J Electr Eng Technol.2017; 12(2): 959-968
https://doi.org/10.5370/JEET.2017.12.2.959

ISSN(Print) 1975-0102
ISSN(Online) 2093-7423

# An Improved Interval AHP Method for Assessment of Cloud Platform-based Electrical Safety Monitoring System

**Shou-Xiang Wang*, Lei-Jiao Ge†, Sheng-Xia Cai** and Dong Zhang*****

**Abstract** – Electrical safety monitoring System (ESMS) is a critical component in modern power systems, which is characterized by large-scale access points, massive users and versatile requirements. For convenience of the information integration and analysis, the software development, maintenance, and application in the system, the cloud platform based ESMS is established and assessed in this paper. Firstly the framework of the system is proposed, and then the assessment scheme with a set of evaluation indices are presented, by which the appropriate cloud product can be chosen to meet the requirements of a specific application. Moreover, to calculate the weights of the evaluation indices under uncertainty, an improved interval AHP method is adopted to take into consideration of the fuzziness of expert scoring, the qualitative consistency test, and the two normalizations in the process of eigenvectors. Case studies have been made to verify the feasibility of the assessment approach for ESMS.

**Keywords**: Cloud computing, Consistency test, Electrical safety monitoring system, Interval analytic hierarchy process

## 1. Introduction

In Smart Grid, electrical safety monitoring system (ESMS) has been drawn more and more attention and has developed a variety of applications, such as anti-tampering, VIP customer management, and power supply quality monitoring. There are many studies on ESMS from the aspects of uncertainty analysis [1], model building [2, 3], optimal control [4, 5], and software development [6]. In [7], it discusses a strategy aligned with leading edge developments in advanced safety management of hazards with high potential for fatality. However, there are numerous challenges need to be addressed such as the limited function, low utilization ratio, and low load ratio of monitoring equipment. Moreover, ESMS has the characteristics of enabling large-scale access points, supporting massive users and accommodating versatile requirements. Therefore, cloud computing is an ideal way to resolve those issues with the advantages of integration, flexibility, and resource on-demand.

Cloud computing is one of the most popular cyber solutions for many applications such as in education and industry. An excellent summary of main developments of cloud computing was given in [8]. The contemporaneous research involves in the definition [9], data storage [10, 11], and load evaluation [12]. K. Zhou [13] proposes a new cloud-based power system operation model. In power systems, especially in the application of ESMS, it is critical to improve the performance and service level through cloud computing [14]. The difficulty to face is to choose the type of cloud platform (CP) from cloud providers among private cloud, public cloud and hybrid cloud platforms. Therefore, the criterion for the choice of the type of cloud platform (CP) from cloud providers among private, public and hybrid cloud platform need be studied. Also, an evaluation index set and a method of CP based ESMS are essential to guide the future construction, operation and maintenance of ESMS. The solution of the multi-attribute decision making problem in the evaluation considering the fuzziness of expert scoring results is also crucial. Currently, the AHP and fuzzy AHP algorithm keep attracting extensive attention, and many results have been achieved on the construction of the judgment [15, 16], uncertainty [17-20] and expert scoring [21, 22].

This paper proposes an improved interval AHP method for the assessment of CP-based ESMS. The main contributions of this paper are as follows: 1) To deal with the problems of massive different user requirements and large-scale decentralized access points that EMSM faces, a framework of CP based EMSM is proposed; 2) A serial of cloud evaluation indices is proposed to guide the construction of the CP based ESMS for different users, which could be adopted by customers to guide the choice of appropriate cloud products from a large number of cloud service providers; 3) In the process of solving the index weight, an improved interval AHP is adopted to solve the problems of fuzzy expert scoring, latency of consistency

† Corresponding Author: Key Laboratory of Smart Grid of Ministry of Education, Tianjin University, China. (legendglj99@tju.edu.cn)
* Key Laboratory of Smart Grid of Ministry of Education, Tianjin University, China. (sxwang@tju.edu.cn)
** Zhou Enlai School of Government, Nankai University, China. (shengxia77@nankai.edu.cn)
*** State Grid Tianjin Electric Power Company, China. (jackzhangua@sina.com)
Received: October 29, 2015; Accepted: November 29, 2016

test and computational efficiency, which provides the reference for multi-criteria decision making in similar situations.

The rest of this paper is organized as follows. The next section gives the framework of a CP based ESMS. In section 3, we present the evaluation indices of a cloud computing application for ESMS. In section 4, the improved interval AHP is proposed to calculate the weights of the index. Section 5 presents case studies to verify the advantages of the proposed interval AHP method. Finally, the paper concludes with the summary of the main points.

## 2. The CP Based ESMS

Cloud computing, which has high scalability, is an integration of grid computing and virtualization technologies. It can also be easily upgraded with the integrated low computability parts, and is very convenient for information integration and analysis, software development, maintenance, and utilization. In this section, the details of the framework of CP based ESMS will be presented. The framework of cloud platform based ESMS is demonstrated in Fig. 1, which consists of infrastructure layer, platform layer, application layer, user layer and cloud safety.

### 2.1 Infrastructure layer

The infrastructure layer is the IaaS layer of the cloud computing architecture, which includes physical and management layers. Physical layer virtualizes two types of devices in ESMS. On one hand, it can manage some devices of ESMS by using virtual machine, which includes servers, disc arrays, and computers. Those servers consist of the front servers, web server and memory server. The disc arrays are mainly data centers. The computers include office PC, and monitoring client. On the other hand, the management of communication devices of ESMS is

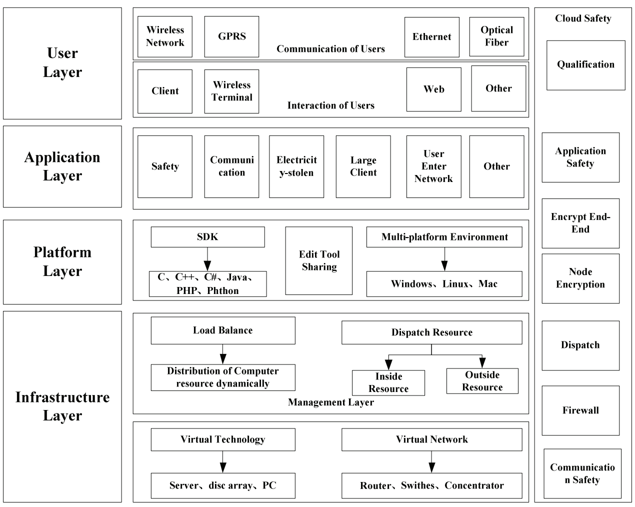


**Fig. 1.** Framework of cloud platform based ESMS

operated by virtual network technology, which includes routers, switches and hubs. The management layer can dispatch and manage IT resources dynamically. It can allocate the computer resources dynamically via the load balance process and manage the resources and external request by resource management process. Therefore, the universal cloud-level management can be achieved by managing the idle computer hardware resources under monitoring.

