Complexity Evaluation Model for Smart Grid Management Information System Based on Entropy Theory

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Abstract. System complexity evaluation is an important part in the process of smart grid management information system construction, but there are seldom researches in this area. By analyzing the complex features of smart grid management information system, this paper establishes a complexity evaluation index system from three aspects of primary station, communication network and intelligence terminal device. Besides, a complexity evaluation method based on entropy theory is proposed to quantify the complexity factors. And complex networks space theory is introduced to establish the complexity evaluation model for the whole system, which is used to provide guidance and support for system design, optimization and maintenance. Finally, the efficiency of this model is verified by a real case of smart grid management information system in a city.

1. Introduction
Smart grid management information system (SGMIS) is an important platform for two-way interaction between power generation and utilization. With the rapidly expanding of the smart grid construction, the complexity of SGMIS has dramatically increased. It’s necessary to quantify the complexity of smart grid management information system in order to provide guidance for system design and optimization as well as maintenance service pricing.

In the system complexity science, entropy has become an important indicator to quantify the system complexity since Shannon proposed this concept to describe the system information content, and it is widely used in many areas such as analysis of multichannel data [1], Alzheimer’s Disease evaluation [2], quantifying the stock market inefficiency [3], detection of driver fatigue [4], etc.

Focusing on the complexity of SGMIS, architectures for SGMIS are proposed to provide guidance for the complexity estimate [5-7]. The complex features of SGMIS are analysed based on complexity adaptive system’s characteristics [8]. However, this paper just rests on the description of the complex features of SGMIS instead of quantifying the system complexity.

In general, the complex features of SGMIS have still not been understand and studied entirely [9], and the complexity assessment on SGMIS remains to be investigated.

Considering the entropy theory has been applied maturely. Firstly, this paper analyses the complex features of SGMIS, and establishes a complexity evaluation index system from three aspects of primary station, communication network and intelligence terminal device. Secondly, a complexity evaluation method based on entropy theory is proposed to quantify the complexity factors. Thirdly, the complex networks space theory is introduced to establish the complexity evaluation model for the whole system, which is used to provide guidance and support for system design, optimization and
maintenance. Finally, the efficiency of this model is verified by a real case of smart grid management information system in a city.

2. Complexity evaluation index system of SGMIS

Integrating the whole process of usage of electricity, SGMIS information flow exists in power generation, transmission, substation, distribution, consumption and so on five links, and contains the data from SCADA(Supervisory Control And Data Acquisition), EMS(Energy Management Systems) and etc. The framework of SGMIS is composed of three parts: primary station, communication network and intelligence terminal device.

According to the framework of SGMIS, this paper evaluates the its complexity from three aspects of primary station, communication network and intelligence terminal device. The evaluation index system of SGMIS is shown in Fig. 1.

![Graph showing the evaluation index system of SGMIS](image)

**Figure 1.** Evaluation index system of complexity about smart grid information management system

3. Complexity evaluation method based on entropy theory

Presented by Shannon, entropy is usually used to measure the amount of information. In the study of system complexity, entropy can be also used to represent the uncertainty of system structure and state. The bigger the entropy is, the greater the uncertainty of system structure becomes.

Assuming that the system has $n$ states, and the structure entropy of this system is shown in (1), where the probability of State $i$ is $P_i$.

$$H = -\sum_{i=1}^{n} P_i \log_2 P_i$$

(1)

3.1. Calculation methods of structure entropy in primary station layer

3.1.1. Number of entity sets

Generally speaking, entities with same attribute are often classed as a set. Squares symbolize entities
while rectangles with a name symbolize entity sets in E-R diagram. The structure entropy of entity set is shown in (2), where the number of entity sets is $n_e$.

$$H_w = n_e \left[ - \frac{1}{n_e} \log_2 \frac{1}{n_e} \right] = - \log_2 \frac{1}{n_e}$$  (2)

