Discussion on energy efficiency evaluation method for smart substation

Bin Zhu[1, 3,a], Fanrong Wang [2,3,b], Yingjie Wan[2,c], Jun Li[1,d]

[1] NARI Electrical Equipment & Engineering Efficency Evaluation Center, Wuhan Hubei, 430074

[2] Collaborative Innovation Center for High-efficiency Utilization of Solar Energy, Hubei University of Technology, 430070

[3] Department of Automation, Wuhan University, Wuhan Hubei 430072

[a] zhubin_email@foxmail.com, [b]wfr@mail.hbut.edu.cn,
[c]iname_mail@qq.com,[d]jun_li_hust@hust.edu.cn

Keywords: Smart Substation, power transmission and distribution, energy efficiency, evaluation index

Abstract. As the key link of power transmission and distribution, the energy saving and emission reduction work of the substation has important significance. Due to its special nature, it is very difficult to evaluate and analyze the smart substation. The purpose of construct the smart substation evaluation system is to analyze the operation status of it in order to promote its upgrading and transformation. This paper discussed and compared several methods for the construction and implementation of the evaluation index to the smart substation, which can provide a reference for its establishment.

Introduction

Smart grid is the goal and direction of China's electric power system; it is also the development trend of electric power system and the innovation of science and technology in the new era. Smart substation is the main node and the central part of the smart grid, which plays a vital role. It is the key and the support of the smart grid.

Smart substation adopts advanced, reliable, integrated, low carbon, environmental protection of modern power equipment, with the total information of the station, communication platform, information sharing standards for the requirements to achieve information collect, measure, control, protect, measurement and detection and other functions of the automatic. The biggest advantage of the smart substation is that, it can be controlled automatically according to the need of electric network, in order to realize the advanced functions such as the automatic adjustment, online analysis, and the cooperation and interaction. Achieve total station unmanned management, remote monitoring and control; autonomous decision-making has been the research direction of smart substation. At present in some areas of China, small numbers of unmanned smart substation pilot projects have been put into operation [1].

Smart substation is different from the previous substation and other energy chemical industry enterprises, which makes it particularly urgent and difficult to evaluate and analyze. The purpose of the construction for smart substation evaluation system is to promote its upgrading and transformation, and provide the corresponding technical reference for the subsequent construction of the smart substation [2].

Construction ideas

A full understanding of the Smart Substation is necessary in order to establish a reasonable evaluation system. On the basis of dividing the main equipment in the substation, the operation characteristic and energy consumption of the equipment are analyzed. From many indexes, the power consumption level and energy efficiency characteristics of the substation can be accurately

characterized, and the multiple and comprehensive evaluation of the smart substation is carried out. The basic idea of the smart substation energy efficiency evaluation (SSEEE) is as follows:

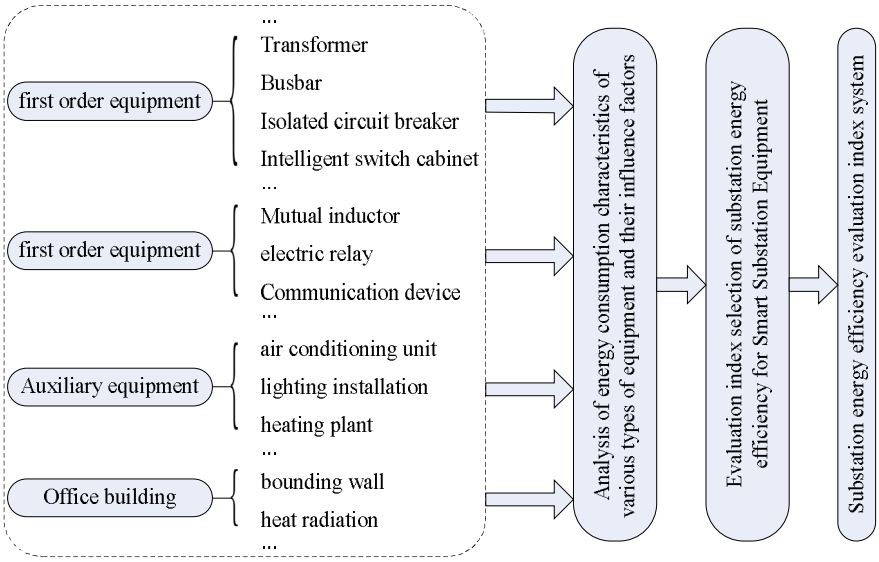

Fig.1 Idea for SSEEE

Principle of evaluation system

Because of its special nature, the smart substation, which makes the evaluation system different from other types of enterprises[3], the evaluation system should be built based on smart, which mainly includes the following principles:

(1) Applicability

The assessment is based on a series of qualitative and quantitative indicators to characterize the smart substation. These indicators need to be selected according to the special nature of the Smart Substation itself, how to make the selection of the quantitative index representative and fully applied to the evaluation is very important.

