Modelling of plug and play interface for energy router based on IEC61850

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Abstract. Under the background of the "Internet Plus", as the energy internet infrastructure equipment, energy router will be widely developed. The IEC61850 standard is the only universal standard in the field of power system automation which realizes the standardization of engineering operation of intelligent substation. To eliminate the lack of International unified standard for communication of energy router, this paper propose to apply IEC61850 to plug and play interface and establishes the plug and play interface information model and information transfer services. This paper provides a research approach for the establishment of energy router communication standards, and promotes the development of energy router.

1. Introduction

Renewable energy such as wind power and photovoltaic power is intermittent and unpredictable, making it hard to provide continuous and stable power support. This has become a bottleneck and inhibited the development and large-scale utilization of renewable energy. A famous American scholar Jeremy Rifkin put firstly forward the vision of Energy Internet in his book "The Third Industrial Revolution", drawing the close attention from all over the world [1]. The proposition of the Energy Internet provides an important technical solution for a more efficient utilization of renewable energy.

The research on energy routers is booming at present. One significant research is initiatedly conducted by the centre of Future Renewable Electric Energy Delivery and Management (FREEDM) funded by the National Science Foundation, USA. The view about the FREEDM is firstly proposed in Huang's paper [2]. The FREEDM envisions a new power distribution infrastructure as the backbone of the future grid, which allows smart grid components to be integrated in plug-and-play manner and enables the bidirectional flow of electricity.

However, the research on energy routers is mostly about topology and control algorithms, while few of them explore the communication protocol [3-5]. Highly integrated Energy Internet requires the function of sharing of information. To meet the requirement, a unified platform and model to achieve the interconnection of equipment and systems in the grid are adopted, which conforms to the design rule of the IEC61850 standard [6]. Since the release of the IEC61850Ed1.0 in 2004, IEC has been considering to apply IEC61850Ed2.0 in the field of smart grid. The name of IEC61850Ed2.0 is also referred to as “communications networks and systems for power utility automation” [7]. China National Grid Corporation also selects IEC61850 standard as the core of smart grid construction in 2013. IEC61850 standard has now become one of the main criteria of smart grid. Up to now, the research on the application of IEC61850 mainly focuses on the model construction, model mapping and fusion in distributed energy. However the application of IEC61850 in energy router has not yet been fully studied [8-10].
In view of the lack of communication standards and the relevant theoretical research of the application of energy router, and to meet the demand of different voltage levels in the future power network and reduce the cost of power switching devices at same time, this paper proposes a Plug-and-Play interface for energy router which is essentially a bidirectional chopper circuit. Based on the analysis of Plug and play interface functions, the logical node, data objects and logical devices of Plug-and-Play interface are established. The communication between interface and load is analysed, and an information exchange model which built based on the IEC61850 is presented. This paper provides a reference case for the research and practice of Energy Internet using IEC61850.

2. Energy router overview
The key technologies needed to construct an energy router include plug and play interface, advanced solid-state transformer technology, and the management of information flow and energy flow [11]. To demonstrate the envisioned FREEDM system, the most recent efforts are made towards the living demonstration of a future home in the FREEDM system [12], as depicted in Figure 1.

![Energy router overview](image)

**Figure 1.** Electric grid diagram showing the interface of a future home in the FREEDM system

Energy router consists of energy management unit, plug and play interface, and solid state transformer (SST). Energy management unit can send command according to the information collected from power generation equipment, storage equipment and load to the SST, plug and play interface. Energy routers interact with external access devices via plug and play interface, which is the basis for generating control variables.

3. Plug and play interface design
In the energy internet, the backbone network will still assume long-distance transmission of energy, distributed energy is not only an energy load, but also an important source of energy supply. Energy router must own the function of achieving the integration of different energy flows [13]. Therefore, the energy router must provide an intelligent plug and play interface for the load, the interface must provide energy and information channels. In the energy layer, the interface must be able to describe loads, storage devices, and generating units. The success of development of such a standard will contribute to the development of the plug and play protocol for the energy internet which similar to the USB port of a computer.

