TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol. 12, No. 10, October 2014, pp. 7082 ~ 7091
DOI: 10.11591/telkomnika.v12i8.5334

Assessment of Intelligent Substation Based on an Improved Fuzzy Sets Method

Yuanchao Hu[1], Lina Yao[2], Jiangjun Ruan*[3], Yunzhu An[4], Fan Chen[5]
[1,3,4,5]School of Electrical Engineering, Wuhan University (WHU)
NO.8. South Road of Eastern Lake, 430072, Wuhan, Hubei Province, P.R.China
[2] Zhengzhou University of Light Industry
No.5. Dongfeng Road, 450002, Zhengzhou, Henan Province, P.R.China
*Corresponding author, e-mail: ruanjiangjun1968@126.com

Abstract

In the construction process of smart grid, an assessment on primary equipments intelligent transformation is an urgent content in the first batch of intelligent substation pilot project. Wide investigation of intelligent substation pilot projects was conducted seriously in several regional power grids in China. An mathematical model was established to assess the substation primary equipments intelligent transformation firstly; then, the Vague sets multi-objective decision theory was applied to the assessment model and the consistency inspection and weight solving method of Vague set theory was improved in this paper. Finally, a practical example was given to show the rationality and accuracy of the above improved method. The method can provide practical guidance to assess primary equipments intelligent transformation.

Keywords: *smart grid, substation intelligent transformation, vague sets, fuzzy set, comprehensive consistency inspection*

1. Introduction

Smart grid is the medium-and-long-term development direction of power grid in China. The key for its evaluation is performance target, performance characteristics, key technology and function implementation [1-4]. Many research institutions and enterprises in China are actively promoting the construction of smart grid and have already made some achievements. In 2009, a staged goal was proposed by China State Grid for constructing strong smart grid: making major breakthrough and widespread use in terms of key technology and equipments. In this case, as the acquisition source and command execution unit for basic operating data of power grid, digitalized stations and smart stations has become the key direction for present smart grid construction to progressively accomplish the transformation and upgrade from traditional substation. According to the 2009-2020 smart grid development plans, the smart transformation of substation will enter a comprehensive construction period since 2012, achieving an intelligent rate of 30-50 percent and 10 percent for new substations and old substations respectively. State Grid has conducted a lot of research since 2010 and the transformation and construction projects for smart substation initiated successively. The first pilot project construction has almost been finished [5-6] and the second pilot project has made great achievement as well. In this case, it has become the top priority to assessment for present intelligent level of substation. According to the High Voltage Equipment Intelligent Technical Guideline, attentions should be firstly paid to the smart transformation level in different areas. In order to achieve the smart transformation of substation it should be made clear the need for smart transformation or upgrade and the standard of intelligence. To cooperate with the secondary pilot project, State Grid Company will arrange some experts specially to investigate and evaluate the pilot project in a wide range. However, comprehensive evaluation of smart transformation level is relatively deficient.

Since Cau and Buehrer advanced the Vague Set Theory in 1993, it has achieved rapid development as a promotion form of fuzzy sets [8-9]. Traditional multi-objective decision-making theoriesare lacking in uncertain information description [10-12], such as Analytic Hierarchy Process, entropy weight method, grey incidence theory and Technique for Order Preference by

Received December 10, 2013; Revised May 18, 2014; Accepted June 6, 2014

Similarity to Ideal Solution.Compared with fuzzy sets, Vague Set Theory can mathematically represent and process more abundant uncertain information. Therefore, Vague Set Theory can be widely applied in fields as fuzzy controller design, MOMSFDM, artificial intelligence and son on. Besides, the power sector is rarely involved in this theory.

Due to the involvement of much uncertain information in smart transformation, Vague Set Theory was applied to the comprehensive evaluation for smart transformation of substation and the consistency check and weight solving of Vague Set Theory was improved in this paper. And the transformation level of several pilot projects was assessed with the above evaluation model. Lastly, a practical example was given to state the calculation process and practical applicability of this method in detail.

