple, a little simple, neutral, a little difficult, difficult, very difficult. The advantage of *CES* is that it can help companies eliminate or reduce obstacles in user service, but *CES* can only point out obstacles in user service, and will not go into details about why users encounter problems or what these obstacles are. Specific obstacles need to be investigated and analyzed with the help of other tools.

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The most typical indicator of customer satisfaction is *CSAT* (Customer Satisfaction), which mainly includes five points, including five choices, very satisfied, satisfied, general, dissatisfied, and very dissatisfied. The *CSAT* value is obtained by calculating the final proportion of users who choose level 4 and level 5. If the *CSAT* value is higher, it means that the user's satisfaction is higher.

After the above research, it is found that there is a lack of existing user index research on social index. As an important part of the feedback reflecting the operation level of the integrated energy system, the research direction should be reflected in user experience, comfort, convenience, and differentiated satisfaction. All kinds of user experience, thereby promoting the improvement of integrated energy service level.

4. Summary of evaluation methods

Comprehensive evaluation, also known as a multi-index comprehensive evaluation method. Its principle is to use standardized methods to evaluate multiple targets. At present, there are many different methods for a comprehensive evaluation, such as the TOPSIS method, analytic hierarchy process, RSR method, fuzzy comprehensive evaluation method, grey system method, etc. Due to many factors, these methods have their characteristics and have their advantages and disadvantages. The evaluation methods and descriptions are shown in Table 2.

Table 2. Comprehensive evaluation method summary

Multi-index comprehensive evaluation	Description
TOPSIS[11]	Based on two benchmarks close to the ideal solution and far from the negative ideal solution, the order of each evaluation object is optimized.
AHP[12]	The elements related to decision-making are decomposed into target level, criterion level, and plan level, and qualitative and quantitative analysis and decision-making are carried out.
Grey Correlation Method[13]	One of the grey system analysis methods is to replace the continuous concept with discrete data.
Entropy method[14]	Mining the numerical information related to the index to obtain the index weight, complete the objective evaluation of the evaluation object.
Fuzzy Comprehensive Evaluation Method[15]	The fuzzy index is quantified by constructing a fuzzy subset of grades and an overall evaluation is made.

At this stage, there has been a certain amount of research on the evaluation system of integrated energy systems at home and abroad. As one of the most commonly used algorithms for evaluation problems, the AHP method has also been widely used in the evaluation of integrated energy systems. Literature [12] established a comprehensive energy evaluation method based on the AHP method for the distribution network, heating network, load equipment and other elements, with the first law of thermodynamics energy analysis as the core. Literature [16] fully considers equipment static parameters, dynamic operating status, and user-type index, uses the AHP evaluation method to achieve a quantitative evaluation of comprehensive energy efficiency and finds weak links in the energy system.

However, when the AHP method is used for evaluation, the standards and empowerment operations in the evaluation process are affected by the professional level and academic experience. Therefore, experts and scholars have adopted AHP combined with other objective empowerment methods and made many practical attempts based on this method. Literature [14] The comprehensive evaluation method of power grid safety and benefit based on the BWM-entropy weight-TOPSIS method effectively solves the problem of excessive subjective awareness and lack of objective raw data caused by the current use of traditional single evaluation methods in the diagnosis of power grid development. And the problem of uneven distribution of weights. The literature [17]determines the weight assignment of various index based on the AHP-improved entropy weight method, establishes a VIKOR multi-criteria evaluation system, and integrates the integrated energy system of the park microgrid from the four aspects of the economy, reliability, energy consumption, and environmental

ISSN: 2414-1895
DOI: 10.6919/ICJE.202107_7(7).0053

protection. Evaluation. The literature [18] fully considers the comprehensive energy evaluation system in terms of multi-energy coupling, system energy consumption, etc., and establishes an evaluation system that considers the efficiency of the system, and uses the composite method of network analysis method (ANP)-entropy weight method to assign index. right. Literature [19] proposed a comprehensive evaluation method based on AHP-TOPSIS, to improve the scientific nature of the energy Internet system evaluation.