3.1.2. Number of contact sets
Referring to the relation between entities, contacts with same attribute are often classed as a contact set, and it is symbolized by a diamond in E-R model. The structure entropy of contact set is shown in (3), where the number of contact sets is $n_r$.

$$H_u = n_r \left[ - \frac{1}{n_r} \log_2 \frac{1}{n_r} \right] = - \log_2 \frac{1}{n_r}$$  (3)

3.1.3. Number of attributes
Attribute is the nature of each object in the entity sets or contact sets. The number of attributes is equal to the number of ellipses in the E-R model. Assuming that the number of entity sets and contact sets is $n_p$, where $n_p = n_e + n_r$. The structure entropy of attribute is shown in (4), where the number of attributes of entity set $i$ or contact set $i$ is $n_i$.

$$H_a = \sum_{i=1}^{n_p} n_i \left[ - \frac{1}{n_i} \log_2 \frac{1}{n_i} \right] = - \sum_{i=1}^{n_p} \log_2 \frac{1}{n_i}$$  (4)

3.1.4. Number of tuples
Corresponding to one row in data sheet, each tuple has a unique number. Assuming that there are $n$ data sheets, the structure entropy of data sheet $i$ is shown in (5), where the number of tuples in data sheet $i$ is $n_t$.

$$H_u = \sum_{i=1}^{n} n_t \left[ - \frac{1}{n_t} \log_2 \frac{1}{n_t} \right] = - \sum_{i=1}^{n} \log_2 \frac{1}{n_t}$$  (5)

3.1.5. System visit quantity
After the modeling analysis of static complexity in primary station layer, dynamic complexity can be described by system visit quantity. Supposing that the number of user actions during a observing period is $n_v$, the structure entropy of system visit quantity is shown in (6).

$$H_v = n_v \left[ - \frac{1}{n_v} \log_2 \frac{1}{n_v} \right] = - \log_2 \frac{1}{n_v}$$  (6)

3.2. Calculation methods of structure entropy in communication network layer
3.2.1. Number of communication equipments
The structure entropy of the number of communication equipments is shown in (7), where the number of communication equipments is $n_c$.

$$H_w = n_c \left[ - \frac{1}{n_c} \log_2 \frac{1}{n_c} \right] = - \log_2 \frac{1}{n_c}$$  (7)

3.2.2. Type number of communication equipments
The structure entropy of the type number of communication equipments is shown in (8), where the type number of communication equipments is $n_{tc}$.

$$H_u = n_{tc} \left[ - \frac{1}{n_{tc}} \log_2 \frac{1}{n_{tc}} \right] = - \log_2 \frac{1}{n_{tc}}$$  (8)

3.2.3. Packet loss rate
The structure entropy of packet loss rate is shown in (9), where the packet loss rate of type $i$ communication equipments is $r_i$.
\[ H_i = \sum_{r=1}^{\infty} (-\frac{1}{r_i} \log_2 \frac{1}{r_i}) \]  

(9)

3.3. Calculation methods of structure entropy in intelligence terminal device layer

3.3.1. Number of terminal devices
Supposing that the number of terminal devices is \( n_a \), the structure entropy of it is given in (10).

\[ H_n = n_a (-\frac{1}{n_a} \log_2 \frac{1}{n_a}) = -\log_2 \frac{1}{n_a} \]  

(10)

3.3.2. Type number of terminal devices
Supposing that the type number of terminal devices is \( n_t_a \), the structure entropy of it is given in (11).

\[ H_n = n_t_a (-\frac{1}{n_t_a} \log_2 \frac{1}{n_t_a}) = -\log_2 \frac{1}{n_t_a} \]  

(11)

3.3.3. Acquisition frequency
The structure entropy of acquisition frequency is shown in (12), where the acquisition frequency of type \( i \) terminal devices is \( f_i \).

\[ H_f = \sum_{i=1}^{\infty} f_i (-\frac{1}{f_i} \log_2 \frac{1}{f_i}) \]  

(12)

4. Complexity evaluation model based on complex networks space theory
Introducing the complex networks space theory, a complexity evaluation model is built in order to analyse the system complexity ponderance and resultant.