2. Construction of Smart Transformation Evaluation Model for Substations

Smart station is composed of process level (equipment level), compartment level and station level. The integrated intelligent equipment is used to fulfill functions such as collection, measurement, control, protection, calculation, monitor and real-time online analysis and decision, which assure the collaborative interactive operation of the power grid. Intelligentialized substation is mainly featured by digital measurement, control network, state visualization, functional integration, and information interaction. It basically requires total digital information, communication network platform and information sharing standardization. In accordance with technological features and requirements, the digital measurement and information interaction of important electric accessory is the key to fulfill intelligentialized substation. Therefore, in the construction of the first and second smart substation, the integrated level of intelligent components and advanced application of monitoring information are the concentrated reflection of smart transformation level of pilot substation projects.

(a) Transformer intelligent monitoring of oil and gas

(b) Potential transformer intelligent components

(c) GIS partial discharge monitoring devices

(d) switching intelligent assembly cabinet

Figure 1. The Intelligent Transformation Arrangement of Substation Primary Equipments

According to the accomplishment of the transformation and construction, State Grid Company successively arranged some experts for Hi-pot test and equipment to investigate and evaluate the first and second pilot projects of equipment intelligentialization. Layered evaluation decision principle was utilized from the whole to the part: selecting converting station for evaluation and performing an integral evaluation for equipment such as transformer, GIS (HGIS) combination unit, breaker and lightning arrester [13-14]. And according to the requirements for intelligent components of each electric accessory in *Intelligent Substation Technical Guideline* and *Intelligent Substation Design Specifications*, it refines the monitoring category of each equipment such as the oil temperature, brackish water and partial discharge, and so on.

Practical researches showed that differences among smart transformation of different voltage levels are about the reform difficulty and programs of different manufacturers. In spite of the installment of intelligent components, different equipments of the same converting station could all be evaluated in terms of measurement, control and communication according to the technical guide [15]. An evaluation model for smart transformation level was proposed in this paper to transform and evaluate the main high-pressure equipments such as transformer, GIS combination unit, mutual inductor, switch, lightning arrester and electric cable

Table 1. Intellectualization Assessments of Substation Equipment Objects

First indicator	Second indicator	First indicator	Second indicator
Measurement function	Digitized samples	Protection	PDIF, PTRC and other standard model
	MMXU, MMXN standard model		Network control
	GMRP multicast protocol dynamically allocated		Digitized samples
	Dynamic, steady-state comprehensive collection of data		Place installation
	Power Quality Monitoring		GMRP multicast protocol dynamically allocated
Control functions	CSWI, CILO standard model	Metering function	MMTR standard model
	Network control		Digitized samples
	GMRP multicast protocol dynamically allocated		GMRP multicast protocol dynamically allocated
	Emergency Operation	Communication function	Virtual LAN (VLAN)
	Contemporaneous function with the same period the voltage selector		Priority transmit
Condition Monitoring	Monitoring data digitization		IEC61588-precision network time
	Standardization of the measurement results		GMRP multicast protocol dynamically allocated
	Abnormal alarm state		Wireless handheld communication devices

3. Promoting Vague Set Theory as a Multi-objective Decision-making Theory

The biggest promotion of Vague sets as from fuzzy sets is that the degree of membership, non-membership and hesitation degrees (uncertainty) were considered more flexible and richer with Vague sets thanthat with traditional fuzzy sets.

3.1. Vague Value Judgment Matrix

According to the definition of Vague sets, the domain X (any element of the domain represented by x) on the Vague set V use real membership function t_v and fake membership function f_v characterization:

$$t_v: X \rightarrow [0,1]\ ,\quad f_v: X \rightarrow [0,1] \tag{1}$$

Assuming that $t_v(x)$ and $f_v(x)$ respectively represents the membership degree lower bound derived from the evidence of for and against x ,and $t_v(x)+f_v(x)\leq 1$, the membership of element x in Vague set V will be defined by the subinterval $[t_v(x),\ 1-f_v(x)]$ on [0, 1]. According to this definition, the necessity of supporting $x \in x$ is characterized with $t_V(x)$; the possibility of supporting $x \in x$ $(1 - f_v(x))$ is characterized with $(1-f_v(x))$; And $(1 - t_v(x) - f_v(x))$ describe mathematically the uncertainty of x.

