Equipment Modeling Technology in Power Internet of Things

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Abstract. With the advancement of smart IoT system, equipment modeling technology that adapts to the power Internet of Things becomes more and more important. In the power grid system, various types of equipment access processes are not standardized, the collected data format is not uniform, and the data is difficult to share. There is an urgent need to build a set of equipment modeling methods suitable for the power Internet of Things. By comparing traditional equipment modeling methods, we propose the static modeling structure of equipment in the power Internet of Things, and constructs a description method of terminal equipments on the cloud platform; combined with the construction requirements of the smart IoT system, design the Cloud-side collaborative dynamic modeling technology which based on equipment online status management, resource status management, alarm management and application management. At the same time, integrated equipment management methods for static modeling and dynamic modeling are realized in combination with application cases, providing technologies basis for unified device access, unified data transmission, and open sharing of data.

Keywords: Equipment modeling; power internet of things; smart IoT system; static modeling; dynamic modeling

1. Introduction
After more than ten years of development, the State Grid Corporation of China has a certain foundation for IoT applications. However, compared with the promotion goals of ubiquitous power Internet of Things [1-3], "holographic perception, ubiquitous connection, open sharing, integration and innovation", there are still some shortcomings. It is mainly embodied in four aspects: perception depth and breadth, perception layer resource sharing, business immediacy, and standardized intelligence. Therefore, in the construction and development of the current ubiquitous power Internet of Things, it is an important topic to promote the realization of ubiquitous interconnection and in-depth perception, gather various resources to participate in system adjustment, promote coordinated interaction between source, network, and load, and improve capabilities of grid on optimization of resource allocation, security assurance, and intelligent interaction through the construction of smart Internet of Things system [4-7].

Smart IoT system mainly includes the IoT management platform, edge IoT agents and standardized access of various types of terminals, forming a “Cloud Network Edge Terminal” CNET architecture [8-10]. The IoT management platform is responsible for collecting the data of new IoT terminals, and realizing the functions of access, monitoring, and remote maintenance of edge IoT agent equipment. To make unified definition and management of power equipment terminals in the real world, the IoT
management platform abstracts them to object models by equipment type, and sends models to the edge IoT agent; at the edge IoT agent, the sensor information of terminals is checked against object models.

The IoT management platform needs to access a large number of devices of different types and different manufacturers, in order to make the management of devices standardized, intelligent, convenient, and reduce manual intervention, there is an urgent need for a set of compatible device modeling solutions to deal with the device information. Therefore, how to model the device can more efficiently complete the data collection and the forwarding and pushing of uplink and downlink data is an urgent problem to be solved at present.

Traditional equipment modeling is based on defining and extending the key business information of the equipment. Zhu Ran et al. [11] used key business information to model the equipment of charging and swap station, and proposed a modeling scheme of key equipment based on IEC 61850. It uses IEC 61850 to model the parameters of AC/DC charging piles, DC chargers, battery replacement equipment, and battery compartments. However, due to the inconsistency of equipment parameters, this modeling method is not compatible with equipments of different manufacturers, so its advancement is a long and arduous process. Yu Ying et al. [12] used a layer-by-layer definition model for device modeling based on the server's convenience for device management, and proposed a CPS-based device definition and modeling. Liu Qiankuan et al. [13] proposed a modeling scheme for secondary equipment and circuits in substations for digital design by modeling equipment objects and application attributes of equipment objects. To sum up, the traditional equipment modeling is only based on the static modeling of the equipment, it can neither be compatible with a large number of equipments of different types and different manufacturers, nor dynamically monitor and operate equipments in real time, so cannot be applied to IoT management platform.

In order to meet the actual needs in the smart IoT system, this paper statically models the device from device identification, device attributes and device actions, generating object model files. Also, based on the object model file generated by static modeling, dynamic modeling is carried out from edge IoT agents and terminal equipments to complete the dynamic operation and monitoring. In practice, based on the equipment modeling method proposed in this paper, a provincial power company successfully accessed equipments of different types and manufacturers, and successfully collected and processed equipment information in real time.