Therefore, in order to meet the massive and heterogeneous hardware and software in end-user, the infrastructure layer of CP based ESMS not only needs to have a strong ability to virtual, and also has a fast respond to ensure the plug and play.

### 2.2 Platform layer

Platform layer is the Platform-as-a-Service (PaaS) layer of the cloud calculation framework. It mainly includes the Software Development Kit (SDK) exploitation environment, the sharing of the editing tools, and cross-platform exploitation environment in order to build the exploitation of the platform quickly. The SDK exploitation environment endorses different types of programming language, such as C, C++, C#, Java, and so on. Cross-platform exploitation environment supports Windows, Linux, Mac, etc.

### 2.3 Application layer

Application layer is the Software-as-a-Service (SaaS) layer of cloud computing framework for the related business application of ESMS. It includes user authentication, communication administration, electric tampering administration, key electricity consumers' administration, new customer' administration and other related applications.

The application layer not only faces a large number of real-time online users, but also should quickly and timely reply to the different requests of the end-users, and therefore, this layer must be able to guarantee the power quality of service.

### 2.4 User layer

User layer allows the flexible access from the users and administrative staff. It mainly comprises the users' communication mode and interaction methods. The communication mode refers to wireless internet, General Packet Radio Service (GPRS), Ethernet network and private optical fiber access, etc. The users' interaction methods includes client-side, wireless terminal, web explorer，etc.

Since there are so many end-users accessing to the cloud platform through a variety of different ways and different modes of communication, the cloud platform should support vast amounts of communication protocols.

### 2.5 Cloud safety

Cloud safety is a significant factor which could directly impact the normal operation of the ESMS. It is mainly concerned with network communication safety, firewall of software and hardware, permissions of hierarchical administration, nodes' encryption, point to point encryption, the safety of applications, etc.

## 3. Evaluation Index of a CP Based ESMS

In the construction process of CP based ESMS, how to choose the appropriate CP for ESMS is a critical problem. In this section, a serial of evaluation indices for the cloud computing applications of ESMS is proposed from three aspects of switching capability of network architecture $A_{11}$, fast response capability of memory architecture $A_{12}$, and virtual ability $A_{13}$. The indices are summarized in Table 1. Some key indices are expounded as follows.

### 3.1 Switching capability of network architecture index set $A_{11}$

$A_{11}$ is a capacity of the network for cloud platform in ESMS, mainly including routing throughput $A_{111}$, packet forwarding per second $A_{112}$, time-lag $A_{113}$, transmission speed $A_{114}$, total number of supporting router protocols and standards $A_{115}$ and total number of checklist per second $A_{116}$. To measure this ability of communication requirement of massive end-user in cloud platform, we choose the $A_{111}$ and $A_{113}$. The index $A_{111}$ is calculated as.

$$A_{111} = R * \sum_{i=1}^{n} S_i \tag{1}$$

**Table 1.** Evaluation indices of CP based ESMS

| First index | second-level index | third-level index |
|---|---|---|
| Evaluation index of cloud platform based ESMS $A_1$ | Switching capability of network architecture $A_{11}$ | Routing throughput $A_{111}$ |
| | | Packet forwarding per second $A_{112}$ |
| | | Time-lag $A_{113}$ |
| | | Transmission speed $A_{114}$ |
| | | Total number of support routing protocols and standards $A_{115}$ |
| | | Total number of checklist per second $A_{116}$ |
| | Fast response capability of memory architecture $A_{12}$ | Total number of user connections per second $A_{121}$ |
| | | Total number of user service per second $A_{122}$ |
| | | Service utilization ratio $A_{123}$ |
| | | Memory read and write speed $A_{124}$ |
| | | Input/output ratio $A_{125}$ |
| | | Service response time $A_{126}$ |
| | Virtual Ability $A_{13}$ | Total time of running $A_{131}$ |
| | | Total number of virtual CPU $A_{132}$ |
| | | Total number of virtual memory $A_{133}$ |
| | | Total number of virtual I/O $A_{134}$ |
| | | Deceleration ratio $A_{135}$ |
| | | Acceleration ratio $A_{136}$ |

where $R$ is the number of node for receiving data, and $S_i$ is a packet received by the receiving node.

The index $A_{113}$ has the form

$$A_{113} = \sum_{i=1}^{n} (\mathrm{Ts}_i + Tc_i + Th_i + Tq_i) \tag{2}$$

where $T_{si}$, $T_{ci}$, $T_{hi}$ and $T_{qi}$ denote a sending time delay, a propagation delay, a time of processing delay, and a time of queuing delay, respectively.

### 3.2 Fast response capability of memory architecture index set $A_{12}$

$A_{12}$ is a reflection of the overall storage capacity in CP based ESMS. It main includes total number of user connections per second $A_{121}$, total number of user service per second $A_{122}$, server utilization ratio $A_{123}$, memory reading and writing rate $A_{124}$, I/O ratio $A_{125}$ and service response time $A_{126}$. We compute the quantitative data service of massive user according to (3)-(4).

$$A_{121} = \sum_{i=1}^{n} R_i, R_i = \begin{cases} 1, \text{on}-\text{line} \\ 0, \text{off}-\text{line} \end{cases} \tag{3}$$

where $R_i$ belonging to {0,1} is the network nodes of cloud computing. While $R_i$=1, the network node is online, otherwise, the node is offline. In addition, the service response time $A_{126}$ is given by

$$A_{126} = \sum_{i=1}^{k} N_i + \sum_{j=1}^{m} A_j \tag{4}$$

where $N_i$ and $A_j$ are the network latency and waiting time for an application of cloud computing, respectively.

### 3.3 Virtual ability index set $A_{13}$

Virtual ability is a reflection of virtualization level in CP based ESMS. It can be evaluated by the total time of running $A_{131}$, total number of virtual CPU $A_{132}$, total number of virtual memory $A_{133}$, total number of virtual I/O $A_{134}$, deceleration ratio $A_{135}$, and acceleration ratio $A_{136}$. Among those indices, $A_{132}$ is the most important one reflecting virtual ability, defined as

$$A_{132} = \sum_{i=1}^{n} V_i \tag{5}$$

where $V_i$ is the number of virtual CPU in the $i$-th node of cloud computing.

The proposed index system takes into considerations the requirement of massive participants, scattered points, the difficulty of the subdividing service, and the high demand to service level. It allows us to solve the following problem, that is, different suppliers have different product performance among private cloud, public cloud and hybrid cloud, but the evaluation criteria recognizing cloud computing technology is insufficient. And it can also be used to guide the selection of CP for different user groups such as power grid enterprises, industrial users, commercial users and resident users, which have relatively large discrepancy in demand.

