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Routing Architecture of Software Defined Energy Internet

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Abstract. Energy Internet is a new and constantly evolving technology, of which the most critical part is how the energy flows. The concept of software customization used in the field of information will decouple the control plane from the data plane. It adopts a logical centralized control model. The control part of the device is implemented by a centralized programmable controller. Referring to the basic concept of computer network, the energy internet can be divided into energy resource subnet and energy transmission subnet. Energy micro-network, wide area energy internet and global energy internet are introduced. The concept of software-defined is applied to the field of smart grid which is the foundation and critical part of energy internet. This paper describes a software defined wide area energy internet routing architecture and implementation approach, which not only takes into account the compatibility of power devices with smart grid standards such as IEC61850 but also provides flexible software defined innovative application deployment.

1. Introduction

With the development of smart grid, new energy technology, and information technology, energy internet combines the Internet and renewable energy technology. This technology makes people produce green renewable energy at factory, office and home, and the excess energy can be shared with others, just as we share information on the Internet now. Compared with other energy forms, electric energy has instantaneous generation and supply characteristics. In the future, energy internet will take electricity as the majority of the energy form. The future of energy internet is bound to integrate power grid, energy network, information network, traffic network and other types of network, so as to achieve comprehensive utilization of various energy forms.

Energy Internet is a new and constantly evolving technology, of which the most important part is energy flow. In traditional power grids, the power generated by large power plants is sent to users through transmission, transformation and distribution. With the development of distributed power, power electronic technology and information technology, electrical energy has evolved from the original one-way flow to two-way flow. That allows energy internet access to a controllable load. Distributed power supply and distributed energy storage are integrated into the energy internet anytime and anywhere.

IEC61850 was originally designed for substation automation systems. It allows the interconnection of Intelligent Electronics Device (IED) produced by different manufacturers and provides object-oriented modelling technology and communication service support. After that, the IEC61850 standard continues being extended for smart grid applications. The goal of IEC61850 is to solve the interoperability problems between different IED in the smart grid. IEC61850 can be used in the fields of renewable energy, equipment state monitoring, intelligent power use and distribution automation.

2. Significance
Software Defined Network (SDN) puts forward a new network structure. By decoupling the control plane and the data plane of network, the control ability of the network device is concentrated to the central controller. Network control and service configuration of the network operating system can be flexible and highly automated through software driven approach. Network structure adjustment, extension and upgrading can be easier. A large number of network equipment to be configured or replaced one by one is no longer needed when there is a new service to be deployed. Besides, it brings shorter deployment time and higher efficiency

3. Related work
At present, research on energy internet is mainly focused on the overall architecture of the energy internet and the prototype implementation of energy routers based on power electronic transformation. There are few studies on the routing of energy internet.

In [1], the authors design a software-defined approach for the IoT environment to dynamically achieve differentiated quality levels to different IoT tasks in very heterogeneous wireless networking scenarios. For this, they extend the Multinetwork INformation Architecture (MINA), a reflective (self-observing and adapting via an embodied Observe-Analyze-Adapt loop) middleware with a layered IoT SDN controller.

In [2], the authors propose that energy routers are required which adjust dynamically the energy distribution in the grid, which is so called the Energy Internet in order to manage efficiently the energy supply and demand in the power grid. [2]'s work-in-progress on the design and implementation of energy router, a critical equipment to enable intelligent energy management in the smart grid.

In [3], the authors consider the objective of efficient transfer of electric energy between subsystems, where each 1 subsystem can generate, store, or consume energy. To ensure energy exchange, the interconnection of the storage and load devices is performed by using power converters.

Some key features of an energy internet compared with conventional energy grid such as openness and peer-to-peer are introduced in [4]. The definition of an energy internet call for a much greater degree of interactive flexibility for efficient energy management than the present system is designed to handle.

In [5], the authors present an architecture for a future electric power distribution system that is suitable for plug-and-play of distributed renewable energy and distributed energy storage devices.