2. Equipment Modeling Design

In this paper, static modeling and dynamic modeling are both carried out for the equipment in the power Internet of Things. The static modeling refers to the logical definition of equipment on the cloud platform side to form an object model file, including equipment identifications, attributes and action definitions. Dynamic modeling is a device mirror modeling method, based on cloud-side interaction, which makes real-time monitoring and operation of state and actions of edge IoT agents and terminal devices on the cloud platform.

2.1. Static Modeling

The static modeling of the equipment focuses on the inherent properties of equipments, the related information of equipments is maintained through the object model file. The static modeling lays the foundation for the equipment modeling.

2.1.1. Equipment Identification Design. In order to achieve unified management and modeling of power Internet of Things equipment, it is necessary to design an identification management method that can be recognized in all majors such as transmission, transformation, distribution, and use. According to the provincial deployment model of the Internet of Things management platform of the State Grid Corporation, the device ID is the unique identification of the device in the mirroring model of IoT management platform, which is compiled based on basic attributes such as power major, device type, manufacturer, region, production date, and factory serial number, as shown in table 1.
Table 1. IOT system equipment identification rule table.

| 999 | 9999 | 999 | 9999999999 |
|-----|------|-----|------------|
| Business system number | Device type number | Region ID | Uniform number of equipment |

On account of the characteristics of the power Internet of Things, the unique identification of the device is given practical meanings such as the business system, the type of the device, and the region. The device ID adopts decimal integer numbers coding rule with a total length of 21 digits, of which the first three digits represent the business system number, ranging from 100 to 999, indicating that the IoT management platform supports up to 899 business systems in the northbound connection; the next four digits represent the device type number, which ranges from 1000 to 9999, and means that the same business system can access up to 8999 types of equipments; the next four digits is the area code of the equipment, the first two represent cities, such as Xi'an, Weinan, etc., the second two represent districts and counties, such as Yanta District, Xi'an and Chang’an District, Xi'an, etc., and its value ranges from 1000 to 9999. The last 10 digits represent the unified code of the equipment, which is assigned to equipments in a certain area by IoT management platform. The proposed device identification is set to a 21-digit long integer, which has a small storage footprint. It is not only convenient for transmission, and conducive to make rapid identification and business docking, with good applicability and promotion.

2.1.2. Device Attribute Design. In the power grid system, there are various types of sensors, smart meters [14], low-voltage switches, lightning detection devices and other equipment with different characteristics and data collection indicators, it is necessary to be compatible with different device types so that the data of devices connected to IoT management platform can be accurately identified. Device attribute includes all indicators used to describe its own identity and interact with external data, that is, all devices have static attributes such as manufacturer, model, and specialty, and the personalized dynamic properties of each device, such as the three-phase current [15,16] and three-phase voltage [17] of the electric meter. As shown in figure 1.

![Equipment attribute modeling diagram](image)

**Figure 1.** Equipment attribute modeling diagram.

According to the attribute identifier, name, data type, and whether it is required, the description methods of static indicators and dynamic indicators can be consistent, as shown in table 2. Attributes defined, the object notation (JSON) method can be used to assemble the application during the data transmission process [18-20]. If the data type of attribute is structure, it supports multi-level nested representation. As shown in figure 2, the two attributes of a professional electricity meter are expressed in JSON format: "daily frozen positive active energy" and "daily frozen A reverse total active energy".
Table 2. Device attribute definition

| Field Name       | Identification | Description                                                                 |
|------------------|----------------|-----------------------------------------------------------------------------|
| Attribute identifier | id             | The unique identification of the attribute is represented by a string        |
| Attribute name    | name           | The attribute name is represented by a string                               |
| required          | required       | Indicates whether the current attribute is a required attribute during device transmission, including two states: required (Y) and non-required (N) |
| type of data      | structure      | The attribute data types include:                                           |
|                   |                | String                                                                      |
|                   |                | Number                                                                      |
|                   |                | Single-precision floating point (float)                                    |
|                   |                | Double precision floating point (double)                                   |
|                   |                | Enumerated type (enumerate)                                                |
|                   |                | Array                                                                       |
|                   |                | Structure                                                                   |

```json
{
    "DFPAE": 15.5, //Daily Freeze Positive Active Energy
    "Phase-a-TEEODFRAP": {
        "dataitemId": 1000000003480007,
        "dataitemValue": 20,
        "datatime": "2021-01-01 00:00:00"
    }
}
```

Figure 2. JSON description of electricity meter properties.