With the development of the times, some traditional evaluation algorithms are no longer applicable to systems with complex index and huge data in the regionally integrated energy system. Therefore, other documents directly abandon the traditional evaluation method to reduce the problems in the evaluation process. The literature [14] uses the matter-element extension theory (MEE) to rank the similarity of the ideal solution (TOPSIS) from the three levels of economic benefit, environmental benefit and social benefit to conducting comprehensive benefit evaluation. Literature [15] conducted a subjective evaluation and analysis based on the cloud model and used the TOPSIS method to integrate the evaluation value obtained from the cloud model and the objective evaluation value obtained by entropy. The proposed CM-EM-TOPSIS method evaluates and analyzes the development status of 11 countries. Literature [21] introduced mature operations research, established a comprehensive efficiency evaluation model based on the cross-over-efficiency CCR model, and then constructed an evaluation index system from the aspects of the economy, reliability, environmental protection, and energy consumption, and calculated the index values from the scheduling results, And then calculate the cross-over efficiency value as the comprehensive efficiency value of IES for evaluation. Literature [22] considered 16 standards of technology, economy, society, engineering and related, adopted fuzzy analysis and cloud model to determine the weight of the standards, and finally gave the evaluation results in actual cases in China. Literature [23] has solved the uncertainty problem based on the cloud model and fuzzy set theory, using the advantages of performance evaluation information, fully considering the operation of the system during the formation of the planning scheme, and proposed a multi-scalable matter element. Attribute decision model to evaluate the comprehensive benefits of the multi-energy microgrid.

Although the above-mentioned documents have established different comprehensive evaluation models for the comprehensive energy system, the comprehensive evaluation methods in existing research remain at the theoretical level, and it is difficult to verify the practicality of supporting the implementation of specific cases. How to overcome subjectivity is the most critical issue in the current regional integrated energy system assessment research. Although many scholars have given certain solutions, the effects of different methods are uneven, and the evaluation methods have not been unified. Therefore, this article gives some suggestions on the evaluation method, mainly in the following 2 points.

1) In terms of subjectivity, whether the AHP method can be completely abandoned, most of the existing studies are based on AHP and subjectively determine the weight of the constructed index group. Some scholars have chosen the combination weight method combining entropy weight method-objective weight method and subjective weight method, which can weaken the subjective influence of AHP method to a certain extent, but still cannot eliminate the influence of experts in the evaluation process fundamentally.

2) For some methods that abandon traditional evaluation and adopt new evaluation algorithms, these methods have not been reasonably verified, whether they really overcome the criticism of traditional evaluation algorithms. The scientificity and rationality of these new methods need further verification and induction.

5. Key technologies and prospects

Through the research status, it can be found that certain progress has been made in this field, but most of the researchers currently have built a comprehensive evaluation index system that is not comprehensive enough. Most of the index are concentrated on the evaluation side of the power grid.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202107_7(7).0053

There are fewer index for cold and natural gas. The problems with most index are the independent consideration of energy forms such as electricity, gas, cold, and heat, and most of them are limited to the field of a single energy system and do not fully consider the characteristics of multi-energy coupling and multi-energy synergy and vertical source network The interaction between the Dutch and the reserve. At present, due to the simplification of evaluation methods, the existing evaluation methods are only suitable for evaluation problems with relatively simple indicator systems, and cannot be applied to comprehensive evaluation problems with multiple index and complex levels of the integrated energy system. Only by avoiding the limitations of a single method and using a variety of effective comprehensive evaluation methods, can the comprehensive evaluation method constructed have important practical significance.

If we want to overcome the existing evaluation problems of the current integrated energy system, we will continue to solve the complex coupling relationships involving multiple energy forms. Therefore, it is necessary to establish a comprehensive evaluation index system covering electricity, gas, cold, and heat from a new perspective and new thinking, and use advanced evaluation methods to solve this problem. Therefore, this article gives breakthroughs in the following two areas.