In [6], the authors present the security, agility, robustness and survivability of a large-scale power delivery infrastructure. Similar as [6], the security and privacy issues in the Smart Grid are explored in [7], [8] discusses about integrating renewable energy sources into the smart power grid through industrial electronics

4. Architecture of energy internet
The computer network is composed of the resource subnet and the communication subnet, in which the resource subnet including end system provides resource service and the communication subnet provides the data transmission service for the end system. Referring to the basic concept of computer network, the energy internet can also be divided into energy resource subnet and energy transmission subnet. As shown in Figure 1, the smart grid is the main part of the energy Internet. Various types of energy networks at the end are fused together.

The resource subnet is composed of equipment for energy production and energy consumption. Of course, it also covers the equipment of power generation and power use in the smart grid, including the large-scale power plant station, power load, electric vehicle, energy storage devices, distributed power supply that can be directly connected to the distribution network. The energy transmission subnet is composed of transmission, distribution and substation equipment and power cable, which provides energy transmission services for power generation and electrical equipment in the energy resource subnet.

The energy micro-network is the basic unit of the energy internet. It connects the energy terminal equipment belonging to the resource subnet in a region. Generally speaking, energy micro-networks not only connect traditional loads, but also connect with elastic loads such as electric vehicles and smart appliances. At the same time, it may connect different types of distributed power generation such as photovoltaic and bio power generation, and may also connect some smart energy storage devices. Energy micro-network is an autonomous system that can realize self-control, protection and management. It can realize power balance control, system operation optimization, fault detection and protection, power quality control and so on relying on its own control and management functions. The control function of the micro-network is done by the energy micro-network interconnection equipment called energy switch. These include the realization of distributed generation control, energy storage control, off grid switching control, real-time control of micro-network, energy management of micro-network, etc.

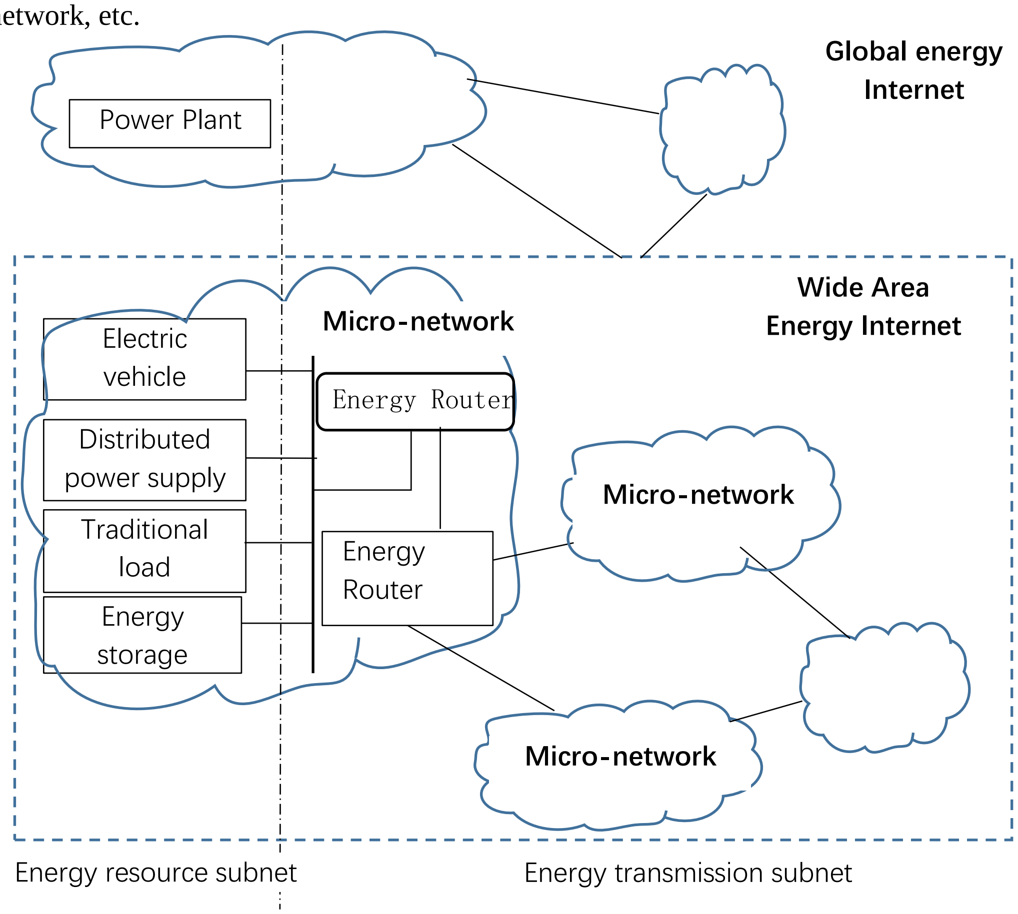

Figure 1. Energy Internet architecture.