## 4. Interval AHP Method

For the index system built previously, a key issue is to determine the weight for each index. This is a multi-group decision making problem. Currently, there exist the subjective or objective methods to solve this problem. In this section, we propose an improved analytic hierarchy process (IAHP). The basic process of IAHP is illustrated in Fig. 2, and we explain it in detail as follows.

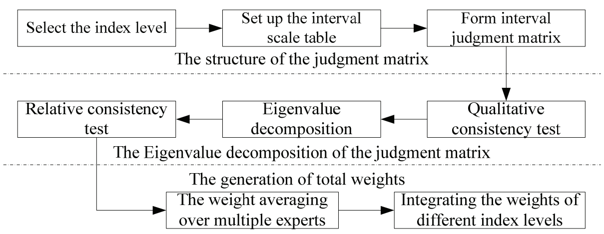


**Fig. 2**. The basic process of IAHP

### 4.1 Main idea of IAHP

IAHP can be divided into three phases: the construction of the judgment matrix, the eigenvalue decomposition of the judgment matrix, and the generation of total weights. In the first phase, we use intervals to represent the weights of indices, considering the weights of index are relative and uncertain to some extent from the perspective of cognition. Specifically, the interval scales from 1 to 5 are adopted to simplify the complexity of the expert scoring. The IAHP is used to solve the problem of fuzzy insufficiency of experts scoring in AHP.

A difficulty we face is the consistency test of the judgment matrix, so in the second phase, the qualitative consistency test is firstly performed so as to improve the effectiveness and rationality of the expert scoring. Then, in order to pass through the consistency test for the judgment matrix, the eigenvalue decomposition is conducted and in the decomposition two normalizations are used to improve the convergence speed. Last, in the third phase, we provide a strategy to obtain the total weight of the selected level index by the combination of the eigenvalues corresponding to multiple scoring experts.

### 4.2 The judgment matrix construction

The judgment matrix is constructed according to the following steps.

**Step 1**: Select the index level

As described in the previous section, the analytical index system for CP based ESMS is formed by the first indices, the second-level indices, and the third-level indices, corresponding to the target layer, index layer, and the scheme layer in AHP. To construct the judgment matrix, we first select the second-level indexes, and let selected N experts score according to the next step. Once we finish computing the weights for the second level indexes, the third-level indexes will be selected, for which we continue to calculate their weights.

**Step 2**: Set up the interval scale table

Interval scale consists of the interval midpoint and the width. The interval midpoint is a cardinal number of the expert scoring, which is denoted by $a_{ij}$ while comparing the $i$-th index to $j$-th index in the considered index level. The width is a fuzzy number according to the uncertainty or ambiguity of the expert's experience, which is denoted by $\mu$. In general, the experts determine firstly the midpoint $a_{ij}$, then, determine the width $\mu$ based on the uncertainty and fuzziness. The interval proportional scale of the expert scoring is listed in Table 2.

**Table 2.** Interval proportional scale

| Importance (compare i to factor j) | Interval mid-point values $a_{ij}$ | Interval widths $\mu$ |
|---|---|---|
| The same important | 1 | $0<\mu<1$ |
| Slightly important | 2 | |
| More important | 3 | |
| Strongly important | 4 | |
| Extremely important | 5 | |

**Step 3**: Form interval judgment matrix $A_m$

The interval judgment matrix $A_m$ is of size n×n, where n denotes the total number of the indicators in the selected index level, as shown in (6). Each element of the matrix $A_m$, denoted by $a'_{ij}=[a_{ij},\mu]=[a'_{ij\_},a'_{ij-}]$ at $(i,j)$, is a vector composed of the upper and lower bounds of the interval determined by the interval midpoint $a_{ij}$ and the width $\mu$. Letting $a'_{ij}=[a_{ij},\mu]=[a'_{ij\_},a'_{ij-}]$, the element can be obtained according to the following rules.

$$A_m=\begin{bmatrix} a'_{11} & a'_{12} & \cdots & a'_{1n} \\ a'_{21} & a'_{22} & \cdots & a'_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a'_{n1} & a'_{n2} & \cdots & a'_{nn} \end{bmatrix} \tag{6}$$

When the $i$-th index is thought to be more important than the $j$-th one in the selected index level, resulting in $a_{ij}\geq 1, i\neq j$, the element is determined by

$$a'_{ij}=[a'_{ij\_},\ a'_{ij-}]=\begin{cases} a'_{ij\_}=a_{ij}-\mu \\ a'_{ij-}=a_{ij}+\mu \end{cases} \tag{7}$$

Oppositely, if the $j$-th index is thought to be more important than the $i$-th one, which gives rise to $1/a_{ij} \geq 1, j \neq i$, the element is computed as

$$a_{ij}^{'} = [a_{ij\_}^{'}, a_{ij-}^{'}] = \begin{cases} a_{ij\_}^{'} = 1/(a_{ij} + \mu) \\ a_{ij-}^{'} = 1/(a_{ij} - \mu) \end{cases} \quad (8)$$

## 4.3 The eigenvalue decomposition of the judgment matrix

In this phase, two operators should be carried out on the constructed matrix $A_m$, the consistency test and the eigenvalue decomposition.

The qualitative consistency test of $A_m$ is passed only when it satisfies the equation (10) in the condition of the equation (9). If the test fails, the contradiction information will be transmitted to the experts. Then, the procedure returns to the step 2, where the expert will decide the score again according to the feedback information.

$$\begin{cases} a_{ij}^{'} > a_{lj}^{'} \\ a_{lj}^{'} > a_{kl}^{'} \end{cases} (i \neq l, k \neq l) \quad (9)$$

$$a_{ij}^{'} > a_{kl}^{'} (i \neq l, k \neq l) \quad (10)$$

Next, the eigenvalues of the matrix $A_m$ passing through the above test is derived by an improved power method. For convenience, we use $k$ to denote the iteration number. The initial vector $X^{(0)}$ is a randomly chosen non-zero vector, and its updated version for the $k$-th iteration is represented by $X^{(k)}$. The iterative vector is denoted by $Y^{(k)}$ for the $k$-th iteration. With the introduced notations, the improved power method is described as follows.

### 4.3.1. Initialization

The vectors $X^{(0)}$ and $Y^{(0)}$ are initialized by

$$\begin{cases} X^{(0)} = (x_1^{(0)}, x_2^{(0)}, \cdots, x_n^{(0)}) \\ \quad = ([x_{1\_}^{(0)}, x_{1}^{-(0)}], [x_{2\_}^{(0)}, x_{2}^{-(0)}], \cdots, [x_{n\_}^{(0)}, x_{n}^{-(0)}]) \\ k = 0 \\ m_0 = \| X^{(0)} \| = \max_i | x_i^{(0)} | = \max_i | x_i^{-(0)} | \\ Y^{(0)} = X^{(0)}/m_0 \end{cases} \quad (11)$$

where $m_0$ is a temporary parameter, and $\|\cdot\|_q$ stands for $l_q$ norm, and $|\cdot|$ is an absolute value operator.