5.1 Multi-energy coupling evaluation index

When constructing the indicator system, research sites should break through the barriers of independent evaluation of the existing index of electricity, gas, heat, cold and other different energy forms, and fully consider the multi-energy coupling, multi-energy synergy, and multi-energy complementarity of the energy Internet. Since the initial design of the integrated energy system is the concept of energy-saving, environmental protection, ecology, intelligence, etc., it will build a comprehensive energy index system from a more comprehensive dimension to the comprehensive energy development requirements of multi-energy coordination, green and low carbon, safety and efficiency.

To this end, build an evaluation index system that takes into account various energy conversion laws of the regional energy Internet, reflects the characteristics of complementary energy substitution, takes into account the diverse energy needs of users, and the characteristics of the multi-agent game. The evaluation index need to cover the technical and economic aspects of regional integrated energy. At the environmental protection level, the evaluation system is constructed in four dimensions at the social level, including specific aspects such as energy supply reliability, energy supply loss, system profitability, equipment loss, pollutant emission reduction level, resource utilization efficiency, and user comfort.

In the process of defining index, the principles of achievable, operable, and measurable need to be shown concretely, and they need to be as realistic as possible and cover the complex factors of system operation in different environments. The relevant index at the technical level are relatively mature. However, concerning economy, environmental protection and comprehensive energy utilization efficiency interweaving and affecting each other, when setting index, it is necessary to focus on the level of coupling substitution law that considers different factors. User satisfaction at the social level will directly reflect whether the integrated energy system can provide users with differentiated and high-quality integrated energy services, and is an important manifestation of whether the integrated energy system has sufficient advantages and service levels.

5.2 Comprehensive evaluation system based on multi-source data fusion

The regional integrated energy technology model has the characteristics of high complexity, cumbersome structure, and a huge amount of data. It is these characteristics that make traditional evaluation algorithms unable to scientifically and objectively evaluate. Taking into account the situation of big data applications, we can make full use of new data processing technologies based on multi-source data fusion.

Multi-source data fusion technology refers to the use of related methods to integrate all the information obtained by investigation and analysis, and conduct a unified evaluation of the

ISSN: 2414-1895
DOI: 10.6919/ICJE.202107_7(7).0053

information, and finally obtain a unified information technology. The purpose of this technology is to develop. Multi-source data fusion, as a special data processing method, integrates various data information, absorbs the characteristics of different data sources, and extracts unified, better and richer information than single data, which can be perfect It fits into the assessment techniques of the integrated energy system. The massive data generated by the operation of the system, based on multi-source data fusion, starting from the data itself, overcoming subjective problems, can effectively solve the objectivity problem in the current assessment process, and is dynamic and time-effective. At present, intelligent algorithms such as multi-source data fusion and cloud models have been relatively mature, and have a high degree of matching for the comprehensive assessment of the regionally integrated energy system.

6. Conclusion

With the continuous advancement of new technologies and new projects, under the environment of policy-supported development, the development level of integrated energy system engineering is also continuously improving, gradually transitioning from the initial stage to the exploratory development stage. Scientific and objective evaluation of the integrated energy system is an important means to reflect whether new technologies, new strategies, and new equipment are effective after they are put into the project. This article first sorts out the current evaluation index and summarizes the existing evaluation algorithms. Then, fully considering the characteristics of multi-energy coupling and multi-energy synergy of the integrated energy system, the characteristics and construction ideas that the evaluation index should have been put forward. Finally, given the complexity of the comprehensive energy system evaluation itself, the many problems caused by the evaluation algorithm and evaluation index, the future research direction of the comprehensive energy system evaluation has prospected. Comprehensive evaluation methods based on big data, cloud computing, and multi-source data fusion will be an important research direction for comprehensive energy system comprehensive evaluation in the future.

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ISSN: 2414-1895 DOI: 10.6919/ICJE.202107_7(7).0053

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