The energy micro-network needs to connect to the main grid through the energy router which aims to ensure the efficient and safe transfer of energy. A wide range of energy network status monitoring, control, scheduling and transmission systems can ensure the energy balance between interconnected energy micro-networks. All energy micro-networks connected by energy routers form a wide area energy internet. Multiple wide area energy internet can be further connected through energy routers to form a wider range of wide area energy internet, so the wide area energy internet can also be considered as a network of networks.

The global energy internet connects and the large energy bases from the equator to the two poles. All States through intercontinental, transnational backbone and different voltage levels of the power grid (transmission network and distribution network) to meet the world's energy needs. This will achieve full utilization of renewable energy in the context of adequate and sustainable energy supply. National power grids (transmission networks and distribution networks) with different voltage levels are connected to meet the world's energy needs. In this way, the full use of renewable energy can be achieved in the context of adequate and sustainable energy supply.

5. Routing architecture

According to the overall structure of energy internet above, micro-networks are the terminals of the entire energy internet. Interconnection is carried out through internal energy switches, and the external interface is based on energy routers. The wide area energy internet is a network of networks that connect multiple micro-networks or lower levels of wide area energy internet through energy routers. For the global energy Internet, the issue of interconnection between the energy Internet managed by different management entities should be considered, but the regional energy Internet needs to consider about strategic issues.

In this paper, the method of software defined is applied to the field of smart grid as the main body of energy internet. A wide area energy internet routing architecture and implementation method based on software defined are described. This paper not only takes the compatibility between IEC61850 and other smart grid standards into account, but also provides flexible software-based innovative application deployment. The routing architecture and implementation method described in this paper can also be extended to the global energy internet. In the global energy Internet, the architecture defined by software is more likely to support policy based routing.

As shown in Figure 2, the substation automation system based on the IEC61850 standard introduces software defined switches for communication, energy routers for conversion and flow of energy flows and local controllers that control the information flow and energy flow. The control center is the brain of the entire energy internet. It detects the whole grid state by communicating with local controllers of each substation. The function of the control center is to control the flow of energy flow in the whole energy internet.