### 4.3.2. Iteration

The vector $X^{(k+1)}$ for the $k$+1-th iteration and the corresponding convergence factor $m_1$ can be obtained by the iterative rule

$$\begin{cases} X^{k+1} = AY^{(k)} = \sum_{r=1}^{n} A_{ir} y_r^{(k)} = \sum_{r=1}^{n} [a_{ir\_}, a_{ir}^{-}][y_{r\_}^{(k)}, y_r^{-(k)}] \\ = ([\sum_{r=1}^{n} a_{ir\_} y_{r\_}^{(k)}, \sum_{r=1}^{n} a_{ir}^{-} y_r^{-(k)}]) \\ m_1 = \| X^{(k+1)} \| = \max_i \{x_i^{-(k+1)}\} \end{cases} \quad (12)$$

### 4.3.3. The first normalization

In this step, the iterative vector $Y^{(k+1)}$ for the $k$+1-th iteration and the temporary parameters $m_2$ and $m_3$ are determined by

$$\begin{cases} Y^{(k+1)} = X^{(k+1)}/m_1 \\ m_2 = \| Y^{(k+1)} \| = \max_i \{y_i^{-(k+1)}\} \\ m_3 = (m_1 + m_2)/2 \end{cases} \quad (13)$$

### 4.3.4. The second normalization

Here, the iterative vector $Y^{(k+1)}$ is updated again and the temporary parameters $m_4$ and $m_5$ are computed by

$$\begin{cases} Y^{(k+1)} = X^{(k+1)}/m_2 \\ m_4 = \| Y^{(k+1)} \| = \max_i \{y_i^{-(k+1)}\} \\ m_5 = m_1 - \dfrac{(m_2 - m_1)*(m_3 - m_1)}{m_4 + m_1 - m_2 - m_3} \end{cases} \quad (14)$$

### 4.3.5. Convergence

If $| m_5 - m_0 | \leq \varepsilon$, (15)

Where $\varepsilon$ is $1 \times 10^{-6}$, let $k$=$k$+1, and $m_0$=$m_5$, and go to b. Otherwise, continue.

### 4.3.6. Normalization

The largest eigenvalue and eigenvector, denoted by $\lambda_{\max}$ and w respectively, are obtained by the normalization operator

$$\begin{cases} w = Y^{(k+1)} \Big/ \frac{1}{2} \sum_{i=1}^{n} (y_{i\_}^{(k+1)} + y_i^{-(k+1)}) \\ \lambda_{\max} = m_5 \end{cases} \quad (16)$$

Last, we carried out the relative consistency test on the matrix $A_m$. We use $CR$ to denote the value of the relative consistency test, which is calculated as (17), where the freedom index $RI$ takes values from Table 3, and CI=..

**Table 3.** Freedom index RI

| Dimension (n) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| RI | 0 | 0 | 0.58 | 0.96 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 |

Generally, the smaller *CR*, the better the consistency of $A_m$ is. If *CR* of $A_m$ is less than 0.1, $A_m$ is feasible and passes the consistency test. Otherwise, $A_m$ fails to pass the test, then the procedure goes back to the step (2), and reconstructs the qualified judgment matrix $A_m$.

$$\begin{cases} CR = CI/RI \\ CI = (\lambda_{\max} - n)/(n-1) \end{cases} \quad (17)$$

### 4.4 The generation of total weights

For N experts, by repeating the above operations, we can obtain the N eigenvectors $w_i$, $i$=1,…, N. Then, we calculate the average value of these eigenvectors as

$$\overline{w}_2 = \frac{1}{N}\sum_{i=1}^{n} w_i \quad (18)$$

and use it as the comprehensive weight of the selected level index.

In the same way, the comprehensive weight vector of the third index level can be obtained. Last, the weight vector for the first index level, i.e., the total weight, is written as,

$$\overline{w}_1 = \overline{w}_2 * \overline{w}_3 \quad (19)$$

where $\overline{w}_1$ indicates that each dimension of $\overline{w}_2$ is multiplied by the corresponding dimension of $\overline{w}_3$ .

## 5. Case Study

### 5.1 Case 1

In order to verify the effectiveness of the qualitative consistency test in the improved interval AHP, a case study has been presented through the second level index of the CP based ESMS. A power grid expert has been selected to score for the index. The results are shown in Table 4 and Table 5.

In Table 4, S1 represents a no-qualitative consistency test, and S2 represents a qualitative consistency test.

We can infer from Table 4 and 5 as follows.

1) In Table 4, considering the expert scoring with no-qualitative consistency test, the midpoint of the important interval of $A_{13}$ comparing to $A_{11}$ is 5, that can be depicted as $A_{13}$-$A_{11}$=5. And the midpoint of the importance interval of $A_{12}$ comparing to $A_{11}$ is 4, that is depicted as $A_{12}$-$A_{11}$=4. According to the basic mathematical rule, $A_{13}$-$A_{12}$=1, that means the importance of $A_{13}$ comparing to $A_{12}$ is around 1. However, from Table 4, the midpoint of the importance of $A_{13}$ comparing to $A_{12}$ is 4, which is contradicted with the result from the basic mathematical rule. So, the inconsistent problem arises.
2) In case of a qualitative consistency test, the inconsistent problems are found and solved e.g. in table 4, the expert scoring in case of S2 has been modified through the feedback information, the importance interval of $A_{12}$ comparing to $A_{11}$ is changed from [3.5, 4.5] to [2.5, 3.5], and the importance interval of $A_{13}$ comparing to $A_{12}$ is changed from [3.6, 4.4] to [1.6, 2.4]. The midpoint of the importance interval of comparison among $A_{11}$, $A_{12}$ and $A_{13}$, that can be depicted as $A_{13}$-$A_{11}$=5, $A_{12}$-$A_{11}$=3, and $A_{13}$-$A_{11}$=2. Now it completely matches the basic theory of mathematics.
3) In Table 5, there are less difference between the largest eigenvalue and the weight. In partial, it has the same trend of the weight, that is $W_{A11}$<$W_{A12}$<$W_{A13}$. Therefore, it is obvious that the interval AHP has strongly fuzzy,

**Table 4.** Scores of power grid expert

| $A_1$ | S1 | | | S2 | | |
|---|---|---|---|---|---|---|
| | $A_{11}$ | $A_{12}$ | $A_{13}$ | $A_{11}$ | $A_{12}$ | $A_{13}$ |
| $A_{11}$ | [1.0, 1.0] | [0.222, 0.286] | [0.175, 0.233] | [1.0, 1.0] | [0.285, 0.4] | [0.175, 0.233] |
| $A_{12}$ | **[3.5, 4.5]** | [1.0, 1.0] | [0.227, 0.278] | **[2.5, 3.5]** | [1.0, 1.0] | [0.417, 0.625] |
| $A_{13}$ | [4.3, 5.7] | **[3.6, 4.4]** | [1.0, 1.0] | [4.3, 5.7] | **[1.6, 2.4]** | [1.0, 1.0] |

