Self-organizing Network Synchronization Technology based User-side Information Communication Method in Energy Internet

Liangzhong Yao¹, Bo Yang¹, Shengchi Yan¹, Jilei Ye¹, Minghao Ai¹,², *, Hongfen Cui¹, Xianjun Ge²

¹China Electric Power Research Institute, Beijing, China
²Tsinghua University, Beijing, China
*Corresponding author e-mail: aci_minghao@126.com

Abstract. With the global energy Internet four major changes in future, a variety of new grid business came into being. User side energy equipment is not only energy consumers, but also will serve as the role of energy suppliers, so the information exchange between users is becoming more and more complicated, a large number of multi-form user terminal access and out of the grid through the "plug and play", and there will be a decentralized self-organizing information interaction between large-scale distributed clients. In the physical information integration of the Energy Internet, the synchronization method of information between the energy endpoints greatly affects the timeliness and reliability of communication. The paper summarizes the core characteristics of the wireless ad hoc network. According to the demand of development trend of the energy Internet to the information exchange between users, the centralized and distributed self-organized network will be analyzed. It will compare the synchronization performance difference between the information interaction of the Energy Internet user sides, and simulate the typical self-organization synchronization technology in the energy Internet user side scenario. Finally, based on the simulation results, I make a summary and analysis of the next step facing the problem, and propose solutions.

1. Introduction

In 2014 IEEE PES Annual meeting, SGCC first proposed the concept of Global Energy Internet, analyzed the severe challenges the sustainable development of human society faced, and believed that the key to meeting such challenges as energy security, environmental pollution, and climate change is to accelerate energy changes, develop and utilize clean energy on a large scale, optimize energy structure, increase energy efficiency, improve ecological environment, and realize clean development[1]. Energy Internet is the combination of Internet technology, renewable energy technology and modern power systems. Compared with traditional power grids, the two-way exchange of energy and information makes Energy Internet has higher requirements for communication technologies. The Energy Internet differs greatly from traditional grids in terms of information and communication networks, which including: First, in the energy internet, there is a double-way flow of energy and information between the user-end devices and the user and the power grid, rather than a simple one-way flow of energy.
Second, in traditional grids, the role of users is single and only takes on the role of energy consumers, however, in Energy Internet, large-scale distributed customer equipment plays a dual role of energy consumers and energy suppliers. At the same time, the types of devices connected to the power grid at the user side are complex and diverse, causing difficulties for information communication between nodes. Third, Energy Internet is more open on the interaction between users and the grid as well as user-side power generation devices, energy storage devices, and loads can be "plugged in", and information interaction between users can be "decentralized"[2].

The frequent interaction, various types, and plug-and-play characteristics of nodes in the Energy Internet make traditional information interaction technologies difficult to satisfy such user-side communication needs. Self-organizing network technology can provide an effective solution to the problem of synchronization performance between users. Self-organizing network features self-organization, self-configuration, self-optimization, self-healing and self-adaptation[3]. For the needs of information communication on user side of the Energy Internet, self-organizing networks have the following advantages: First, The self-organizing network can flexibly and efficiently realize decentralized spontaneous information interaction and energy transaction between user side devices. Second, Its synchronization technology can achieve rapid synchronization for large-scale distributed clients. Third, its algorithm for heterogeneous networks can provide an efficient synchronization method among various types of access devices on user side of the Energy Internet.

This paper proposes a user-side information communication method in Energy Internet based on self-organizing network synchronization technology. First, it analyzes the needs of self-organizing synchronization technology for the characteristics of user-side information interaction in Energy Internet. Then it introduces the typical synchronization technology in the self-organizing network and compares its performance in Energy Internet application, and makes simulation verification and summary for the typical synchronization technology.

2. Analysis of Information Communication Characteristics on User Side of Energy Internet

2.1. Changes Caused By Energy Internet

The construction of Energy Internet will cause four major transformation scenarios of energy grid structure, including changes in energy production methods, changes in energy allocation methods, changes in energy consumption patterns, and changes in production and lifestyles. These four change scenarios raise a higher demand for the information communication methods that support the energy grid.

(1) The energy production method will translate from fossil-based energy to renewable energy such as wind energy and solar energy. Distributed renewable energy in households, buildings, and factories will become an important energy supply method. Therefore, the future Energy Internet requires the coverage of a wider range of large-scale communications networks and the rational use of distributed communications technologies.