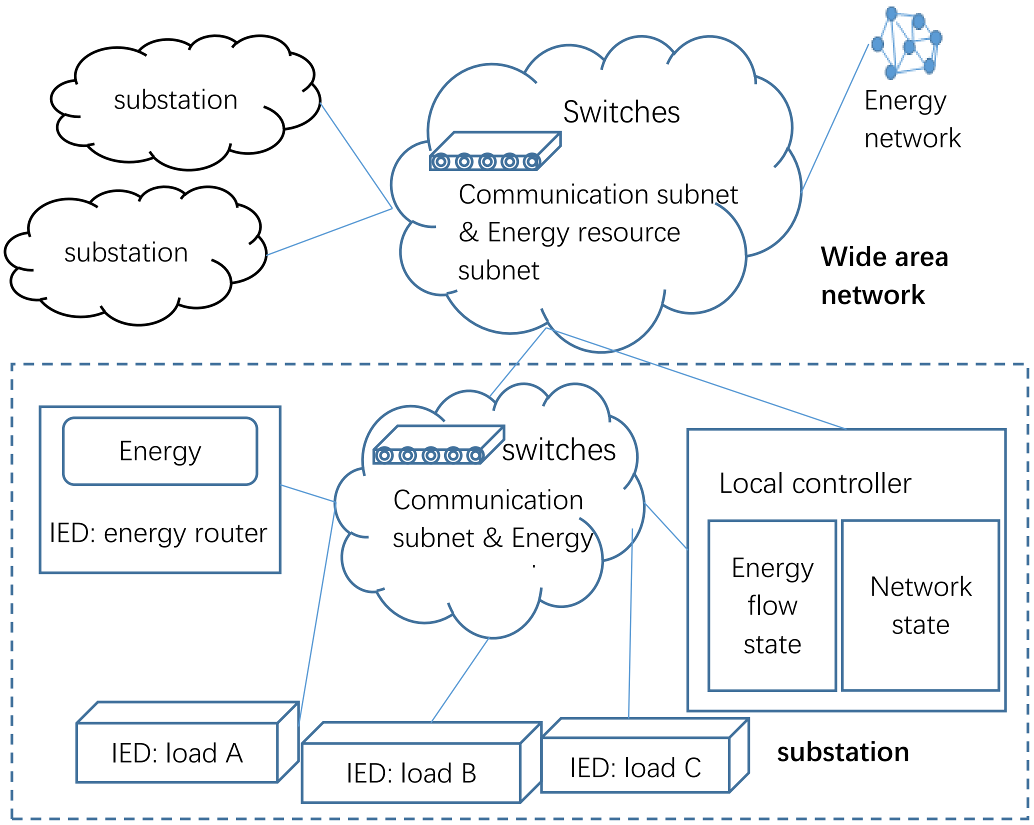

Figure 2. Software defined Energy Internet Routing Architecture.

In the substation based on IEC61850, the basic functions of information acquisition, measurement, control, protection, metering and monitoring are completed automatically through various IED devices. Substation can realize real-time automatic control, intelligent adjustment, online analysis and decision making, coordination and interaction when needed. The above functions require that IED devices exchange messages through the communication network inside the substation. The message exchange

between IED devices can take the Manufacturing Message Specification (MMS) above the point to point TCP connection and the universal object - oriented subsystem of the Ethernet multicast (Generic Object Oriented Substation Event, GOOSE) and sampling value protocol. Because these messages have different requirements of service quality, traditional Ethernet switches used to provide information exchange support for each IED device are replaced by software defined switches. The control plane of the software defined switch is stripped from the data plane. The actual control is carried out by the local controller. Software defined switches report the network topology and load by exchanging messages with local controllers. The local controller determines the switch path that these messages pass through and the scheduling and queue parameters of the switch according to the global topology information of the switch reports and the quality of service requirements for different types of 61850 messages. The local controller sends control instructions to the software defined switches.
Considering the bidirectional energy flow between different nodes in the energy Internet, energy routers are introduced. One or more energy routers are responsible for connecting various types of loads, distributed energy storage, and distributed power sources in the smart grid. At the same time, these energy routers are connected with energy routers in other substations or main distribution networks through corresponding energy networks. We divestiture the control part of the energy routers from the actual execution part. The energy router is also an IED device inside the substation. In addition to the previous control of the communication network in the substation, the local controller is also responsible for obtaining the distributed energy and load in the substation based on the IEC61850 standard from each IED device. These are sent to the energy network control center. After receiving the dispatch instruction of the energy network control center, the local controller sends corresponding control instructions to the energy router managed by IEC61850. The executive part of the energy router actually controls the flow of energy according to the instructions received. In addition to the control of the communication network in the substation, the local controller is also responsible for obtaining the information of distributed energy and load in the substation from each IED device based on the IEC61850 standard. These are sent to the energy network control center. After receiving the dispatch instruction of the energy network control center, the local controller sends corresponding control instructions to the energy router based on IEC61850. The executive part of the energy router actually controls the energy flow according to the instructions received.

6. Information flow

The information flow inside the substation is controlled by software defined switches and local controllers. The Openflow protocol in [9] is used between switches and local controllers. As shown in Figure 3, the basic operation is as follows:

6.1 The local controller reads the Substation Configuration Description (SCD) created at the substation deployment at startup. The SCD file is described by Substation Configuration Language (SCL). A part of the configuration file describes the instance configuration, communication parameters of all IED and the contact information between IED.

6.2 The software defined switch regularly sends the link layer discovery protocol (Link Layer Discovery Protocol, LLDP) messages through all of its interfaces, and forward the LLDP messages received by each interface to the local controller. In this way, the topology of all software defined switches can be obtained by local controllers.

6.3 When the IED device sends a message, the software defined switches forward the message which is the first time received to the local controller. The local controller obtains the location of the switch, the IED.