(2) Measurable

To assess and quantify the indicators need it to be measurable. This measurable is mainly reflected in two aspects, one is the quantitative indicators to be able to detect and measure with Instruments to determine its scale value; another is for qualitative indicators can be transformed into indirect measurable scale under the right premise and clear expression through improve the establishment of objective evaluation criteria[4], and try to avoid too much subjective judgments.

(3) Association

The evaluation of the smart substation is not simple levels determine, nor the simple sum of the quantitative indicators. For each index participate in the evaluation, they have different degree of correlation with the inherent characteristics of physical and electrical characteristics. An index can be made from other related lower index, and it is combined with other relevant index to be higher. These interrelated indicators usually have some inherent logic relations, which should be paid attention when selection and processing.

(4) Retrospective

The purpose of the evaluation system is to analyze and monitor the smart substation. The general order of the assessment is usually divided into prior, event and post event. Follow-up and analysis shout be carried out to the results of the assessment after doing it, the tracking on one hand is to check the consistency of the assessment to avoid the accident, on the other hand is the feedback tracking, detection and control of index data in order to provide support for the follow-up assessment system's improvement and refining.

(5) Comprehensive

The evaluation aims at evaluating the smart substation overall, so the evaluation system should focus on the overall view. The selection of the evaluate index and the construct of the evaluation system should be able to comprehensively reflect the overall energy efficiency level of the smart substation, rather than just a certain part or one aspect of it[5].

Evaluation system content

The substation's energy efficiency evaluation (EEE) index system is shown in the following diagram:

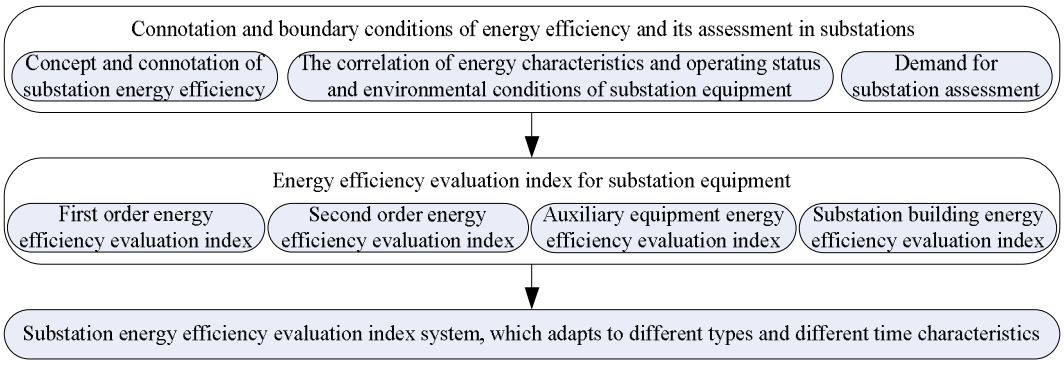

Fig.2 energy efficiency evaluation index hierarchy diagram

The evaluation system of Smart Substation includes two parts: first, the single energy consumption characteristics of the substation are analyzed and evaluated in order to determine their own level. The second is the comprehensive evaluation of the energy consumption and operating characteristics of different Smart Substation. Those two can be implementation in separated, or combine with the static energy consumption and dynamic performance to make comprehensive evaluation, and usually, the latter assessment results can be more fully and comprehensively[6].

According to the properties of the smart substation equipment and buildings, evaluation can be divided in to following areas:

(1) Energy efficiency assessment of major equipment

The main equipment of the smart substation is divided into the conversion equipment of the first order system and detection and control equipment of the second order system. Those two have a certain degree of correlation, as well as dispersion. The relationship between then should be correctly handled in the process of the actual assessment, the content can be divided into the following structural.