**Table 5.** Weight of the second level index

| $A_1$ | S1 | | S2 | |
|---|---|---|---|---|
| | $\lambda_{max}$ | W | $\lambda_{max}$ | W |
| $A_{11}$ | [0.2363, 0.2530] | [0.0838, 0.0948] | [0.2600, 0.2750] | [0.1018, 0.1208] |
| $A_{12}$ | | [0.3256, 0.3356] | | [0.3201, 0.3269] |
| $A_{13}$ | | [0.5796, 0.5806] | | [0.5590, 0.5713] |

**Table 6.** Scores of AHP and improved interval AHP

| $A_1$ | AHP | | | Improved Interval AHP | | |
|---|---|---|---|---|---|---|
| | $A_{11}$ | $A_{12}$ | $A_{13}$ | $A_{11}$ | $A_{12}$ | $A_{13}$ |
| $A_{11}$ | 1.0 | 0.25 | 0.2 | [1.0, 1.0] | [0.285, 0.4] | [0.175, 0.233] |
| $A_{12}$ | 4.0 | 1.0 | 0.25 | [2.5, 3.5] | [1.0, 1.0] | [0.417, 0.625] |
| $A_{13}$ | 5.0 | 4.0 | 1.0 | [4.3, 5.7] | [1.6, 2.4] | [1.0, 1.0] |

and S2 is convenient to the expert scoring.

### 5.2 Case 2

In order to verify the convergence speed of the eigenvector in the improved interval AHP, a case is presented to compare between AHP and improved interval AHP. The input data of the improved interval AHP is the power grid expert scoring, and the AHP of which is the interval midpoint of the power grid expert scoring. The results are shown in Table 6-7, where S3 is a AHP and S4 is an improved interval AHP.

We can find the following rules.

In Table 6, the input data of AHP is the interval midpoint of the improved interval AHP. The results of the AHP belong to the interval range of the improved interval AHP in Table 7, includes CR, the largest eigenvalue and the weights. So, there is a good consistent between AHP and the improved interval AHP.

The convergence of the improved interval AHP is better than that of AHP, for it need less iterations of calculation. And the calculation speed of the improved interval AHP is faster too.

### 5.3 Case 3

A CP based ESMS for a large city in the Southern China is selected for a case study. Some experts are invited to guide the construction of this ESMS, who possesses knowledge in the three different fields of the grid enterprises, industrial users and commercial users. For the application of evaluation index of CP based ESMS, the expert scorings are listed in Table 8-11.

According to the calculation process in the section 4, the results of those selected expert scoring are shown in table 12 and figure.3, including the weight of the second level index $W_{10}$ and the total index $W_1$.

We can infer the following results.

**Table 7.** Weight of S3 and S4

| | S3 | | | S4 | | |
|---|---|---|---|---|---|---|
| | $A_{11}$ | $A_{12}$ | $A_{13}$ | $A_{11}$ | $A_{12}$ | $A_{13}$ |
| CR | | -2.6577 | | | [-2.6607, -2.6461] | |
| $\lambda_{max}$ | | 0.2425 | | | [0.2600, 0.2750] | |
| $W$ | 0.1097 | 0.3258 | 0.5645 | [0.1018,0.1208] | [0.3201,0.3269] | [0.5590, 0.5713] |
| Time(s) | | 1.87 | | | 1.5 | |
| Iterations | | 9 | | | 5 | |

**Table 8.** The expert scoring of the first level index $A_1$

| $A_1$ | | $A_{11}$ | $A_{12}$ | $A_{13}$ |
|---|---|---|---|---|
| Grid Enterprise | $A_{11}$ | [1.0, 1.0] | [0.285, 0.4] | [0.217, 0.294] |
| | $A_{12}$ | [2.5, 3.5] | [1.0, 1.0] | [0.417, 0.625] |
| | $A_{13}$ | [3.4, 4.6] | [1.6, 2.4] | [1.0, 1.0] |
| Industrial User | $A_{11}$ | [1.0, 1.0] | [0.4, 0.667] | [1.8, 2.2] |
| | $A_{12}$ | [1.5, 2.5] | [1.0, 1.0] | [3.5, 4.5] |
| | $A_{13}$ | [0.455, 0.556] | [0.222, 0.285] | [1.0, 1.0] |
| Commercial User | $A_{11}$ | [1.0, 1.0] | [4.5, 5.5] | [2.4, 3.6] |
| | $A_{12}$ | [0.182, 0.222] | [1.0, 1.0] | [0.455, 0.556] |
| | $A_{13}$ | [0.278, 0.416] | [1.8, 2.2] | [1.0, 1.0] |

