Modeling of Integrated Energy Service System Based on Ontology

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Abstract. Integrated energy system integrates the production, transportation, distribution, conversion, storage and consumption of all kinds of energy. The complex structure of integrated energy system makes it difficult to model by analytical method. At present, the modeling of integrated energy system is mostly static modeling of all kinds of equipment in the system, and the coupling and logical relationship between the new equipment and each part is not clear, which makes the further development of integrated energy system, planning and operation meet certain difficulties. In this paper, the integrated energy system is modeled by ontology. Ontology modeling enhances the interoperability between heterogeneous systems, making data transmission between different systems or tools; Ontology improves clarity and reduces the cost of requirement analysis by describing problems and tasks.

Introduction

The integrated energy service system based on the power system and is highly coupled with energy systems such as gas systems and thermal systems. Unified planning, operation and dispatching of various energy systems such as electricity, natural gas, and hot and cold. Energy Internet, energy hubs and pan-energy networks are the manifestations of integrated energy service systems. The various forms of integrated energy systems are basically the same at the basic physical structure and equipment level, including the production, transmission, storage and consumption of electricity, heat, cold and other types of energy. The integrated energy system can realize the coordination between different energy supply and use systems, and improve the flexibility, security and reliability of energy supply and use. At the same time, the interaction and cooperation between different energy supply and consumption systems in the integrated energy system can be used to achieve optimal energy dispatch and improve efficiency. Integrated energy system integrates the production, transportation, distribution, conversion, storage and consumption of all kinds of energy. Its structure is complex and its mathematical modeling is difficult. At present, the modeling of integrated energy system is mostly static modeling of all kinds of equipment in the system. The coupling and logical relationship between the new equipment and each part is not clear. There is lack of in-depth study on the dynamic mechanism, control law and optimization characteristics of the integrated system. So there are some difficulties in the subsequent development, planning and operation of the comprehensive energy system.[1]

Ontology is an important tool for knowledge discovery and knowledge modeling. Neches et al. first gave the definition of ontology in the field of artificial intelligence. Ontology is defined as "The basic terms and relationships that constitute the vocabulary of the relevant field are given, and the definitions of the rules for the extension of these terms are made using these terms and relationships."[2] In addition, Noy F.N. proposes that "Ontology is a formal and explicit representation of concepts in a certain domain, and the characteristics of each concept describe all aspects of the concept and the characteristics and attributes of its constraints."[3] The goal of ontology is to capture domain knowledge in related domains, identify common vocabulary within the domain by providing a common understanding of the domain knowledge, and give clear definitions of the relationships between these vocabulary and vocabulary from different levels of formal patterns.
Ontology describes the semantics of concepts through the relationship between concepts. Supporting interoperation among different systems is the foundation of requirements analysis and system design. Separating domain knowledge from operational knowledge of domain knowledge, the core of ontology is knowledge sharing. Ontology reduces conceptual and terminological ambiguities, provides a unified framework and normative model for an organization or work system, solves the differences between different terms and norms in complex systems, and maintains semantic consistency.[4] Ontology modeling is used to enhance the interoperability between heterogeneous systems and data transmission between different systems or tools. Ontology improves the clarity and reduces the cost of demand analysis by describing problems and tasks. The construction of domain ontology is one of the hot topics in ontology research.

In general, an ontology represents a shared, consistent, and detailed model (or set of concepts) of a problem domain. One of the main advantages of using domain ontology is that it can define the semantic model of data in combination with relevant domain knowledge. Ontology can also be used to define links between different types of semantic knowledge. Therefore, ontology can be used to formulate some data search strategies.[5]

There are many ways to model knowledge ontology, which are currently summarized in two categories: One class starts from the most basic and abstract general concepts, and continuously refines the concept hierarchy to form the ontology structure of a specific domain. For example, knowledge ontology of WordNet is reused. This method can describe more detailed and comprehensive by using the conceptual hierarchy developed by predecessors. But there are many conceptual hierarchies of ontology, and it is difficult to extract information directly related to application. The other is to establish a preliminary knowledge ontology directly from the application of domain-related knowledge, and then introduce new knowledge to enrich the content of knowledge ontology. This method is more direct and easy to understand by domain engineers. It is also easy to modify and expand according to the needs.[6]