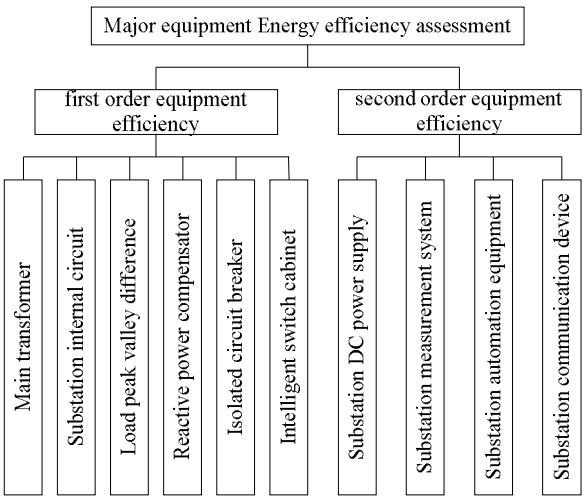

Fig.3 main equipment evaluation structure diagram

(2) Energy efficiency assessment of auxiliary indicators

Smart substation is a complex set of intelligent power transformation and distribution, which is a combination of equipment and device of conversion energy, and also includes the office, construction and other auxiliary facilities[7]. To conduct a comprehensive and effective assessment of the smart substation, various elements of the substation need to be taking into account. In the process of evaluation, any aspect is an essential part of the index system. The auxiliary index of smart substation includes the energy consumption evaluation of auxiliary equipment and energy efficiency evaluation of buildings[8]. The structure of the auxiliary equipment is divided as follows.

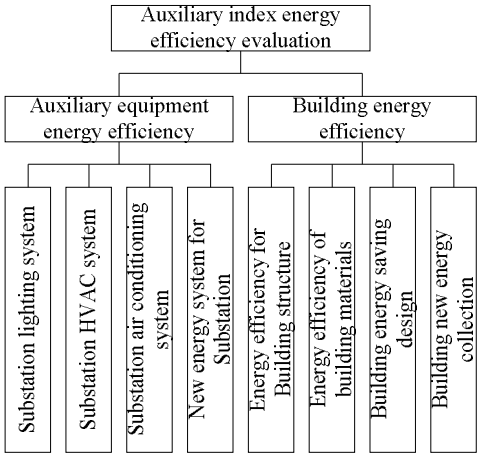

Fig.4 index evaluation structure

Establishment of evaluation index

Modern smart substation is a comprehensive synthesis with technology, economic, social and practical, in order to carry out a comprehensive energy efficiency assessment, all the relevant indicators need to be take full account, they constitute llevel evaluation index of Smart Substation[9]. Technical indicators mainly reflect the characteristics of smart substation, the economic indicators reflect the cost efficiency ratio of the smart substation, social indicators means social impact, and the utility index mainly reflects the practical application. Detail indicator system can be expressed in the following figure.

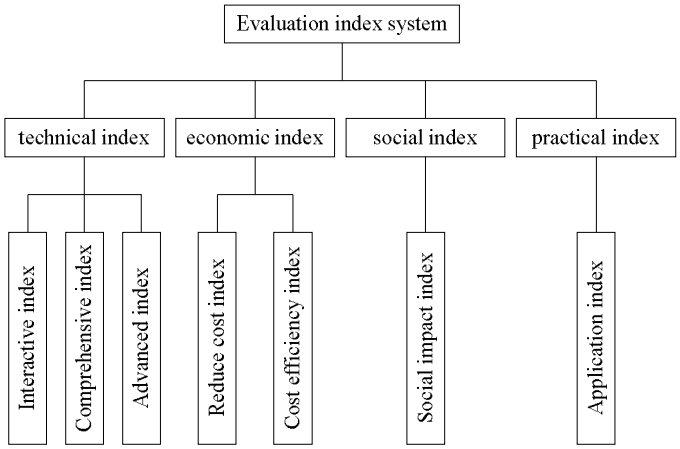

Fig.5 structure of evaluation index system

Energy efficiency evaluation method

Fuzzy comprehensive evaluation method. The nature of many variables in the smart substation is not very clear, and some of the variables are difficult to be expressed in a precise quantitative relationship, thus showing ambiguity [10].

The fuzzy comprehensive evaluation method is a kind of theory, which is based on fuzzy set theory, and the method of analyzing the fuzzy information in the process of evaluation. These method use extents belong to the relation of fuzzy information to alternative Belong to or not. In quantitative analysis, the degree of membership function is usually used to describe the fuzzy information of the substation. The steps of fuzzy evaluation method are as follows:

(1) Divide the evaluate indicators of the Smart Substation in the evaluation to determine the evaluation of the problem that with a hierarchical evaluation index set, and in its scope of selection evaluation content B_i(i=1,2,…,n) and factor B_{ij} (j=1,2,... , m).