(2) The energy allocation method will be transformed from a long-distance power distribution mode to a power distribution mode combining large-scale power transmission and local balance. The power grid dispatching will extend to the power distribution side and provide control support for the power supply and local consumption on the user side. Therefore, the grid information communication needs to improve the user-side information access capability between the access and the terminals, strengthen the real-time communication, and maximize the energy allocation efficiency through a combination of distributed and centralized information and communication technologies.

(3) The energy consumption mode will be transformed from grid marketing, which focuses on the resale of electricity, to a grid-based energy allocation and trading platform, large-scale renewable energy bases, dual-identity grid users, and third-party energy operators to conduct complex transaction marketing models. Electricity trading will become the main act of social energy allocation. Therefore, we must ensure the stability and robustness of the trading communications network.
(4) In the future, Energy Internet will be integrated into all areas of social life, including sensing terminals, information collection terminals, interactive terminals, and business applications across the grid, which will support a variety of social services to achieve changes in people's lifestyle. Therefore, each virtual terminal device in the communication network should be substitutable, and any node information cannot affect the operation of the entire network when it fails to access.

2.2. User-side key applications

The architecture of Energy Internet is shown in Figure 1. Micro-grid, distributed energy and other energy autonomous units can be used as the basic components in Energy Internet, whose access, interconnection and scheduling are flexible. Energy Internet adopts a bottom-up distributed self-coordinated management model, which is in line with the trend of integration and distribution of power grid development [4].

![Energy Internet Architecture Diagram](image)

**Figure 1.** Energy Internet architecture

Distributed Energy

In order to increase the efficiency of energy access and disconnection from the power grid, reduce installation costs, and increase the scalability of Energy Internet, distributed energy sources in Energy Internet need higher self-management capabilities to achieve "plug and play" of distributed power sources. That is to say, distributed generation and energy storage equipment can be flexibly and quickly connected to or disconnected from the grid as required, and information interaction activities can be efficiently implemented.

Micro Grid

Micro-grid technology provides the possibility for distributed renewable energy to support a balance of supply and demand for localized energy. Micro-grid has high autonomy, which can rely on their own power generation equipment, energy storage equipment, and loads to achieve power balance. Its "plug-and-play" nature also requires energy flexible access and disconnection from the grid, and it does not affect the stability of the grid.
Energy trading

In the energy trading of Energy Internet in the future, users are not only energy consumers, but also can assume the role of energy suppliers. The change of users' dual roles will increase the diversity and complexity of services in Energy Internet, and more energy trading behaviors and information interactions will emerge[5]. In order to improve the efficiency of information exchange, energy trading activities may also have the characteristics of decentralization, which is Peer-to-Peer (P2P) mode without the central node, and Customer to Customer (C2C) direct trading will become an important mode of energy trading.

From the analysis of the four major changes in Energy Internet and important business applications at the user side, it can be seen that user-side information interaction needs to meet higher standards to support the development of Energy Internet. In the grid where the CPS is integrated with each other, various customer end equipment are distributed on a large scale, which perform decentralized energy exchanges to realize peer-to-peer (P2P) interactions among energy participants, and information is exchanged in a manner of “plug and play” access and disconnection to the power grid. These characteristics require that the future energy Internet communication network be dynamic, scalable, heterogeneous, and flexible.

3. Self-organizing network synchronization technology

3.1. Self-organizing network

In recent years, self-organizing networks have become more and more important in wireless communication technologies due to their features of ad hoc networks, self-configuration, self-optimization, self-healing, adaptive environment awareness, dynamic routing and load balancing. Wireless self-organizing network is a computer communication network that uses wireless communication channels for packet switching. The network node is mobile and has the ability to send and receive radio signals. Each node in the network is equal and can be either a routing node or a terminal node. The entire network does not depend on the base or the central node, and it adopts a distributed self-organizing management operation. The joining of a new node or the decommissioning of any node can manage itself[6]. These characteristics of the wireless self-organizing network make it have many advantages, such as rapid and flexible networking, easy access, strong anti-destroy capability, and strong topological variability.

The networking mechanism of the self-organizing network greatly satisfies the user-side information interaction requirements in Energy Internet. By using self-organizing network technology, large-scale distributed customer terminal equipment in Energy Internet can be flexibly networked, and their response can be adjusted according to environmental changes to achieve decentralized end-to-end transactions.

3.2. Node synchronization technology

The basic idea of the self-organizing network node synchronization technology is to achieve the synchronization of the entire network node through the mutual exchange and mutual control of the time bases between adjacent nodes in the network. Energy Internet users’ end-to-end energy transactions based on self-organizing network synchronization technology will be more efficient and flexible, and information interaction will be closer to the development characteristics of Energy Internet. In general, self-organizing network synchronization technology can be divided into centralized and distributed.