Setting $X = \{x_1, x_2,... , x_n\}$ as a set of attributes, the 0.1-0.9 scale method [16] is used for pairwise comparison of each attribute,thus constituting the judgment matrix $V=[v_{ij}]_{m\times n}$ based on Vague values, where $v_{ij} =[t_{ij},\ 1-f_{ij}]$ for Vague values, t_{ij} and f_{ij} respectively represents decision makers' preference degree of x_i and x_j , $(1-t_{ij}-f_{ij})$ represents decision makers' uncertainty. According to the nature of the judging matrix structure, it can get $t_{ij}\in[0,1]$, $f_{ij}\in[0,1]$ and $t_{ij}+ f_{ij}\leq 1$, diagonal elements $t_{ii}=f_{jj}=0.5$,non diagonal elements meet the complementary : $t_{ij}=f_{ji}$. In the actual assessment, different experts' judgment on a particular attribute can often be subjective and various, so you can take the mean value of different decision makers' assessment value as the Vague values of the judgment matrix.

3.2. Fuzzy Approximation to Judgment Matrix of Vague Values

Vague sets generally only considers the for and against membership in the multi-objective evaluation, lacking of uncertain information. In fact, as a kind of decision makers' attitude, uncertain information should be fully detailed mining. In addition, Vague value as judgment matrix elements increases the computational complexity. Considering these two aspects, transforming Vague into fuzzy sets is feasible to deal with the Vague value judgment matrix.

Setting *Vague* set as $V=\{[t_v(x),1-f_v(x)] \mid x\in X\}$, fuzzy set as $F=\{[x,F(x)] \mid x\in X\}$, mapping $R:V\rightarrow F$ meet,

$$F(x)=\frac{t_v(x)}{t_v(x)+f_v(x)} \tag{2}$$

Thus F is the fuzzy approximation to Vague set V.

In the same way, promotion to the fuzzy approximation of Vague value judgment matrix, it can get the fuzzy approximation to Vague value judgment matrix $Q=[q_{ij}]_{n\times n}$, where:

$$q_{ij}=\frac{t_{ij}}{t_{ij}+f_{ij}}\ ,\ i, j=1,2,\dots,n \tag{3}$$

3.3. Consistent Check and Modification of Fuzzy Judgment Matrixes

Literature (16) and (17) considered the transitivity of judgment order in the consistency check of fuzzy judgment matrix, avoiding the appearance of sequential logic contradiction such as $x_i\prec x_j\prec x_k\prec x_{iin}$ in the attributes circulation chain, but this method ignored the deviation acceptability [16, 17].Though literature (18) set a deviation threshold, it considerer little of transitivity of judgment order. Actually, fuzzy judgement matrix should satisfy both consistent and logical transitivity at the same time. Therefore, a comprehensive inspection standard and correction method was proposed in present study to make the consistency check more reasonable.

(1) Verification of compatibility indicators

Fuzzy judgement matrix Q meets the complementary condition, $\forall k \in (1,\ n)$, $q_{ij}=0.5+q_{ik}-q_{jk}$ so matrix Q is completely consistent matrix. For various decision information, completely consistent matrix is hard to exist in practical evaluation. Thus, correction is needed for approximation. Generally, consistency index C_I is used to measure the deviation degree (generally take less than 0.1). $Q^{*}=(q_{ij})_{n\times n}$ is taken as the characteristic matrix of Q, where:

$$q_{ij}=0.5+\left(\sum_{k=1}^{n}q_{ik}-\sum_{k=1}^{n}q_{jk}\right)\Big/n \tag{4}$$

Compatibility indicators C_I are expressed by fuzzy judgment matrix and its characteristic matrix Q * deviations as:

$$C_I=\left\|Q-Q^{*}\right\|\big/n^2=\left(\sum_{i=1}^{n}\sum_{j=1}^{n}\left|q_{ij}-q_{ij}^{*}\right|\right)\Big/n^2 \tag{5}$$

In general practice, when C_I is less than 0.15, Q can be regarded as consistent matrix.

(2) Verification of transitivity index

Reachable matrix T in graph theory is cited to verify the logic transitivity of fuzzy judgment matrix Q [19]. Define matrix Q_T as accompany reachable matrix of fuzzy judgement matrix Q, when q_{ij} > 0.5, Q_T takes "true", and expressed as "1". Instead, Q_T to "false", and expressed as "0". Successively solving n-order of the adjoint reachable matrix, get reachable matrix T which can judge the consistency of Q.

$$T = Q_T \,||\, Q_T^{2} \,||\cdots||\, Q_T^{n} \tag{6}$$

Where "| |" means "or" operation in Boolean operation. If all the main diagonal elements of reachable matrix T are "zero" value, Q is considered to meet the test of logic consistent transitivity.