The proposal of energy Internet has broken the demarcation line between the traditional energy industry and promoted the interconnection, intercommunication and complementarity of primary and secondary energy types such as coal, oil, natural gas, heat and electricity to the greatest extent. On the user side, it supports large-scale access of various new and distributed energy sources to realize plug-and-play of power equipment. Through local autonomous absorption and wide-area peer-to-peer interconnection, we can optimize the regulation and efficient utilization of energy flow, and construct an open and flexible industrial and commercial form.[7-9] The integrated energy supply system is usually planned, designed and operated independently, and often lacks organic coordination, so the energy utilization rate is low. Therefore, building an integrated energy system for integrated planning and design of multi-energy is the only way to achieve optimal social energy efficiency and improve the utilization of energy infrastructure.[10] The planning and construction of integrated energy system will drive the development and transformation of energy industry. The whole process of related projects from investment construction to production and operation will bring remarkable benefits to national economy, energy production and utilization mode, environment and so on.[11]

Integrated energy systems are complex, including many different energy systems and equipment, equipment isomerization, standard diversification, multi-source data, modeling difficulties. Ontology solves the difficult problem of modeling in complex systems. Ontology-based modeling of integrated energy systems solves the problem of terminology and specifications differences between different systems. It is of great significance for modeling and expression of integrated energy systems and further research.

The integrated energy service system takes the power system as the core and breaks the existing mode of separate planning, separate design and independent operation of various energy systems such as power supply, gas supply, cooling and heating[10]. These concepts and entities are interrelated, supporting, operating and collaborating with each other, and are an important part of an integrated energy service system[12].
In order to describe these different types of concepts and specifications uniformly, a formal conceptual model is constructed, and a general method is used to construct the integrated energy service system model. This model constitutes the reasoning basis of the common semantics of different types of concepts and information in the integrated energy service system.

**Modeling of Integrated Energy Service System Based on Ontology**

In order to achieve better interoperability among systems of integrated energy system and unify terminology and specifications among systems, The novel modeling of integrated energy service system based on Ontology include 5 modules, which are abstraction of Important Equipment Information, classification of integrated energy equipment, description model of subsystem equipment, attribute model of subsystem equipment, ontology model of subsystem equipment.

**Abstraction of Important Equipment Information in Integrated Energy System**

Each dimension of information consists of a series of non-inferential base values, the smallest unit that can be perceived, called metadata. In a dimension, the base values are not intersecting and detailed, which ensures that the entire information space of the dimension is covered. Depending on the different dimensions, the setting of a base value can be finite or infinite, continuous or discrete. A dimension can have multiple sets of basic values, each of which is characterized by its measuring system.

We abstract the integrated energy service system into an information space that can be divided into multiple dimensions, each with its own structure and relationship parameters, which makes it distinguishable from other dimensions of information. For example, A dimension is a position that can be expressed as a coordinate consisting of three numbers with a given length unit, or as a descriptive term, such as an inflatable station or a charging pile, which represents a symbolic position in an integrated energy service system. Time is another information dimension whose information can be expressed as an instant time, time interval, or a term with relevant temporal semantics, such as Monday or evening. Other dimensions of information include demand, temperature, humidity, equipment and status.