(2) Establish the evaluation set of indicators according to the selected indicators, namely, the evaluation result aggregate of the experts on the assessment question U={u1, u2,... , uk}.

(3) Establish the fuzzy Subordinate relation matrix based on the single index of fuzzy membership evaluation, and the elements of the matrix are solved according to the actual situation of the smart substation [11].

(4) Use a certain weight determining method to get the fuzzy weight of the evaluation index of the evaluation factor, and formed the weight vector A= $(a_i)_{1\times n}$ of the index.

(5) According to the weight and the fuzzy matrix obtained by the preceding, get the evaluation results P=A•R with a certain synthetic operator.

Fuzzy comprehensive evaluation method use accurate mathematical method to carry out scientific and reasonable quantification of qualitative index. That can effectively solve the problem of the uncertain and fuzzy evaluation index to the original data, which is suitable for solving various kinds of non-determinism. However, in this method, the weight vector of index weight is subjective, when the transformer substation is large, the corresponding index set becomes quite complex. At the same time, due to the constraint of weight equals 1, it makes the relative membership degree of fuzzy information smaller, here comes the situation that the weight vector set and the fuzzy matrix does not match, which will lead to the super fuzzy phenomenon of evaluation , and even made the evaluation failure.

Analytic hierarchy processes. The main task of the analytic hierarchy process is to construct the analytic hierarchy structure, and let the evaluation index to be decomposed to reach the concrete evaluation index layer, the concrete steps are as follows:

First according to table 1, field investigation and other methods ware used to make the evaluation index through pair comparison.

Table 1 principle of judgment matrix

Relative importance degree	definition	Explain
1	Equally important	Target **i** is just as important as j
3	Slightly important	Target **i** is slightly important than j
5	Quite important	Target **i** is quite important than j
7	Significantly important	Target **i** was significantly important than j
9	Absolutely important	Target is absolutely important than j
2、4、6、8	Between two important levels	

Then calculate the judgment matrix by the range or Polar ratio method on the basis of comparison matrix, so that the indicators weight coefficient of ri can be get. In the end, through standard treatment of the weight coefficient , the comprehensive evaluation coefficient l i of the substation can be obtained. The energy consumption of the substation can be evaluated by l i. The smaller the l i is, the smaller the overall energy consumption of the transformer substation, the greater the energy efficiency, vice versa, the bigger the l i is, the greater the overall energy consumption of the substation, the lower the energy efficiency. Thus, the energy efficiency grade sequence of the smart substation can be evaluated by l i.

The advantage of analytic hierarchy process is that it can evaluate the energy efficiency rating of single or multiple substations at different levels, and the results are simple and accurate. The disadvantage is that the judgment matrix and the procedures of consistency test are cumbersome and difficult to calculate.

Principal component analysis. The process and principle of principal component analysis is similar to that of analytic hierarchy process [12]. First, calculate the total variance of principal components to the transformer substation by using the underlying index $x=(x_1, x_2, x_3)^T$. Then calculate the eigenvalues and eigenvectors of the covariance matrix by the correlation coefficient matrix between the original x_i and the principal component y_k.

Table 2 correlation coefficient matrix

	y_1	y_2	$\cdots$	y_p
x_1	t_{11}	t_{12}	$\cdots$	t_{1p}
x_2	t_{21}	t_{22}	$\cdots$	t_{2p}
$\vdots$	$\vdots$	$\vdots$		$\vdots$
x_p	t_{p1}	t_{p2}	$\cdots$	t_{pp}

The correlation coefficient indicates the close degree between the principal components and the original variables. The contribution rate of each principal component to the original variables can be obtained by processing the correlation coefficient, which can get the contribution rate matrix from the following table.

Table 3 contribution rate matrix

i	$\rho(y_1,x_i)$		$\rho(y_2,x_i)$	
1	0.925	0.855	0.000	0.855
2	−0.998	0.996	0.000	0.996
3	0.000	0.000	1.000	1.000

The quantitative relationship between principal components and original variables can be obtained from the contribution rate matrix. While giving the quantitative relationship by contribution rate, the main components are sorted, and the energy consumption of the smart substation and the proportion of each single energy consumption in the total energy consumption, so that the energy consumption of the substation can be evaluated.