(3) Comprehensive inspection and correction

When Q satisfies both compatibility and transitivity at the same time, its consistency is acceptable; otherwise, the columns whose deviation is too large need to be corrected. Calculate the sum of deviation value in each row:

$$\Delta h_i=\sum_{j=1}^{n}\left|q_{ij}-q_{ij}^{*}\right|,\ i=1,2,\ldots,n \tag{7}$$

Select the elements of maximum deviation in h-th row and take a k-th correction, where $\alpha(0\le\alpha\le1)$ is the proportion of original matrix information,

$$q_{hj}^{(k+1)}=(1-\alpha)q_{hj}^{(k)}+\alpha q_{hj}^{*(k)},\ j=1,2,\ldots,n \tag{8}$$

Similarly, the element of the maximum deviation in l-th column is corrected:

$$q_{il}^{(k+1)}=(1-\alpha)q_{il}^{(k)}+\alpha q_{il}^{*(k)},\ i=1,2,\ldots,n \tag{9}$$

Q matrix has a consistency check after each correction, until it satisfies the compatibility and transitivity at the same time.

3.4. Solve Evaluation Index Weights

The Q matrix which meets a consistency check have a layering of weights solution.Characteristic vector method is used to calculate the maximum characteristic value λ_{max} of Q matrix and the characteristic vector of characteristic value. Characteristic vector was normalized toget n index weight vectors of k-th layer as $w_j^{(k)}=(w_1^{(k)},w_2^{(k)},\ldots w_n^{(k)})$, where $j=1,2,\ldots,n$. Then the j-th weight evaluation index for the combination of total target is calculated.

$$w_j=w_j^{(k)}\cdot w_j^{(k-1)}\cdot\ldots\cdot w_j^{(1)} \tag{10}$$

3.5. Solve the Comprehensive Evaluation Results

For an evaluation with *m* objects and *n* indexes, constructed a weighted decision matrix $Y=(y_{ij})_{m\times n}$, where y_{ij} determined by experts assessed value or actual parameter values of various indicators of different assessment objects multiplied by the index weights (Pay attention to effective type parameters and cost type parameters' normalization process). Each evaluation index contrast between objects can be directly represented by Weighted decision matrix. In practice, take Level 1 assessment indicators z_j as the column vector of decision matrix $Z=(z_{ij})_{m\times n}$, where:

$$z_{ij}=\sum_{i=1}^{n}\left(y_{ij}\cdot w_j\right) \tag{11}$$

According to the weighted decision matrix, get each appraisal object's final evaluation value η_i

$$\eta_i=\sum_{j=1}^{n}z_{ij}\quad, i=1,2,\ldots,m \tag{12}$$

3.6. Flow Chart of Vague Sets Evaluation Method

Assessing the actual object with *Vague* set evaluation method has been shown from section 3.1 to section 3.5, and the specific flow chart shown in Figure 2.