Centralized synchronization technology

With centralized synchronization technology, Energy Internet users’ devices are combined into clusters, and all users’ devices obtain synchronization through cluster head nodes. Cluster head nodes are synchronized by receiving external synchronization reference signals. The typical representative of the centralized synchronization technology is GPS and NTP(Network Time Protocol), and the synchronization accuracy can reach 200ns, which has been widely used in communication networks[7].
However, in Energy Internet, distributed power generation is distributed on a large scale, and using centralized synchronization algorithms can no longer meet the accuracy requirements of Energy Internet. There is a conflict between network accuracy and the scalability of distributed client. As the increasing of the gap between the user-end device and the cluster head node, the accuracy of synchronization among the user terminals decreases sharply and data transmission delay can cause synchronization errors up to 1ms.

Distributed synchronization technology

Compared with the centralized synchronization technology, the distributed synchronization algorithm avoids the risk of the entire network information exchange failure due to the failure of the cluster head in the centralized synchronization algorithm, which can significantly improve the scalability of Energy Internet users, effectively improve the synchronization speed among the user-end devices.

1) RBS algorithm

RBS (reference broadcast synchronization) algorithm was proposed by J. Elson et al[8]. Using this algorithm, each user in Energy Internet sends physical layer synchronization signals to neighboring users, and the neighboring user determines the relative synchronization time between itself and the sending user by analyzing the received time information of the arrival synchronization signal, thereby adjusting the respective synchronization time to realize the spontaneous synchronization among the users.

2) Bionics-based homogeneous PCO model

Firefly algorithm has been widely promoted in the wireless ad hoc network technology with its rapid development of the bionics principle. It is a heuristic algorithm constructed by simulating the glow behavior of fireflies in foraging and mating.

Pulse-coupled oscillators (PCO) theory is an example of firefly algorithm using the same PCO model for all network nodes [9], whose principle is as follows:

1) The entire network is simulated as N "trigger - ignition" oscillators, with each oscillator pulse defined as:

\[ \frac{dx_i}{dt} = S_0 - \gamma x_i, \quad 0 \leq x_i \leq 1, i = 1, \ldots, N \]

Among them, S0 represents the cumulative amount of trigger energy, and \( \gamma \) represents the trigger energy leak factor.

2) The state variable \( x_i \) is usually a monotonic ascending function. When the value of \( x_i \) reaches 1, the oscillator triggers the ignition and \( x_i \) returns to zero.

3) Synchronization among nodes is achieved by coupling the oscillator to the others. When a oscillator ignites, it will activate the state variable of the nearby oscillator \( j \) to add a value \( \varepsilon \), or to fire it.

The state of the nearby oscillator \( j \) is expressed as \( x_j(t) = 1, \Rightarrow x_j(t^+) = \min(1, x_j(t) + \varepsilon), \forall j \neq i \).

![Figure 2. Peskin PCO Model’s function figure](image)

(3) Bionics-based Heterogeneous PCO model

Heterogeneous PCO [10] model’s principle is as follows:

1) Suppose there are two oscillators A and B, respectively, with the center frequency \( f_A \) and \( f_B \);
2) The phase relationship between the two oscillators is: \[ \phi_i = \frac{T_i}{T_a} \phi_a = \frac{f_a}{f_i} \phi_a; \]

3) By pulse coupling, when the oscillator i state reaches 1, the oscillator j will be awakened: \[ \phi_i = 1 \Rightarrow \phi_j' = \min \left( 1 + \phi_i + \frac{f_j}{f_i} \psi \right), \forall j \neq i; \]

4) When the two coupled oscillators reach synchronization with each other, they can collectively be considered as one logical oscillator and continue to repeat the above operations with the neighboring oscillator until all the network nodes have reached synchronization. This operation can be considered as a multi-oscillator model, and the model can achieve network consistency convergence as long as the following conditions are met:

\[ \begin{align*}
    & f_{\min} (1 + \epsilon_i) \geq 1, \\
    & f_{i} \neq f_{j}, \quad \forall j \neq i,
\end{align*} \]

Among them, \( f_{\min} = \min(f_1, \cdots, f_N) \), \( f_{\max} = \max(f_1, \cdots, f_N) \).

4. Application of Self-Organizing Network Synchronization Technology in Energy Internet Communication Network

4.1. Energy Internet User Information Communication Based on Self-Organizing Network Synchronization Technology

Energy Internet users’ architecture is complex and equipment is versatile, in addition, the influence of various parameters in the network on the synchronization performance between users’ devices cannot be ignored.