**Classify the Equipment of Integrated Energy Service System**

Integrated energy service system integrates cold, heat, natural gas, electric energy and other energy sources, realizing coordinated planning, optimal operation and coordinated management among heterogeneous energy subsystems. Aiming at the numerous equipment in the integrated energy system, it is necessary to classify them clearly in order to describe them conveniently. Typical equipment units of integrated energy system can be divided into independent equipment units and coupling equipment units according to the types of energy and quality carried by the equipment. Independent equipment unit maintains its own unique properties, coupled equipment unit can realize the conversion between electricity, heat, gas, cold. Independent equipment units are divided into independent power equipment, independent thermal equipment and independent natural gas equipment. Power equipment includes photovoltaic DG, transmission and distribution network (lines and substations), energy storage batteries, charging piles. The thermal equipment includes heat pipe network (pipeline, water pump), gas storage tank and heat pump. Natural gas equipment includes natural gas pipeline (pipeline, transformer station), gas storage tank and filling station. Coupled equipment is divided into gas-electricity coupling equipment, electricity-gas coupling equipment, electricity-heat coupling equipment, gas-heat coupling equipment, heat-cold coupling equipment, electricity-cold coupling equipment, electricity-heat-gas coupling equipment and electricity-heat-gas-cold coupling equipment. The gas-electricity coupling equipment has natural gas micro power generation equipment and hydrogen fuel cell. The electricity-gas coupling system is an electric hydrogen production system. Electricity-heat coupling equipment includes electric heating boiler, electric heating, heat pump. The gas-heat coupling equipment is a gas heating boiler. The heat-cold coupling equipment is an absorption chiller. The electricity-cold coupling equipment includes absorption refrigerant and ice storage. The electricity-heat-gas coupling equipment is a
combined heat and power unit. The electricity-gas-heat-cold coupling equipment is cold, heat and power triple production unit.

**Build the Description Model of Subsystems in the Integrated Energy Service System**

There are many devices in the integrated energy service system. In order to achieve the collaboration of various energy systems, these devices need to achieve different functions. Moreover, devices must be able to overcome the heterogeneity between devices, enable unified management, achieve information and data sharing, and achieve interoperability and collaboration. In order to achieve the above objectives, it is necessary to describe the different types of equipment in the integrated energy service system, extract the common information and personality information of the equipment, and establish the abstract model of the equipment. Ontology, as a tool to capture knowledge in related fields, can provide a common understanding of knowledge in this field, and provide a clear definition of the relationship between these domain knowledge from different levels of formal patterns.

**Build the Attribute Model of Subsystems in the Integrated Energy Service System**

There are many manifestations of integrated energy service system, such as energy Internet, energy hub, Pan Energy Net, etc.[13-15] The system contains a large number of equipment units. To describe the differences and commonalities of different equipment, it is necessary to construct its attribute model. Physical indexes of independent power equipment include voltage, current, power, transmission and storage efficiency, charging and discharging power and efficiency, etc. The physical indicators of independent power equipment include temperature, pressure, transmission and storage efficiency; The physical indicators of independent natural gas equipment include pressure, flow, transmission and storage efficiency. The physical indicators of gas-electricity coupling equipment have electric output power, gas consumption, and gas-electric conversion efficiency; The main physical indicators of electricity-gas coupling equipment are hydrogen production - electrolysis voltage, electrolysis current, hydrogen storage capacity; The physical parameters of electricity-heat coupling equipment include power consumption, heat transmission power and electricity-heat conversion efficiency. The parameters of gas-heat coupling equipment include air consumption, heat transfer efficiency and gas-heat transfer efficiency. The physical parameters of heat-cold coupling equipment include input thermal power, output cold power and thermal coefficient. The physical parameters of electricity-cold coupling equipment include temperature, refrigeration efficiency and cold storage efficiency. The physical indexes of electricity-heat-gas coupling equipment include gas consumption, electric transmission efficiency, heat output efficiency, gas-electricity conversion efficiency and gas-heat conversion efficiency.

There are many equipment in the integrated energy service system, including many terms, norms and concepts. The concepts are linked by attributes, and then the equipment and its correlation are described in an all-round way.

**Build the Ontology Model of the Equipment in the Integrated Energy Service System**

Device ontology mainly uses ontology technology to abstract and model the types, performance parameters and functions of devices in integrated energy service system, so as to shield the heterogeneity between devices and lay a foundation for data sharing and interoperability between devices. In the integrated energy service system, the interoperability between the systems is the basis and premise for achieving a comprehensive nature. Integrated energy service system is a process or system that connects power equipment, thermal equipment, natural gas equipment and coupling equipment in integrated energy service system through independent equipment and coupling equipment.