4.1. Complexity ponderance evaluation model
According to the complexity features of SGMIS, management energy [10] is introduced to describe the complexity and administrative cost of each layer. Assuming that \( e_i \) is a an \( n \)-vector, and \( e_i = (e_{i1}, e_{i2}, \ldots, e_{im}) \), where \( e_{im} \) represents the structure entropy of layer \( i \) in the system. On the basis of management energy and Euclidian distance in the complex networks space, system complexity ponderance can be obtained in (13).

\[ w_i = e_{im} \sqrt{|e_i-e_{im}|} \]  

(13)

4.2. Complexity resultant evaluation model
An united structure entropy space is built in order to get the system complexity resultant. Supposing that complexity vector space \( E \) includes \( n \) vectors with \( m \) dimensions, where \( m \) represents the number of layers in the system and \( n \) represents the number of complexity evaluation indexes. Complexity vector \( e_i \) is defined as the element of \( E \) and \( e_i \in H^n \). Then the structure entropy matrix can be obtained.

\[
M = \begin{bmatrix}
    e_{i1} & e_{i2} & \cdots & e_{im} \\
    \vdots & \vdots & \ddots & \vdots \\
    e_{n1} & e_{n2} & \cdots & e_{nm}
\end{bmatrix}
\]

The distance between two vectors in matrix \( M \) is given in (14).

\[
|e_{i1} - e_{i2}| - |e_{i1} - e_{i2} - e_{i3} - \cdots - e_{im}|
\]  

(14)

A complexity vector space with \( n \) dimensions is defined after combining \( m \) vectors: \( e_1 \times e_2 \times \ldots \times e_m \). Assuming that \( \Phi \) is a image and tensor in \( H \), and \( \Phi: e_1 \times e_2 \times \ldots \times e_m \rightarrow H \). \( \Phi \) is defined as \( T_m (H) \) and a vector space in \( H \). 0 elements can be used to supplyment the vector with less columns while the vectors in \( M \) don’t have the same number of columns, and the tensor is described: \( \|\Phi\| = \|e_i\| \), \( \|\Phi\| \) refers to the united structure entropy of layer \( i \).
When the vectors in $M$ have the same attribute, the complexity resultant of the whole system is given in (15).

$$
||C|| = \sum_{i=1}^{m} ||\Phi(e_{i+1}) - \Phi(e_{i})|| = \sum_{i=1}^{m} ||e_{i+1} - e_{i}||
$$

(15)

In (15), $||e_{i+1} - e_{i}||$ is the complexity information that layer $i+1$ generates after layer $i$, and $m$ is the total number of system layers.

Conversely, the complexity resultant of the whole system is given in (16).

$$
||C|| = \sum_{i=1}^{m} ||\Phi(e_{i})|| = \sum_{i=1}^{m} ||e_{i}||
$$

(16)

While both the vectors with the same attributes and those with different attributes exit simultaneously, the complexity information of the vectors with the same attributes can be calculated by (15), whereas the complexity information of the vectors with different attributes can be calculated by (16). Finally, the complexity resultant of the whole system is the sum of the two above-mentioned results.