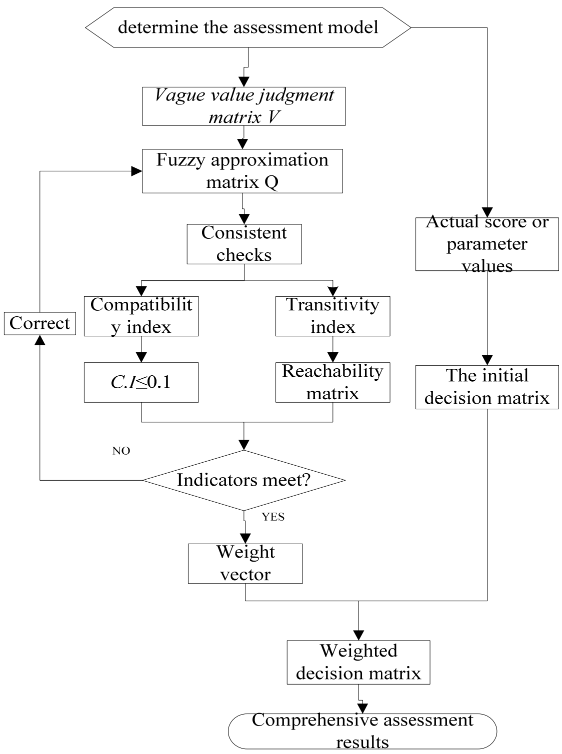

Figure 2. The whole Flow Chart of Vague Sets Assessment Method

4. Analysis on Practical Example

4.1. Practical Example

Main primary equipment of the pilot project of the initial completed substations was taken as the appraisal target. It mainly including 110kV Intelligent Substation transformation including transformers in three statons and GIS HV combined electrical equipment in two stations for evaluation object. The intelligence reform level of each primary equipment was assessed according to Evaluation system in Table. Firstly, use Vague sets assessment methods to solve the weight vector for each level indicator of the first and second indicators. Take the secondary indicator as an example, Vague value judgment matrix was constituted by the mean value of the second indicator from different experts.

$$V = \begin{pmatrix} [0.50, 0.50] & [0.35, 0.50] & [0.41, 0.68] & [0.38, 0.73] & [0.48, 0.73] & [0.59, 0.67] \\ [0.50, 0.65] & [0.50, 0.50] & [0.53, 0.68] & [0.48, 0.73] & [0.48, 0.78] & [0.68, 0.88] \\ [0.32, 0.59] & [0.32, 0.47] & [0.50, 0.50] & [0.38, 0.68] & [0.48, 0.68] & [0.35, 0.45] \\ [0.27, 0.62] & [0.27, 0.52] & [0.32, 0.62] & [0.50, 0.50] & [0.50, 0.67] & [0.65, 0.47] \\ [0.27, 0.52] & [0.22, 0.52] & [0.32, 0.52] & [0.33, 0.50] & [0.50, 0.50] & [0.54, 0.76] \\ [0.33, 0.41] & [0.12, 0.32] & [0.55, 0.65] & [0.53, 0.35] & [0.24, 0.46] & [0.50, 0.50] \end{pmatrix}$$

Using Equation (2), seeking fuzzy approximation matrix Q of Vague value judgment matrix, According to Equation (4) and (5), verify the compatibility indicators of the matrix, and C_I was equaled to 0.0458, which meet the compatibility requirements deviations. Verifing the transfer of Q according to Equation (6), not all elements of the main diagonal are zero. Thus, correct the most biased line 6, column 6 according to α=0.4. After two times of correction, it got the final fuzzy judgment matrix:

$$Q = \begin{pmatrix} 0.50 & 0.41 & 0.56 & 0.58 & 0.64 & 0.65 \\ 0.58 & 0.50 & 0.62 & 0.64 & 0.69 & 0.78 \\ 0.44 & 0.38 & 0.50 & 0.54 & 0.60 & 0.52 \\ 0.42 & 0.36 & 0.46 & 0.50 & 0.60 & 0.57 \\ 0.36 & 0.31 & 0.40 & 0.40 & 0.50 & 0.60 \\ 0.35 & 0.22 & 0.48 & 0.43 & 0.40 & 0.50 \end{pmatrix}$$

After correction, transitivity indicators meet the requirements, C_I was equaled to 0.0228. Thus, compatibility bias has also been corrected. Successively solving the two indicators Vague value judgment matrix and conducting fuzzy approximation and consistency of judgments. The results are shown in Table 2

Table 2. Vague Sets Matrix of Secondary Indexes and Consistency Check Results

First indicator	Consistent checks		Successive correction matrix Q		
			1st	*2nd*	*3rd*
Measure	C_I	0.1125	0.0781	0.0566	—
indicators	T	N	N	Y	—
Control	C_I	0.0696	0.0475	—	—
indicators	T	N	Y	—	—
Monitor	C_I	0.1111	0.0815	0.0652	0.0489
indicators	T	N	N	N	Y
Protection	C_I	0.1437	0.0991	—	—
indicators	T	N	Y	—	—
Estimate	C_I	0.0531	—	—	—
indicators	T	Y	—	—	—
Communicate	C_I	0.0926	0.0653	0.0495	—
indicators	T	N	N	Y	—

With the correction fuzzy judgment matrix,using the eigenvector method to obtain one index weight vector $w^{(1)}$=(0.1866,0.2133,0.1661,0.1614,0.1416,0.1310). Similarly, according to fuzzy judgment matrix of each two indicators to solve corresponding weight vector $w_j^{(2)}$, according to Equation (10) obtained two overall index weight vector shown in Table 3.