**Table 9.** The expert scoring of the second level index $A_{11}$

| $A_{11}$ | | $A_{111}$ | $A_{112}$ | $A_{113}$ | $A_{114}$ | $A_{115}$ | $A_{116}$ |
|---|---|---|---|---|---|---|---|
| Grid Enter prise | $A_{111}$ | [1.0, 1.0] | [0.909, 1.111] | [0.196, 0.204] | [0.189, 0.213] | [0.278, 0.417] | [0.435, 0.588] |
| | $A_{112}$ | [0.9, 1.1] | [1.0, 1.0] | [0.238, 0.263] | [0.244,0.256] | [0.455, 0.556] | [0.833, 1.25] |
| | $A_{113}$ | [4.9, 5.1] | [3.8, 4.2] | [1.0, 1.0] | [0.833, 1.25] | [1.8, 2.2] | [2.9, 3.1] |
| | $A_{114}$ | [4.7, 5.3] | [3.9, 4.1] | [0.8, 1.2] | [1.0, 1.0] | [1.7, 2.3] | [2.8, 3.2] |
| | $A_{115}$ | [2.4, 3.6] | [1.8, 2.2] | [0.455, 0.556] | [0.435, 0.588] | [1.0, 1.0] | [0.9, 1.1] |
| | $A_{116}$ | [1.7, 2.3] | [0.8, 1.2] | [0.323, 0.345] | [[0.313, 0.357] | [[0.909, 1.111] | [1.0, 1.0] |
| Industrial User | $A_{111}$ | [1.0, 1.0] | [1.5, 2.5] | [1.2, 2.8] | [0.6, 1.4] | [4.2, 5.8] | [3.6, 4.4] |
| | $A_{112}$ | [0.4, 0.667] | [1.0, 1.0] | [0.5, 1.5] | [0.833, 1.25] | [3.2, 4.8] | [2.6, 3.4] |
| | $A_{113}$ | [0.357, 0.833] | [0.667, 2.0] | [1.0, 1.0] | [0.417, 0.625] | [2.1, 3.9] | [1.5, 2.5] |
| | $A_{114}$ | [0.714, 1.667] | [0.8, 1.2] | [1.6, 2.4] | [1.0, 1.0] | [3.3, 4.7] | [2.6, 3.4] |
| | $A_{115}$ | [0.172, 0.238] | [0.208, 0.313] | [0.256, 0.476] | [0.213, 0.303] | [1.0, 1.0] | [0.455, 0.556] |
| | $A_{116}$ | [0.227, 0.278] | [0.294, 0.385] | [0.4, 0.667] | [0.294, 0.385] | [1.8, 2.2] | [1.0, 1.0] |
| Commercia l User | $A_{111}$ | [1.0, 1.0] | [0.4, 0.667] | [0.455, 0.556] | [1.3, 2.7] | [2.4, 3.6] | [3.7, 4.3] |
| | $A_{112}$ | [1.5, 2.5] | [1.0, 1.0] | [0.833, 1.25] | [2.8, 3.2] | [2.9, 3.1] | [3.1, 4.9] |
| | $A_{113}$ | [1.8, 2.2] | [0.8, 1.2] | [1.0, 1.0] | [2.6, 3.4] | [3.7, 4.3] | [4.7, 5.3] |
| | $A_{114}$ | [0.370, 0.769] | [0.313, 0.357] | [0.294, 0.385] | [1.0, 1.0] | [0.8, 1.2] | [1.4, 2.6] |
| | $A_{115}$ | [0.278, 0.417] | [0.323, 0.345] | [0.233, 0.270] | [0.833, 1.25] | [1.0, 1.0] | [0.9, 1.1] |
| | $A_{116}$ | [0.233, 0.270] | [0.204, 0.323] | [0.189, 0.213] | [0.385, 0.714] | [0.909, 1.111] | [1.0, 1.0] |

**Table 10.** The expert scoring of the second level index $A_{12}$

| $A_{12}$ | | $A_{121}$ | $A_{122}$ | $A_{123}$ | $A_{124}$ | $A_{125}$ | $A_{126}$ |
|---|---|---|---|---|---|---|---|
| Grid Enterprise | $A_{121}$ | [1.0, 1.0] | [0.9, 1.1] | [0.227, 0.278] | [0.233, 0.270] | [0.238, 0.263] | [0.244, 0.256] |
| | $A_{122}$ | [0.909, 1.111] | [1.0, 1.0] | [0.192, 0.208] | [0.196, 0.204] | [0.313, 0.357] | [0.323, 0.345] |
| | $A_{123}$ | [3.6, 4.4] | [4.8, 5.2] | [1.0, 1.0] | [0.8, 1.2] | [1.5, 2.5] | [2.6, 3.4] |
| | $A_{124}$ | [3.7, 4.3] | [4.9. 5.1] | [0.833, 1.25] | [1.0, 1.0] | [1.4, 2.6] | [1.2, 2.8] |
| | $A_{125}$ | [3.8, 4.2] | [2.8, 3.2] | [0.4, 0.667] | [0.385, 0.714] | [1.0, 1.0] | [1.3, 2.7] |
| | $A_{126}$ | [3.9, 4.1] | [2.9, 3.1] | [0.294, 0.385] | [0.357, 0.833] | [0.370, 0.769] | [1.0, 1.0] |
| Industrial User | $A_{121}$ | [1.0, 1.0] | [4.6, 5.4] | [0.9, 1.1] | [1.5, 2.5] | [2.8, 3.2] | [0.833, 1.25] |
| | $A_{122}$ | [0.185, 0.217] | [1.0, 1.0] | [0.208, 0.313] | [0.286, 0.4] | [0.294, 0.385] | [0.185, 0.217] |
| | $A_{123}$ | [0.909, 1.111] | [3.2, 4.8] | [1.0, 1.0] | [1.3, 2.7] | [1.5, 2.5] | [0.455, 0.556] |
| | $A_{124}$ | [0.4, 0.667] | [2.5, 3.5] | [0.370, 0.769] | [1.0, 1.0] | [0.9, 1.1] | [0.270, 0.435] |
| | $A_{125}$ | [0.313, 0.357] | [2.6, 3.4] | [0.4, 0.667] | [0.909, 1.111] | [1.0, 1.0] | [0.222, 0.286] |
| | $A_{126}$ | [0.8, 1.2] | [4.6, 5.4] | [1.8, 2.2] | [2.3, 3.7] | [3.5, 4.5] | [1.0, 1.0] |
| Commercial User | $A_{121}$ | [1.0, 1.0] | [0.833, 1.25] | [3.5, 4.5] | [2.1, 3.9] | [3.2, 4.8] | [1.4, 2.6] |
| | $A_{122}$ | [0.8, 1.2] | [1.0, 1.0] | [3.2, 4.8] | [2.6, 3.4] | [4.3, 5.7] | [1.3, 2.7] |
| | $A_{123}$ | [0.222, 0.286] | [0.208, 0.313] | [1.0, 1.0] | [0.909, 1.111] | [1.8, 2.2] | [0.313, 0.357] |
| | $A_{124}$ | [0.256, 0.476] | [0.294, 0.385] | [0.9, 1.1] | [1.0, 1.0] | [1.5, 2.5] | [0.357, 0.833] |
| | $A_{125}$ | [0.208, 0.313] | [0.175, 0.233] | [0.455, 0.556] | [0.4, 0.667] | [1.0, 1.0] | [0.323, 0.345] |
| | $A_{126}$ | [0.385, 0.714] | [0.370, 0.769] | [2.8, 3.2] | [1.2, 2.8] | [2.9, 3.1] | [1.0, 1.0] |