5. Case study

5.1. Introduction of SGMIS in a city

On the basis of the various electric power load control systems built before, a city power supply bureau establishes a SGMIS through energy management system(EMS), distribution management system(DMS) and so on. Statistic of complexity data is shown in Table 1.

| Mesurement domain          | Mesurement factor                  | Statistic | Structure entropy calculation |
|---------------------------|------------------------------------|-----------|-------------------------------|
| Primary station           | Number of entity sets              | 96        | 6.5850                        |
|                           | Number of contact sets             | 150       | 7.2288                        |
|                           | Number of data attributes          | ——        | 103.3971                      |
|                           | Number of tuples                  | ——        | 328.7741                      |
|                           | System visit quantity             | 7293881   | 22.7983                       |
|                           | Number of communication equipments| 266193    | 18.0221                       |
| Communication network     | Type number of communication equipments | 24     | 4.5850                        |
|                           | Packet loss rate                  | ——        | 28.0494                       |
|                           | Number of terminal devices         | 6615248   | 22.6574                       |
| Intelligence terminal device | Type number of terminal devices    | 12        | 3.5850                        |
|                           | Acquisition frequency             | ——        | 55.7879                       |

5.2. Calculation analysis

The complexity ponderances can be calculated by (13), and the united structure entropy of each layer can be obtained according to $||\Phi|| = ||e||$. The result is given in Table 2.

| Mesurement domain          | complexity ponderance | united structure entropy |
|---------------------------|-----------------------|--------------------------|
| Primary station           | 7635.843              | 335.706                  |
| Communication network     | 521.6113              | 33.6539                  |
| Intelligence terminal device | 1279.7324             | 60.32                    |

Because the complexity vectors have different attributes, the complexity resultant is calculated by (16).
From the complexity ponderances, $w_1 > w_3 > w_2$, the primary station is the most complex part. Meanwhile, the increasing complexity in communication network layer and intelligence terminal device layer makes it essential to define relative standards of the devices, in order to standardize the management and reduce the management cost.

6. Conclusion

System complexity evaluation is a precondition for estimating the maintenance cost. This paper proposes the complexity evaluation model based on complex networks space theory, broadening a new horizon and leads to the complexity evaluation.

According to the complexity ponderances $w_1$, $w_2$, $w_3$, and complexity resultant $||C||_T$, the system complexity can be evaluated locally or generally. The bigger the complexity resultant is, the more complex the system is. It provides a guidance for design scheme optimization, which is very practical in application. And it will be more useful in wider area if corresponding software could be developed.

7. References

[1] Ahmed M U and Mandic D P 2011 Multivariate multiscale entropy: a tool for complexity analysis of multichannel data Physical Review E Statistical Nonlinear & Soft Matter Physics 84(6 Pt 1):061918.
[2] Morabito F C, Labate D, Foresta F L, et al 2012 Multivariate Multi-Scale Permutation Entropy for Complexity Analysis of Alzheimer’s Disease EEG Entropy 14(7):1186-1202.
[3] Zunino L, Zanin M, Tabak B M, et al 2012 Complexity-entropy causality plane: A useful approach to quantify the stock market inefficiency Physica A Statistical Mechanics & Its Applications 389(9):1891-1901.
[4] Zhang C, Wang H and Fu R 2014 Automated Detection of Driver Fatigue Based on Entropy and Complexity Measures IEEE Transactions on Intelligent Transportation Systems 15(1):168-177.
[5] Cao JW, Wan YX, Tu GY, et al 2013 Information system architecture for smart grid Chinese Journal of Computers 36(1):143-167
[6] Kim KD and Kumar P R 2012 Cyber-physical systems:A perspective at the centennial Proceedings of the IEEE 100(Special Centennial Issue):1287-1308
[7] Ericsson G N 2010 Cyber security and power system communication—essential parts of a smart grid infrastructure IEEE Transactions on Power Delivery 25(3):1501-1507
[8] Liu XM and Ju J 2013 Analysis of the complexity features for information management system of smart grid Journal of North China Electric Power University (Social Sciences) (02):20-24
[9] Liu XM, Tian HY and Qin C 2012 Research on smart grid information management system based on complex scientific management thinking and multi agent system technology Power System Technology 36(8):204-208.
[10] Song HL, Jin ZX, Li JK, et al 2006 The Three Dimension Metric Model of Management System Complexity for Enterprise Journal of industrial engineering and engineering management 20(1):103-108.