The main body of the integrated energy service system is a variety of devices in different systems, including photovoltaic DG, transmission and distribution networks, energy storage batteries, charging piles, thermal pipe networks, heat storage tanks, heat pumps, natural gas pipe networks, gas storage tanks, gas stations, natural gas micro-combustion power generation equipment, hydrogen fuel cells, electric hydrogen production systems, electric heating boilers, heat
pumps, ice storage, network equipment and control equipment. Achieving interconnection and interoperability among these devices is a major part of achieving integrated energy services. In order to describe the basic system information, equipment performance, equipment function and control relationship of various equipment in each system clearly, we construct the ontology model of integrated energy service system equipment. The model uses OWL language to abstract the types, general attributes and functions of equipment in the integrated energy service system, and describes them in a unified way. It shields the heterogeneity between devices, facilitates the contribution and interoperability of information between devices, and lays a foundation for automatic control between devices.

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**Demonstration of Integrated Energy Service System Based on Ontology**

There are a lot of equipment in the integrated energy service system. In order to achieve the integrated energy service mode, which combines energy sales service, distributed energy service, energy saving and emission reduction service and demand response service. These devices need to achieve different functions, and between devices to overcome the heterogeneity between devices, to achieve unified management, information and data sharing, interoperability and cooperation. In order to achieve the above objectives, it is necessary to describe the different types of equipment in the integrated energy service system uniformly, extract the common information and personality information of the equipment, and establish the abstract model of the equipment. Ontology, as a tool that can capture knowledge in related fields, can provide a common understanding of knowledge in this field, and provide a clear definition of the relationship between these domain knowledge from different levels of formal patterns, which can meet our modeling needs. So we use ontology to model the equipment of integrated energy service system, that is, to construct the equipment ontology of integrated energy system, and combine different kinds and different nature of equipment together, that is, to achieve integration.

Taking an intelligent park in a certain area as an example, the modeling process is introduced in detail. The comprehensive energy system structure of the intelligent park is shown in Figure 1.

![Figure 1. Structure diagram of integrated energy system in Intelligent Park.](image)
The equipment of Intelligent park is complex, and there are many independent equipment and coupling equipment. Ontology can be used to sort out the energy system architecture of intelligent park, weaken the differences of each system, and facilitate the unified management of the park.

In order to show the relationship between the systems in detail, each part is modeled separately to display its attributes and characteristics. Independent equipment can maintain its own properties, and there is no coupling transformation and complementary utilization with other energy flows. The coupling device can achieve the conversion between electricity, heat, gas and cold. Using ontology to model each part, the attributes and differences between independent devices and coupling devices can be clearly displayed.

![Ontology model of independent equipment attribute.](image)

The independent equipment unit includes electrical equipment, thermal equipment and natural gas equipment. The power equipment mainly includes photovoltaic DG, transmission and distribution network and energy storage battery [16-17]. Independent power equipment only produces, transplants and stores electrical energy. Independent thermal equipment only transmits and stores thermal energy [18-20]. Independent natural gas equipment only produces, transplants and stores natural gas.

![Ontology model of coupling equipment attribute.](image)

Coupling equipment is an important part of the integrated energy service system. It combines various independent devices, its structure is complex, and its parameters are numerous. Through ontology modeling, the common attributes and differences between different coupling equipment units can be analyzed intuitively.
Ontology model is a typical structural framework, which has strong inherent relevance. It has unique advantages in information discovery, flexible access and information synthesis, and can express any form of information. Through ontology modeling of the integrated energy system in the intelligent park, the relationship between the systems and the attributes of the equipment can be well understood, and the original complex structure is clearer and clearer. It establishes a unified semantic platform for the integrated energy service system of the intelligent park, and lays a foundation for the coordination among the equipment.

Conclusion
Compared with traditional modeling methods, ontology, as a structured framework, is often used to organize information on the semantic web. Because of its inherent relevance, it has unique advantages in information discovery, flexible access and information synthesis. Compared with other terminology, relational database schema or other standard methods of building framework, the advantages of ontology are as follows: Firstly, ontology can express any form of information, including unstructured, semi-structured and structured data. Secondly, ontology has flexible access nodes because any specialized terms within the ontology can be traced and associated with their related concepts, and there is no fixed structure or method for interaction with the ontology. Thirdly, ontology has the ability of reasoning. By standardizing a concept in the ontology model, we can infer a related concept. Fourthly, ontology has the ability to match concepts, which means that even if we describe the same concept in different ways, we can still match the same concept through ontology. These advantages of ontology make it not only be used in semantic search, but also in other fields, and begin to use its ability of information integration to integrate heterogeneous information in related fields to achieve information sharing and reuse, which will also become the most valuable use of ontology.