**Table 11.** The expert scoring of the second level index $A_{13}$

| $A_{13}$ | | $A_{131}$ | $A_{132}$ | $A_{133}$ | $A_{134}$ | $A_{135}$ | $A_{136}$ |
|---|---|---|---|---|---|---|---|
| Grid Enterprise | $A_{131}$ | [1.0, 1.0] | [0.8, 1.2] | [1.6, 2.4] | [2.5, 3.5] | [3.6, 4.4] | [4.8, 5.2] |
| | $A_{132}$ | [0.833, 1.25] | [1.0, 1.0] | [0.9, 1.1] | [1.6, 2.4] | [2.6, 3.4] | [3.4, 4.6] |
| | $A_{133}$ | [0.417, 0.625] | [0.909, 1.111] | [1.0, 1.0] | [0.9, 1.1] | [1.8, 2.2] | [2.4, 3.6] |
| | $A_{134}$ | [0.286, 0.4] | [0.417, 0.625] | [0.909, 1.111] | [1.0, 1.0] | [0.8, 1.2] | [1.6, 2.4] |
| | $A_{135}$ | [0.227, 0.278] | [0.294, 0.385] | [0.455, 0.556] | [0.833, 1.25] | [1.0, 1.0] | [0.8, 1.2] |
| | $A_{136}$ | [0.192, 0.208] | [0.217, 0.294] | [0.278, 0.417] | [0.417, 0.625] | [0.833, 1.25] | [1.0, 1.0] |
| Industrial User | $A_{131}$ | [1.0, 1.0] | [1.4, 2.6] | [1.5, 2.5] | [2.6, 3.4] | [0.4, 0.667] | [0.455, 0.556] |
| | $A_{132}$ | [0.385, 0.714] | [1.0, 1.0] | [0.9, 1.1] | [1.8, 2.2] | [0.294, 0.385] | [0.303, 0.370] |
| | $A_{133}$ | [0.4, 0.667] | [0.909, 1.111] | [1.0, 1.0] | [1.2, 2.8] | [0.208, 0.313] | [0.217, 0.294] |
| | $A_{134}$ | [0.294, 0.385] | [0.455, 0.556] | [0.357, 0.833] | [1.0, 1.0] | [0.192, 0.208] | [0.196, 0.204] |
| | $A_{135}$ | [1.5, 2.5] | [2.6, 3.4] | [3.2, 4.8] | [4.8, 5.2] | [1.0, 1.0] | [0.6, 1.4] |
| | $A_{136}$ | [1.8, 2.2] | [2.7, 3.3] | [3.4, 4.6] | [4.9, 5.1] | [0.714, 1.667] | [1.0, 1.0] |
| Commercial User | $A_{131}$ | [1.0, 1.0] | [1.5, 2.5] | [2.6, 3.4] | [3.8, 4.2] | [0.8, 1.2] | [0.909, 1.111] |
| | $A_{132}$ | [0.5, 0.667] | [1.0, 1.0] | [1.5, 2.5] | [2.6, 3.4] | [0.455, 0.556] | [0.294, 0.385] |
| | $A_{133}$ | [0.294, 0.385] | [0.4, 0.667] | [1.0, 1.0] | [1.2, 2.8] | [0.476, 0.526] | [0.313, 0.357] |
| | $A_{134}$ | [0.238, 0.263] | [0.294, 0.385] | [0.357, 0.833] | [1.0, 1.0] | [0.227, 0.278] | [0.196, 0.204] |
| | $A_{135}$ | [0.833, 1.25] | [1.8, 2.2] | [1.9, 2.1] | [3.6, 4.4] | [1.0, 1.0] | [0.370, 0.769] |
| | $A_{136}$ | [0.9, 1.1] | [2.6, 3.4] | [2.8, 3.2] | [4.9, 5.1] | [1.3, 2.7] | [1.0, 1.0] |

**Table 12.** The weight of the second level index $W_{10}$

| $W_{10}$ | Power Grid | Industrial User | Commercial User |
|---|---|---|---|
| $A_{11}$ | [0.1129, 0.1343] | [0.2746, 0.3058] | [0.6323, 0.6493] |
| $A_{12}$ | [0.3484, 0.3541] | [0.5419, 0.5889] | [0.1233, 0.1285] |
| $A_{13}$ | [0.5173, 0.5330] | [0.1365,0.1532] | [0.2221, 0.2444] |

1) In $W_{10}$, it is obvious that the cognition to the importance of the cloud platforms index is different for different experts since they come from different fields. An expert in the field of power grid enterprises believes that the most important index is virtual ability due to the maximum weight of $A_{13}$ in table 12 ($W_{A13}>W_{A12}>W_{A11}$). An expert from industrial users focuses on the fast response capability of memory architecture because of the maximum weight of $A_{12}$ in table 12 ($W_{A12}>W_{A11}>W_{A13}$). An expert from commercial users thinks that the switching capacity of network architecture is the most important according to the maximum weight of $A_{11}$ in table 12 ($W_{A11}>W_{A13}>W_{A12}$). Therefore, we can infer that the CP based ESMS need to be promoted in future, and different users have had different service of the product.
2) In $W_1$, it is obvious that different users have different performance requirements for cloud platform, when the three biggest weights of $W_1$ are selected. The most important index of $W_1$ to power grid enterprise is $A_{111}$ due to the maximum of $W_{A111}$ in Fig. 3 ($W_{A111}>W_{A122}>W_{A133}$). The industrial user of which is A126 because of the weight of $W_{A126}$ in Fig. 3 ($W_{A126}>W_{A123}>W_{A121}$). The commercial user is $A_{113}$ according to the weight of $W_{A113}$ in Fig. 3 ($W_{A113}>W_{A112}>W_{A111}$). Therefore, we can infer that the product performance of the cloud computing needs the strong pertinence to different customer.
3) According to the characteristics of cloud computing, and considering the type of cloud computing, we infer that

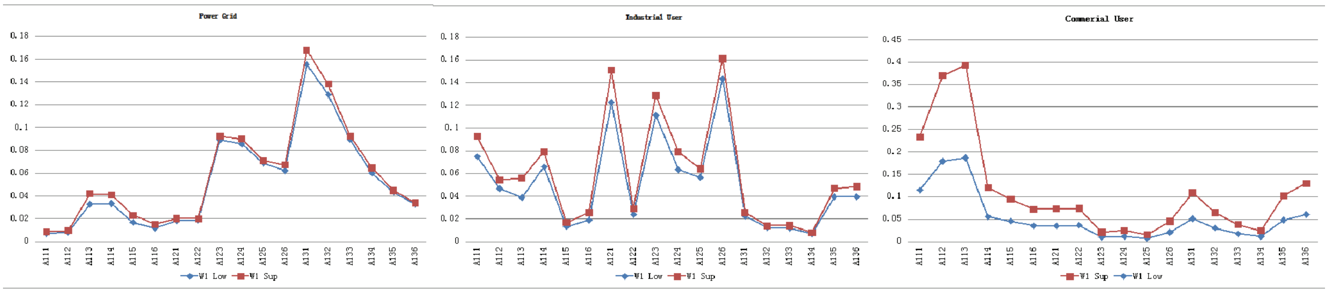


**Fig. 3.** Weight of the total index $W_1$

the commercial users are suitable for public clouds, the power grid enterprise users are suitable for private cloud, and the industrial users are suitable for hybrid cloud.

## 6. Conclusions

An improved interval AHP method is not only effective to solve the problem of the multi-level attribute and multi-decision making, but also provides a quantitative method for the assessment of CP based ESMS, and provides a strong basis for the construction of this platform.

The electric safety issue becomes more and more important and complicated with the integration of large-scale new devices into distribution system, such as electric vehicles (EVs), distributed generations (DGs) and energy storage devices, micro-grids, smart home,. A high standard for the management level and quality of service of ESMS are required, the challenges and opportunities will be coming in many aspects, including technology, personnel and management. Those related topics are worthy of further study.