Table 3. Comprehensive Weight Vectors Solution of Secondary Indexes

First indicator	The two overall index weights w_j
Measure indicators	(0.0466, 0.0307, 0.0267, 0.0429, 0.0397)
Control indicators	(0.0510, 0.0538, 0.0414, 0.0292, 0.0378)
Monitor indicators	(0.0648, 0.0446, 0.0567)
Protection indicators	(0.0274, 0.0333, 0.0285, 0.0211, 0.0206)
Estimate indicators	(0.0545, 0.0449, 0.0421)
Communicate indicators	(0.0303, 0.0377, 0.0244, 0.0134, 0.0251)

Select the primary equipment to be evaluated of the substation,the secondary indicators to evaluate each equipment intelligent modification rating (Table 1). Among them, for and against a target to completed level scores were $t_V(x)$ and $f_V(x)$(Score $t_V(x)+f_V(x)\leqq 1$), then this index review scores constitute a Vague value: $[t_V(x),1-f_V(x)]$, according to Equation (2) to take the fuzzy approximation $F_v(x)$ as the indicator's actual scores. Different decision-makers assess the Vague value of a particular index varies, take the average value of the two fuzzy approximation of indicators that make up the equipment review scores vector $F_i(v)$. As an example, the review scores vector solving in transformer A, after the assessment by experts according to Table 1, the review scores results of transformer A shown in Table 4.

Table 4. Score Results of Transformer A Based on Vague Sets

First indicator	The two indicators mean score results $\overline{F_v}$
Measure indicators	(0.8095, 0.7857, 0.7021, 0.8171, 0.6923)
Control indicators	(0.7701, 0.8816, 0.7021, 0.7857, 0.7701)
Monitor indicators	(0.8252, 0.7627, 0.8182)
Protection indicators	(0.8861, 0.8736, 0.9239, 0.6364, 0.8929)
Estimate indicators	(0.8667, 0.9135, 0.8590)
Communicate indicators	(0.7609, 0.8462, 0.9184, 0.8947, 0.5769)

Sequentially calculate score results of other primary equipment and constitude decision matrix Z according to formula (11). The weighting values of each intelligent primary equipment evaluation indexare shown in Table 5.

Table 5. Weighted Values of Evaluation Index of Intelligent Primary Equipment

Index / Objects	Measure	Control	Monitor	Protection	Estimate	Communicate
Transformer *A*	0.1431	0.1678	0.1339	0.1115	0.1244	0.1038
Transformer *B*	0.1397	0.1665	0.1316	0.1141	0.1238	0.1133
Transformer *C*	0.1307	0.1561	0.1217	0.1086	0.1167	0.1086
GIS equipment *A*	0.1337	0.1586	0.1251	0.1098	0.1158	0.1076
GIS equipment *B*	0.1135	0.1386	0.1055	0.0981	0.1107	0.0995

By the formula (12) the primary equipment intelligent transformed comprehensive evaluation results are shown in Table 6. At the same time, Table 6 shows the calculated values using AHP [10] and TOPSIS method [7]. Because different assessment methods used in calculation steps are different, the final assessment value will be different, but different assessment's sequence results are consistent.

Table 6. Assessment Result of Intelligent Primary Equipment

Assessment	Vague sets Assessment Act		AHP Assessment Act		TOPSIS Assessment Act	
Objects	η_i	Sequence	η_i	Sequence	η_i	Sequence
Transformer *A*	0.7845	2	0.6707	2	0.7061	2
Transformer *B*	0.7890	1	0.6830	1	0.7180	1
Transformer *C*	0.7424	4	0.6276	4	0.6682	4
GIS equipment *A*	0.7506	3	0.6682	3	0.6830	3
GIS equipment *B*	0.6659	5	0.5993	5	0.5993	5

4.2. Analysis on Assessment Results

Assessment results show that, as the main power equipment in the substation, the intelligent transformation of transformer is prior to the other primary equipments in the intelligent transformation process.New smart intelligent substations were constructed in accordance with standard construction,and the intelligence level of the primary equipments were higher than other transformation substations.The appraised value of the GIS equipment A is higher than the transformer C in the numerical example. That's because the substation which GIS (electrical equipment A) located in is a new built intelligent substation, and the substation which transformer C located in is a transformation substation.The assessment results meet the practical project accurately.