2.1.3. Device Action. In order to implement equipment modeling, IoT management platform needs to define and describe the actions of the real equipment, including actively sending messages and passively receiving messages. When a power IoT device fails or becomes abnormal, it will actively send a message to the cloud, after being sensed, IoT management platform will make corresponding processing operations. Conversely, when IoT management platform or business system needs to perform operations such as parameter settings on IoT device, it needs to issue instructions to the device, meanwhile, the device needs to be able to receive and process messages. Based on JSON, the actions of sending and receiving messages of devices are statically modeled to a device shadow by IoT management platform, in an object-oriented way. The device action definition is described in table 3.

Table 3. Device action definition.

| Field Name       | Identification | Description                                                                 |
|------------------|----------------|-----------------------------------------------------------------------------|
| Action identifier | id             | The unique identification of the action, represented by a string             |
| Action name      | name           | Action name, represented by string                                          |
| Action direction | direct         | Refers to the device actively sending messages or passively receiving message input: the device actively sends a message with event, the device passively accepts messages as service |
| Action type      | type           | Refers to the type of equipment action, such as control type, parameter setting, data call test type, alarm trigger type, fault indication type, etc., which can be described and defined by string |
### Input parameters

**params**

Refers to the input parameters included in the execution of the action, which are defined in the device properties in advance, specifically the unique identification id of the device properties.

### Output parameters

**results**

Refers to the output parameters included in the execution of the action, which are defined in the device properties in advance, specifically the unique identification id of the device properties; if the action is a one-way action, this parameter is optional.

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#### 2.2. Dynamic Modeling

Dynamic modeling is realized on the basis of static modeling. Static modeling will form an object model file, and IoT management platform maintains the same object model file as the equipment. The essence of dynamic modeling is realized based on the dynamic changes of parameters in the object model file.

##### 2.2.1. Edge IoT Agent Modeling

The edge IoT agent is divided into system resource management, edge framework [21, 22], container management, APP management, network management and other modules. On the basis of static modelling, IoT management platform conducts dynamic modeling of each module, and finally forms an overall model of edge equipment. Device operation actions on cloud side include system upgrade, edge framework upgrade, container/APP upgrade, parameter configuration, etc. As shown in figure 3, when the user conducts the device action defined in advance by the edge device model of the IoT management platform, the relevant service information will be issued to the edge IoT agent through cloud-side interaction. When the side devices perform the same operation synchronously, remote dynamic modeling can be initiated in the cloud.

Conversely, when the status of the edge device changes, the event is initiated based on device action in the object model, and the edge device actively sends messages including regular network status reporting, container/APP running status reporting, resource usage status reporting, etc. IoT management platform receives the event and synchronously updates edge device model in the cloud, keeping it consistent with the real edge device, that is, realizing the dynamic modeling initiated by the edge device.

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![Figure 3. Dynamic mapping between edge IoT agents and cloud models.](image)

#### 2.2.2. Terminal Equipment Modeling

Most of the devices in the power Internet of Things are relatively low in intelligence, so their interaction with the cloud needs to be carried out through edge IoT agents. When terminal device is powered on and connected to side device, the corresponding APP in side device automatically senses the access of the terminal device and obtains its basic information (name, ESN, manufacturer, model, etc.). The APP assembles basic information of the terminal...
device's access into the specified format of the static model defined by the cloud, and executes the action reporting. The edge device reports action information to IoT management platform through MQTT, and platform verifies the action of terminal access to complete automatic modeling of the end device.

On the cloud platform, the dynamic modeling of terminal equipment will build a multi-model nesting based on one edge device and multiple end devices, to form a topology model. As shown in figure 4, the fusion terminal model is based on a structure, the smart meter model and the temperature and humidity sensor model are correlated to form a cloud topology model by nestling the smart meter ID and the temperature and humidity sensor ID. The characteristic of the topology model is that it can digitally and intuitively display the complex Internet of Things structure relationship, and improve the identification and maintainability of the equipment on the cloud platform.