The modeling of integrated energy service system based on ontology solves the problem of complex structure and poor interoperability of each part of the system, which is of great significance to the follow-up research.

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References
[1] Z. Ming, “Review and Prospects of Integrated Energy System Modeling and Benefit Evaluation,” Power System Technology, vol. 42, no. 6, pp. 1697–1706, 2018.
[2] R. Neches, “Enabling Technology for Knowledge Sharing,” Ai Mag., vol. 12, no. 3, pp. 36–56, 1991.
[3] N. F. Noy and D. L. Mcguiness, “A Guide to Creating Your First Ontology,” Stanford Univ., no. 2, p. 14, 2001.
[4] R. Studer, V. R. Benjamins, and D. Fensel, “Knowledge engineering: principles and methods,” Data Knowl. Eng., vol. 25, no. 122, pp. 161–197, 1998.
[5] K. Munir and M. S. Anjum, “The use of Ontologies for Effective Knowledge Modelling and Information Retrieval,” Applied Computing and Informatics, 2017.
[6] S. Jingge, “Ontology-based knowledge modeling for optimal adjustment of power plant’s boiler combustion system,” J. Beijing Jiaotong Univ., vol. 36, no. 6, pp. 122–127, 2012.
[7] C. Junwei, “An energy internet and energy routers,” Sci. China Press, vol. 44, no. 6, pp. 714–727, 2014.

[8] N. Bui, A. P. Castellani, P. Casari, and M. Zorzi, “The internet of energy: a web-enabled smart grid system,” IEEE Netw., vol. 26, no. 4, pp. 39–45, 2012.

[9] S. Lanzisera, A. R. Weber, A. Liao, D. Pajak, and A. K. Meier, “Communicating Power Supplies: Bringing the Internet to the Ubiquitous Energy Gateways of Electronic Devices,” IEEE Internet Things J., vol. 1, no. 2, pp. 153–160, 2014.

[10] J. Hongjie, “Research on some problems of regional integrated energy system,” Automation of Electric Power System, vol. 39, no. 7, p. 198–207, 2015.

[11] J. Hongjie, “Thought About the Integrated Energy System in China,” Electric Power Construction, vol. 36, no. 1, pp. 16–25, 2015.

[12] Y. Xiaodan, “A brief review to integrated energy system and energy internet,” Transactions of China Electrotechnical Society, vol. 31, no. 1, pp. 1–13, 2016.

[13] Z. Ming, “Generation-Grid-Load-Storage” Coordinative Optimal Operation Mode of Energy Internet and Key Technologies,” Power System Technology, vol. 40, no. 1, pp. 114–124, 2016.

[14] H. Ran, “‘Generation-grid-load-storage’ coordinative optimal operation mode of energy internet and key technologies,” Power System Technology, vol. 37, no. 6, 2017.

[15] G. Zhongxue, “Ubiquitous Energy Internet—New Energy Internet Coupling with Information and Energy,” Eng. Sci., vol. 17, no. 9, 2015.

[16] L. Dichen, “Outlook of future integrated distribution system morphology orienting to energy internet,” Power Syst. Technol., vol. 39, no. 11, pp. 3023–3034, 2015.

[17] M. Ross, R. Hidalgo, C. Abbey, and G. JoóS, “Energy storage system scheduling for an isolated microgrid,” Renew. Power Gener. Iet, vol. 5, no. 2, pp. 117–123, 2011.

[18] P. Jie, Z. Tian, S. Yuan, and N. Zhu, “Modeling the dynamic characteristics of a district heating network,” Energy, vol. 39, no. 1, pp. 126–134, 2012.

[19] M. Kuosa, K. Kontu, T. Mäkilä, M. Lampinen, and R. Lahdelma, “Static study of traditional and ring networks and the use of mass flow control in district heating applications,” Appl. Therm. Eng., vol. 54, no. 2, pp. 450–459, 2013.

[20] X. Fu, Q. Guo, H. Sun, X. Zhang, and L. Wang, “Estimation of the failure probability of an integrated energy system based on the first order reliability method,” Energy, vol. 44, no. 134, pp. 1068-1078, 2017.