From the results of different assessment methods,Vague sets assessment method introduces uncertainty to characterize fuzzy data mathematically, so it is more reasonable to characterize human factor,the discrimination is higher for the assessment of objects with similar levels, and the method proposed in this paper is more consistent with the actual project.

5. Conclusion

In this paper, Vague sets theory was used to solve assessment questions of substation primary equipment intelligent transformation. First, assessment model was built according to the relevant standards and research information, and Vague sets evaluation algorithm has been improved, which makes the assessment method more reasonable and accurate. The assessment method was applied to assess the intelligence reform level of portion of primary equipments in the substation, and was verified with a given example. The next work target is to apply this method to evaluate the overall intelligent transformation level of the intelligent substation and the regional grid. The work conducted in this paper provides reality basis to assess substation smart transformation and develop appropriate standards for the grid.

References

[1] Haase P. Intelligrid:a Smart Network of Power. *EPRI Journal.* 2005(Fall): 17-25.
[2] Amin M, Schewe P F.Preventing blackouts: Building a Smarter Power Grid. *Scientific American*. 2008; (8): 60-67.
[3] YX YU, WP LUAN. *Smart Grid and Its Implementations*. Proceedings of the CSEE. 2009; 29(34): 1-8.
[4] C XUE, CB LI, XQ HUANG, SW TANG, Y LIU. Application of Intelligent Substation Information Integration. *Electric Power Automation Equipment.* 2011; 31(7):110-114.
[5] Smart Grid Department of China State Grid Company. Intelligent Technical Conditions of High Voltage Switchgear/GIS Equipments. Bei Jing: Smart Grid Department of China State Grid Company. 2009
[6] Smart Grid Department of China State Grid Company. Intelligent Technical Analysis Report on High Voltage Equipments[R]. Bei Jing: Smart Grid Department of China State Grid Company. 2009.
[7] YC HU, JJ RUAN, ZY DU, L RUAN, BH YANG, ZH PU, QJ XIE. Evaluation of Substation Primary Equipment Intellectualization Based on TOPSIS. *Electric Power Automation Equipment*. 2012; 32(12): 22-27.
[8] F. LI, A. LU, L.J. CAI. Multicriteria Decision Making Based on Vague Sets. *J. Huazhong Univ. of Sci . & Tech.*, 2001, 29(7): 1-3
[9] LB ZHU. *Theory and Application Research on Rough Sets and Vague Sets.* Chengdou: South West Jiao Tong University. 2006; 10-19.
[10] YF ZHAO, JF CHEN. Analytic hierarchy process and its application in power system. Electric Power Automation Equipment. 2004; 24(9): 85-87.
[11] HZ NIE, P Lv, Y QIAO, XP YAO. Comprehensive Fuzzy Evaluation for Transmission Network Planning Scheme Based on Entropy Weight Method. *Power System Technology*. 2009; 33(11): 60-64.
[12] WZ YAN, LS GU. Application of the method of Entropy Proportion in the Engineering Mark. *Journal of Xi'an University of Architecture &technology*. 2004; 36(1): 98-100.
[13] Smart Grid Department of China State Grid Company. *Report on printing Intelligent technical conditions of transformers and High Voltage Switchgear*. BeiJing: China State Grid Company. 2010.
[14] China State Grid Company. *Technical specifications for smartness upgrade of substation*. BeiJing: China State Grid Company. 2010.
[15] ZHAO Chenpeng. The selection and Application Investigation of Primary Equipment in Smart Substation. Beijing: North China Electric Power University. 2010.
[16] ZS XU. Research on Compatibility and Consistency of Fuzzy Complementary Judgement Matrices. *Journal of PLA University of Science and Technology*. 2002; 3(2): 94-96.

[17] CY ZHANG, HY ZHOU. Transformation and Entropy for Vague Sets. Computer Engineering and Applications. 2003; 33(4): 20-23.
[18] GX SONG, DL YANG. Methods for Identifying and Improving the Consistency of Fuzzy Judgment Matrix. *Systems Engineering.* 2003; 21(1): 110-116.
[19] SH XIAO, ZP FAN, MG WANG. Study on Consistency of Fuzzy Judgement Matrix. *Journal of Systems Engineering*. 2001; 16(2): 142-145.