The principal component analysis method is more emphasis on the evaluation of a single substation. The results reflect the energy consumption of the smart substation. For example, the first principal component, that the highest in the substation Influence the energy efficiency of the substation most [13], which means reform to this part can achieve better energy saving effect than others.

Delphi method. Delphi method is a kind of method that can be fully integrated domain expert knowledge [14], experience and information, also known as the expert consultation rate method, the steps of this method are as follows:

(1) The coordinator sends reference table to the experts on many occasions, there is no mutual knowledge of the consulting experts, so as to avoid mutual influence. Consulted experts in-depth investigation to the assessment Smart Substation on the electric energy consumption situation, analysis the content of the consultation and then give the weight of the weight of aij according to the actual experience of the individual judge.

(2) Coordinator make a comprehensive analysis of each expert's score to obtain average value of every index aj, and send it back to expert as feedback material, become reference to determine the weight of the new index wj on next round .

(3) Normalize the weight of the new index to get final weight of the evaluation index wj`. In order to get more accurate results, the consultation activity should be carried out several times. Finally, the coordinator deal with the results of seval turns of consultation to obtain the quantitative analysis of expert opinion.

The merit of Delphi is that the evaluation process is simple and intuitive, the calculation method is simple, and the choice of the quantity is larger. The disadvantage is that the evaluation is relatively rough, and can't make a detailed and comprehensive evaluation of the substation, the results of the assessment are more or less with random, the accuracy of the evaluation is low.

Conclusions

There are many factors involved in the assessment of the energy efficiency to the smart substation, and it is difficult to establish a evaluation system that suitable for all substations. Delphi method can be used to evaluate the substation that tight schedule and short cycle. The fuzzy comprehensive evaluation method can be used for the object that hard to accurate quantification. If necessary to proposed feasible upgrading scheme at the time of assessment, it can be evaluated by the principal component analysis method. When multiple substations are encountered to determine the relative efficiency of the case, the analytic hierarchy process becomes the optimal choice at this time. In a word, in the process of building the system of smart substation energy efficiency evaluation, various indexes and methods are involved. How to select the appropriate evaluation method according to the actual situation of the substation has a great impact on the integrity and the scientific nature of the evaluation system. This paper aims at providing some reference and guidance for the selecting of energy efficiency evaluate method to construct the evaluation system.

Reference

[1] Li Jun. Study on the Evaluation Indicator System of the Pilot Project of Smart Grid[J]. Academic Research, 2011, 11

[2] Feng Xing, Zhang Yun. Study on Energy-saving Measurement of Intelligent Substation Design Scheme [J]. Electric Power Survey & Design, 2014, 4

[3] Hu Xiaomei, Zhu Wen hua, et al. Research on design of overalls energy efficiency assessment system for high energy consumption enterprises [J]. Computer Engineering and design,2009, 30 (17)

[4] Zhang Tiqiang, Pi Jianghong, Yang Ying. Research on Substation energy consumption calculation and energy saving measures [J]. Resources Economization & Environment Protection, 213 (7).

[5] Qu Zhaoyang, Wang,Chong, et al. Household Electric Energy Efficiency Evaluation Index System in Smart Electricity Environment[J].East China Electric Power,2014,24(6)

[6] Ren Hui, Wang Jian. The application research of energy efficiency evaluating system [J].Computer Knowledge and Technology, 2008, 4 (2)

[7] Zhu Jianhui. Case analysis of intelligent substation building energy saving design [J]. China Science and technology, 2010 (16)

[8] Zhu Guosheng. Discussion on energy saving design of substation building [J].Science technology and life, 2010(24)

[9] Liu Hui, Meng Fanhua. Analysis on the evaluation index system of Smart Substation [J].Science&Technology Vision, 2012, 8

[10] Han Li, Mei Qiang, et al. AHP-Analysis of fuzzy comprehensive evaluation method [J].China Safety Science Journal, 2004, 14(7)

[11] Luo Yaoming, Mao Lifan, et al. Ecaluation Model of Integrated Energy Efficiency foe Power User[J]. Proceedings of the CSU-EPSA，2011,23(5)

[12] Xu Yong, Wang Jian. To evaluate on the level of enterprise energy consumption based on AHP and PCA [J].Value Engineering,2008(8)

[13] Nan Wenkang.Energy saving transformation of substation lighting system[J].China Science and technology information,2010(1)

[14] Li lianjie, Yao Jiangang, Long Libo, et al.Application of combination Weighing method in fuzzy synthetic evaluation of power quality[J].Automation of Electric Power Systems,2007,31(4)