![Figure 4. The final state case of cloud modeling.](image)

3. Application Examples

Relying on the State Grid Corporation’s promotion of the intelligent power Internet of Things system [23], a provincial power company has established an Internet of Things management platform as a key demonstration area. Its design scheme is based on static modeling and dynamic modeling in this paper, the platform has successfully connected edge IoT agents and terminal equipment of different professions, and collected relevant data sent to the distribution cloud master station and the use and acquisition system, as shown in figure 5.
Table 4 describes the detailed information of different types of edge devices and end devices connected to the demonstration area. It can be seen that the online rates of side devices are all above 90%. Among them, the online rate of the second converged terminal of a certain factory is the highest at 99%; the online rate of the end devices is generally good, maintaining an average of about 90%.

Table 4. Table of access side equipment and end equipment in the demonstration area.

| Equipment type                                      | Access number | APP remote upgrade quantity | Online rate |
|-----------------------------------------------------|---------------|-----------------------------|-------------|
| Edge equipment                                      |               |                             |             |
| A certain factory power distribution station area fusion terminal | 38000         | 35000                       | 97%         |
| A certain factory fusion terminal                   | 2000          | 1650                        | 99%         |
| A certain factory TTU                               | 600           | 590                         | 91%         |
| A certain factory energy controller                 | 150           | 5                           | 96%         |
| Smart meter                                         | 25000         |                             | 99%         |
| Low voltage switch                                  | 100000        |                             | 92%         |
| Temperature and humidity sensor                     | 80000         |                             | 89%         |
| Transformer noise sensor                            | 1000          |                             | 93%         |
| Flood sensor                                        | 4000          |                             | 82%         |
| Branch detection unit                               | 2000          |                             | 93%         |
| Distributed fault sensing equipment                 | 6500          |                             | 96%         |
| Open flame detector                                 | 10            |                             | 100%        |
| Smart circuit breaker                               | 2000          |                             | 87%         |

Among them, edge IoT agents include a certain factory power distribution station area fusion terminal (SCT230A), a certain factory TTU (PDZ833), a certain factory energy controller (4H23-XL01), a certain factory fusion terminal (NRZS-6811), etc. Through the action definition in static modeling and the action execution in dynamic modeling, the remote APP upgrade of the connected edge IoT agent was successfully carried out, which effectively reduced the maintenance cost of on-site
workers. The connected terminal equipment includes smart meters, low-voltage switches, air temperature and humidity sensors, transformer noise sensors, water immersion sensors, branch detection units, distributed fault sensing equipment, open flame detectors, smart circuit breakers, etc. Real-time perception and automatic access are realized through the dynamic modeling mechanism, which effectively simplify the equipment access process in the power Internet of Things.

In the field verification of the demonstration area, edge IoT agent and terminal equipment have achieved good application effects in the cloud modeling solution, which must have the following characteristics:

1) Standardization: The modeling program standardizes the interactive format of equipment access, application installation, command issuance, data collection and other processes, which is the basis for IoT management platform to share the upper-level application data;

2) Versatility: static and dynamic modeling methods are suitable for different professions and different types of equipment to dynamically build models on IoT management platform;

3) Professionalism: The modeling scheme constructs the topological model of various professional dimensions such as power transmission, substation, distribution, and electricity access in the power Internet of Things, and realizes the real-time view of the topological relationship and operating status of the equipment based on the dynamic model.

4. Conclusion
Based on the definition of device attributes and actions, IoT management platform forms a static device model builds a dynamic model through cloud-side interaction with edge and end devices, and builds a platform topology model based on geographic, professional, and model parameters. The equipment modeling program in the power Internet of Things has been verified by practical applications, with characteristics of standardization, versatility, and professionalism, which can support standardized modeling of various types of equipment in various disciplines. The establishment of a basic model for the unified access of smart IoT equipment, unified data transmission, and open sharing of data, is of great significance to the promotion of the development of the power Internet of Things.

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