The DC source is an indispensable part for future residential application due to its good scalability. So, an analysis of the DC interface is necessary. At the energy level, the DC/DC conversion circuit is used to provide the appropriate energy for the accessible device. The circuit topology of the plug and play interface is shown in figure 2.
As shown in figure 2, when energy flows from V1 to V2, the Q1 and Q2 constitute boost chopper, and the Q1 and Q2 constitute buck chopper. When energy flows from V2 to V1, the Q2 and Q1 constitute boost chopper, and the Q2 and Q1 constitute buck chopper. According to actual needs, the value of voltage and the direction of energy transmission can be changed at any time.

In the information layer, IEC61850 is used to provide information support, and the energy conversion can be achieved by controlling the MOSFET according to the information the accessible device transfers.

4. Plug and play interface modelling
IEC61850 standard information model consists of two parts, the data model and the service model. The data model is defined by IEC61850-7-3 and IEC61850-7-4 while IEC61850-7-2 defines the abstract communication service interface of the service model. The definition of data model using server, logical device (LD), logical node (LN), Data object (DO) and data attribute (DA) tree structure to express. The information model mentioned above contains abstract communication interface as well as service model [14]. An information model will be built based on these aspects in the follow-up section of the article.

4.1 Plug and play interface logic node modeling
According to the rule of constructing the distributed energy logic node provided by IEC61850, the logic nodes are determined according to the function of plug and play interface [15]. Plug and play interface functions are classified as: ①Measurement: Power measurement(MMDC), physical quality measurement(STMP,MMET); ②Control : Operation control(DRCT, DRCS, DRCC, DOPM), switch control(XSWI), break control(XCBR); ③DC/DC converter: control and monitor converter(ZINV, ZRCT); ④protect: Over current(PTOC), over voltage(PTOV), overload(PTTR); ⑤system logical node: Physical device information (LPHD), logical node zero (LLNO). The meaning of some logical nodes is shown in table 1.

Table 1. The meaning of some logical nodes

| Logical node | Explanation |
|--------------|-------------|
| DRCT         | Describe the DER type, the electrical characteristics |
| DRCC         | Defines the control actions for one DER unit or aggregations of one type of DER device with a single controller |
| DOPM         | Set the running mode of distributed power supply, such as PQ, VF and so on. |
| ZINV         | Defines the characteristics of the inverter |
| ZRCT         | Defines the characteristics of the rectifier |
| XSWI         | Modelling switches without short circuit breaking capability |
| MMDC         | Measurement of intermediate DC |
| LLNO         | Used to address common issues for logical devices |

4.2 Plug and play interface extension of logical node
With the development of lithium ion energy storage batteries and electric vehicles, storage batteries of electric vehicles can also be used as energy storage units in the Energy Internet in the future. Based on this situation, combined with the actual application of distributed energy, data associated with DRCT is extended, and DERtyp type is added. When DRCT.DERtyp=7, the access of load is considered to be a device like energy storage batteries. The structure of the DRCT extension class is shown in table 2. The 'T' in the table represents transient D0; ‘O’ indicates that the LN defined by the DO is optional; ASG is the set point; LLN0 represents the LD public data.