## Acknowledgments

The authors gratefully acknowledge support provided by the National Natural Science Foundation of China (No. 51361135704, 51377115) and Tianjin Research Program of Application Foundation and Advanced Technology (No. 14JCYBJC21100).

## References

[1] C. Li, K. Chen, and X. Xiang, "An integrated framework for effective safety management evaluation: Application of an improved grey clustering measurement," *Expert System with Applications*, vol. 42, pp. 5541-5553, Aug 2015.

[2] U. Andersson, D.C. Jubert, and T. Evers, "Developing and Installing Substations for Oil and Gas Facilities in Very Cold and Remote Locations," *IEEE Transactions on Industry Applications*, vol. 47, no. 3, pp. 1184-1192, May-Jun 2011.

[3] N. Zhou, X. Xiong, and Q. Wang, "Probability Model and Simulation Method of Electric Vehicle Charging Load on Distribution Network," *Electric Power System Components &Systems*, vol. 42, no. 9, pp. 879-888, 2014.

[4] Z. Lu, J. Liu, Y. Liu, et al, "The interval sensitivity analysis and optimization of the distribution network parameters considering the load uncertainty," *Electric Power and Energy Systems*, vol. 64, pp. 931-936, Jan 2015.

[5] D. Zhang, S. Li, P. Zeng, et al, "Optimal micro-grid control and power-flow study with different bidding policies by using PowerWorld simulator," *IEEE Transactions on Sustainable Energy*, vol. 5, no. 1, pp. 282-292, Jul 2014.

[6] A. R. Messsina, and N. Reyes, Ismael Moreno and Marco A. Perez G, "A Statistical Data-fusion-based Framework for Wide-area Oscillation Monitoring," *Electric Power Components &Systems*, vol. 42, no. 3-4, pp. 396-407, Mar 2014.

[7] H. L. Floyd, II, and B. C. Cole, "Twenty years Later: Creating a Continuous Improvement Environment for Electrical Safety," *IEEE Transactions on Industry Applications*, vol. 51, no.3, pp. 2633-2640, May-Jun 2015.

[8] J. D. Prince, "Introduction to Cloud Computing," *Journal of Electronic Resources in Medical Libraries*, vol. 8, no. 4, pp. 449-458, 2011.

[9] P. T. Jaeger, J. Lin and Justin M. Grimes, "Cloud Computing and Information Policy: Computing in a Policy Cloud? ," *Journal of Information Technology &Politics*, vol. 5, no. 3, pp. 269-283, 2008.

[10] A. R. Alvarez, and M. Humphrey, "A Model and Decision Procedure for Data Storage in Cloud Computing," *2012 12th IEEE/ACM International Symposium on Cluster, Cloud &Grid Computing*, pp. 572-579, 2012.

[11] C. Ji, Y. Li, W. Qiu, et al, "Big Data Processing in Cloud Computing Environments," *2012 International Symposium on Pervasive Systems, Algorithms & Networks*, pp. 17-23, 2012.

[12] Xiong Lu, LizhiCai, Jianhua Li, et al, "Multi-level Load Evaluation Method of Cloud Computing

Platform," Software Industry &Engineering, no. 2, pp. 49-53, 2013.
[13] K. Zhou, and S. Yang, "A framework of service-oriented operation model of China's power system," *Renewable and Sustainable Energy Reviews*, vol. 50, pp. 719-725, Oct 2015.
[14] L. Zhong, and Y. Yu, "An Application of soft computing technique in group decision making under interval-valued intuitionistic fuzzy environment," *Applied Soft Computing*, vol. 13, pp. 2490-2503, May 2013.
[15] J. Wu, H. Huang, and Q. Cao, "Research on AHP with interval-valued intuitionistic fuzzy sets and its application in multicriteria decision making problems," *Applied Mathematical Modeling*, vol. 37, pp. 9898-9906, Dec 2013.
[16] X. Yang, L. Yan, and L. Zeng, "How to Handle Uncertainties in AHP: The Cloud Delphi Hierarchical Analysis," *Information Sciences*, no. 222, pp. 384-404, Feb 2013.
[17] T. Entani, and K. Sugihara, "Uncertainty Index based Interval Assignment by Interval AHP," *European Journal of Operational Research*, no. 219, pp. 379-385, Jun 2012.
[18] S. K. Lee, G. Mogi, and K. S. Hui, "A fuzzy analytic hierarchy process/data envelopment analysis hybrid model for efficiently allocating energy R&D resources: In the case of energy technologies against high oil prices," *Renewable &Sustainable Energy Reviews*, no. 21, pp. 347-355, 2013.
[19] R. Sadiq, and S. Tesfamariam, "Environmental decision-making under uncertainty using intuitionistic fuzzy analytic hierarchy process," *Stoch Environ Res Risk Assess*, no. 23, pp. 75-91, Jan 2009.
[20] L. Abdullah, and N. Zulkifli, "Integration of fuzzy AHP and interval type-2 fuzzy DEMATEL: An application to human resource management," *Expert Systems with Applications*, vol. 42, pp. 4397-4409, Jun 2015.
[21] K. K. F. Yuen, "Fuzzy Cognitive Network Process: Comparisons with Fuzzy Analytic Hierarchy Process in New Product Development Strategy," *IEEE Transactions on Fuzzy Systems*, vol. 3, no. 22, pp. 597-610, Jun 2014.
[22] E. Conde, and M. P. R. Perez, "A linear optimization problem to derive relative weights using an interval judgment matrix," *European Journal of Operational Research*, vol. 201, pp. 537-544, Mar 2010.

**Shou-Xiang Wang** He received the B.S. and M.S. degrees from Shandong University of Technology, Jinan, China, in 1995 and 1998, respectively, and Ph.D. degree from Tianjin University, Tianjin, China, in 2001, all in electrical engineering. He is currently a Professor in the School of Electrical and Information Engineering at Tianjin University. His main research interests are distributed generation, micro-grid and smart distribution system.

**Lei-Jiao Ge** He received Ph.D. degree in electrical engineering from Tianjin University, Tianjin, China, in 2016. He is currently a Lecturer in the School of Electrical and Information Engineering at Tianjin University. His research interests are smart grid and cloud computing.

**Sheng-Xia Cai** She received Ph.D. degree in economics from Nankai University, Tianjin, China, in 2005. She is currently an Associate Professor in the School of Electrical and Information Engineering at Tianjin University. Her research interests are energy management and energy policy.

**Dong Zhang** He received Ph.D. degree in electrical and computer engineering from the University of Alabama, Tuscaloosa, AL, USA, 2013. He is currently a research scientist at State Grid Tianjin Electric Power Company and postdoctoral research associate at Tianjin University. His research interests are residential demand response technology, optimal energy management system in micro-grid and competitive power market.