Using the homogeneous PCO model, we can consider each user in Energy Internet as a firefly, and the sensors it carries can sense the lighting of the surrounding users. Once the user device senses that the surrounding user has triggered the ignition, it will immediately adjust its ignition cadence and respond to the ignition status of the surrounding environment [11]. After one cycle of adjustment, all client devices will achieve a synchronous “bright-out” rhythm that is a synchronized state.

The advantage of this type of model is that it enables the user terminals in Energy Internet to achieve rapid mutual synchronization, effectively improve the synchronization efficiency of the sensing terminals throughout the grid, and significantly expand the scalability of the power grid. The disadvantage is that the network environment is assumed to be ideal when the model is established, without considering the parameters of the actual network, such as signal fading, signal transmission delay, noise, etc. The signal transmission delay in the actual network has a great influence on the synchronization degree of the entire network.

In Energy Internet, the user-side communication network is very complex. Various devices such as smart homes, smart phones, PCs, distributed generation/energy storage devices, and AMI will all access the Energy Internet. Therefore, the Energy Internet must be able to accommodate the interconnection of various heterogeneous networks and make full use of the existing communication network infrastructure. For such applications, a synchronous model that is compatible with different types of nodes is required.

Using the heterogeneous model, the user side of Energy Internet can allow terminal devices with different centre frequencies to be “plugged in”. At any moment, the phase of the pulses among user devices are different, and the phase relationship must be determined to achieve relative synchronization among neighbouring users, thereby achieving synchronization of the entire network. Compared with the homogeneous PCO model, the heterogeneous PCO model fully considers the frequency/phase difference of different nodes, and more easily realizes the synchronization state among the user equipment.
4.2. Performance Analysis of Various Synchronization Methods in Energy Internet

According to various characteristics of Energy Internet, the application scenarios of various self-organizing synchronization algorithms are different:

Centralized NTP algorithm has higher synchronization accuracy, but lower network scalability. The homogenous PCO algorithm solves the problem of scalability of Energy Internet user terminals, but the user-side terminal heterogeneity reduces its synchronization performance. Although the heterogeneity PCO algorithm considers the heterogeneity of user-side devices, the synchronization performance drops sharply when the coupling strength of the network decreases.

The following table provides detailed analysis and comparison of application performance of various types of self-organizing network synchronization algorithms in Energy Internet.

Table 1. Energy Internet user side application synchronization algorithm performance comparison

| Classification   | Algorithm name | Advantage                                      | Disadvantages                                                                 |
|------------------|----------------|-----------------------------------------------|------------------------------------------------------------------------------|
| Centralized      | NTP            | High precision and high reliability            | High complexity; User equipment far away from the cluster head user end has low  |
|                  |                |                                               | synchronization accuracy                                                      |
| Distributed      | RBS            | Synchronization performance no longer depends on the cluster head client | Distributed synchronization requires users to exchange large amounts of synchronized data |
| Homogeneous      | Homogeneous PCO| Physical layer synchronization; Highly scalable |                                                                              |
| Bionics algorithm|                |                                               | When there is signal transmission delay, the synchronization among users will be invalid |
| Homogeneous      | Hong           | Takes full consideration of signal transmission delays in the actual environment | UWB pulse is not easy to detect and affects synchronization performance |
| Bionics algorithm|                |                                               |                                                                              |
| An heterogeneous  |                | Suitable for user-side large-scale distributed device terminal synchronization | User-side weakly coupled environment reduces synchronization performance |

4.3. Simulation analysis

Assume that there are 60 new user nodes in a regional energy network and the node types include power generation nodes, power consumption nodes, and communication nodes. Now we will organize these 60 nodes into a network. Set initial attraction coefficient $\beta=1$, Initial attraction $\gamma_0 = 0.000001$, Movement coefficient $\alpha = 0.6$. The objective function uses the Griewank function:

$$\min f(x) = \sum_{i=1}^{N} \frac{x_i^2}{4000} - \prod_{i=1}^{N} \cos\left(\frac{x_i}{\sqrt{i}}\right) + 1$$

The dimension $N$ that the user-side node focused is set to 10, and each node randomly takes values between [-600,600]. When the number of iterations is set to 20, the self-organization result is:

1) Optimal target value $f(x) : 13.030708$

2) The multi-dimensional $x_i$ value corresponding to the optimal target value:

[-28.23679822, 17.6829421, -38.20544747, -50.20886129, 84.2496698, 38.38203137, 174.17340432, 70.7466468, 37.83753213, 39.84929797]

3) The results of 20 iterations are shown in Table 3-2.
Table 2. Each iteration result

| Number of iterations | Optimal target value | Average value |
|----------------------|----------------------|---------------|
| 1                    | 119.475226           | 280.669553    |
| 2                    | 23.370455            | 28.346877     |
| 3                    | 21.930035            | 22.702671     |
| 4                    | 20.322359            | 21.04994      |
| 5                    | 19.056822            | 19.64929      |
| 6                    | 17.718098            | 18.390117     |
| 7                    | 16.474267            | 17.133798     |
| 8                    | 15.447553            | 15.990177     |
| 9                    | 14.400902            | 14.960456     |
| 10                   | 13.351413            | 13.775583     |
| 11                   | 13.07106             | 13.233767     |
| 12                   | 13.045377            | 13.220654     |
| 13                   | 13.037259            | 13.226274     |
| 14                   | 13.037259            | 13.22474      |
| 15                   | 13.037259            | 13.221036     |
| 16                   | 13.037259            | 13.225651     |
| 17                   | 13.037259            | 13.215075     |
| 18                   | 13.030708            | 13.186543     |
| 19                   | 13.030708            | 13.227966     |
| 20                   | 13.030708            | 13.258482     |

4) The iterative process fitting curve is shown in Figure 3.

Figure 3. Curve fitting

5. Conclusion
The article first analyzes the characteristics of Global Energy Internet user-side information communication and the necessity of node synchronization. Then, on the basis of comparing various self-organizing network synchronization technologies, it proposes a self-organizing network application approach in energy internet and assumes a regional energy network in order to simulate and analysis to
demonstrate the feasibility of application of self-organizing network synchronization technology in Energy Internet communication. The use of self-organizing network method for self-synchronous communication of nodes in the Energy Internet has the flexibility, scalability and self-organization, and has good practical value.

Acknowledgments
This work was financially supported by SGCC’s Science and Technology Project: Research on Key Technology of Large-scale Energy Storage Application Adapting to Global Energy Internet.

References
[1] LIU Zhenya. Global Energy Internet[M]. Beijing: China Electric Power Press, 2015: 2-5.
[2] WANG Yi. Research on Information and Communication Architecture of Energy Internet[J]. Electric Power Information and Communication Technology, 2015, 13(07):15-21.
[3] Zhang, Zhongshan, et. On swarm intelligence inspired self-organized networking: Its bionic mechanisms, designing principles and optimization approaches[C]. Institute of Electrical and Electronics Engineers Inc., 3 Park Avenue, 17th Floor, New York, NY 10016-5997, United States
[4] LI Jianqi, SHI Wenhao, ZHAN Dexiang. Research on Information Communication Network of User Side in Energy Interconnection[J]. Electric Power Information and Communication Technology, 2016,14(04):13-17.
[5] LI Xiaolu, SONG Yanmin, TANG Chuntong, PAN Yi. Study on Cross-Border Electricity Trading Maturity Model for Global Energy Interconnection[J]. Electric Power Information and Communication Technology, 2017,15(03):7-13.
[6] WANG Bo, YE Xiaohui, ZHAO Yuting, YAN Xueli. Research on Clock Synchronization of Ad Hoc Networks: A Survey[J]. Computer Science, 2010,37(05):30-33+39.
[7] XU Shiwu, WANG Ping, HUANG Xi, et al. The Review of Time Synchronization Algorithm for Wireless Sensor Networks[J]. Microcomputer Applications, 2011,32(05):32-38.
[8] Wang Yijun, Qian Zhihong, Wang Guiqin, Zhang Xu. Research on Energy-efficient Time Synchronization Algorithm for Wireless Sensor Networks[J]. Journal of Electronics & Information Technology, 2012,34(09):2174-2179.
[9] CHEN Haidong, ZHUANG Ping, XIA Jiankuang, et al. Optimal power flow of distribution network with distributed generation based on modified firefly algorithm[J/OL]. Power System Protection and Control, 2016,44(01):149-154.
[10] WANG Jiquan, WANG Fulin. Improvement analysis and application of firefly algorithm[J]. Journal of Computer Applications, 2014,34(09):2552-2556.
[11] LIU Changping, YE Chunming. Novel bioinspired swarm intelligence optimization algorithm:firefly algorithm[J]. Application Research of Computers, 2011,28(09):3295-3297.