| Data name | CDC  | Explanation                                                                 | T  | M/O |
|-----------|------|------------------------------------------------------------------------------|----|-----|
| LN Name   | CDC  | Shall be inherited from logical-node class (see IEC 61850-7-2)               |    |     |
| DERNum    | ING  | Number of DER units connected to controller                                 | M  |     |
| DERtyp    | ING  | Type of DER unit                                                            | M  |     |
|           |      | 0: Not applicable / Unknown                                                  |    |     |
|           |      | 1: Virtual or mixed DER                                                      |    |     |
|           |      | 2: Reciprocating engine                                                     |    |     |
|           |      | 3: Fuel cell                                                                |    |     |
|           |      | 4: Photovoltaic system                                                      |    |     |
|           |      | 5: Combined heat and power                                                  |    |     |
|           |      | 6: wind energy                                                              |    |     |
|           |      | 7: Battery Energy Storage System                                            |    |     |
|           |      | 99: Other                                                                   |    |     |
| MaxWLim   | ASG  | Nominal max output power                                                    | M  |     |
| MaxVarLim | ASG  | Nominal max output reactive power                                           | M  |     |
| StrDITms  | ING  | Nominal time delay before starting or restarting                            | M  |     |
| StopDITms | ING  | Nominal time delay before stopping                                           | M  |     |
| LodRampRte| ING  | Nominal ramp load or unload rate, power versus time                         | M  |     |

Once the logical node contained in the IED is determined, it is determined which data classes can be owned in the logical node. The logical node's data class is divided into mandatory (M/O=M) and optional (M/O=O). "M" data is mandatory, logical node class must include the mandatory data, and "O" data can be decided according to the actual function of IED. If the "M" and "O" data can't meet the actual function of IED functional requirements, we need create new data based on IEC61850's extension.

### 4.3 Plug and play interface logic device modeling

A logical device is a virtual device in an IED, and IEC61850 does not define how the LD is divided. The logical device model consists of logical nodes and additional services. A logical device contains at least 3 logical nodes, that is, the core function logic node, the physical device information (LPHD) and the logical node zero (LLNO).

As stated above, according to the function of plug and play interface, this paper divides it into 5 LD: DC converter, cell controller, measurement unit, protection unit and electrical connection point. Among them, LD1 is responsible for providing information to control unit and generate control signals; LD2 is responsible for monitoring the power system and the physical quantity; Electrical connection point act as logical device 3(LD3); LD4 is responsible for the protection function; DC/DC converter act as logical device 5(LD5).

Here is the logical node ZNotisoDCC, for example. The data object is shown in Figure 3, and the rest of the logical nodes can be referenced.
Figure 3. Data of logic node ZNotisoDCC

Figure 4. Anatomy of an IEC61850 Object Name

The function constraint (FC) defines the information characteristics of a data class, the “CF” means the data is configuration file. We can quickly find the type of data required by FC. For instance, if you want to know the output power set point of interface, to determine this you would read the object shown in Figure 4.

4.4 Plug and play interface server modeling

The hierarchical information model of IEC61850 is divided into 4 levels: server, logical device, logical node and data. Server describes all external visible action of the device. Server can encapsulate logical nodes and provide interfaces for access to the outside world. In order to achieve information interaction, three servers are designed, which are located at three access points: S1 (MMS service), G1 (GOOSE service) and M1 (sample value service). S1 access point server using client / server communication mode; G1 access point under the server using publisher / subscriber communication mode in GOOSE; M1 access point server adopt publisher / subscriber communication mode in IEC61850-9-2 sampled value transmission service. An example of a server component of plug and play is shown in Figure 5.

Figure 5. Server component of plug and play interface

Data processing mainly includes control and substitution operation, at the same time put other kinds of data object, attribute data into a data set for report, log records, GOOSE message transmission and sampling data exchange service. Take the logical device LD3 as an example, if you want to get the name of all logical nodes that it contains, the customer uses the service GetLogicDeviceDirectory (LD3) to get the logical nodes that LD3 contains from the IED. To this end, the information model and the service model of the plug and play interface have been constructed.
5. Conclusion

This paper established the IED information model and service interface which conforms to the IEC61850 standard. The utilization of IEC 61850 for energy router communication is a complex work, and much work remains to be done. In the field of distribution network communication, the existing research results and pilot projects have proved the great advantage of IEC 61850 in solving the communication problem of distribution network. So after several years of efforts, IEC 61850 will be widely applied in the distribution network! The application of IEC 61850 on energy router will also be inevitable.

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