6.4 When the IEC61850 message sent by IED arrives, it will be forwarded to the local controller if the message is the first packet. There are different requirements of service quality in the transmission of IED devices between substations. Based on the previous steps 1, 2 and 3, the local controller determines the forwarding path of the load flow, the scheduling and queue parameters of the various switches on the way according to the information about the topology of the communication network, the type of the load flow and the communication configuration between the IED devices. Finally, these control instructions are sent to the software defined switches.

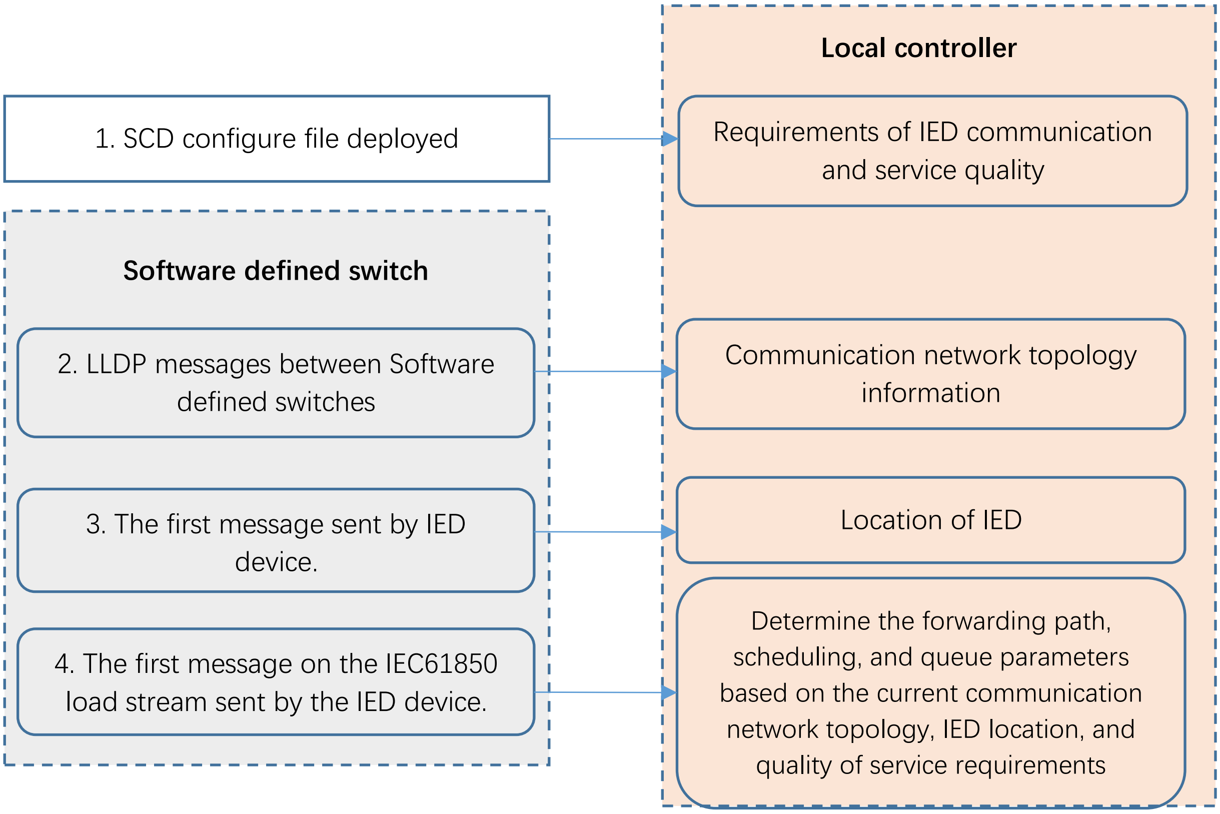

Figure 3. Information flow.

Each substation's local controller communicates with energy network control center through wide area communication network. Wide area communication network can adopt the existing technology in the power industry. Wide area network software defined switch can also be used in SDN. The local controller acts as an agent (Agent) in the wide area network as well as the controller of the software defined network inside the substation. The local controller can implement the function of the virtual switch. It summarizes the state information of the communication network in the substation and reports the state information to the energy network control center. The local controller and the wide area network software are defined as the agent. The actual routing, service quality and so on are determined by the control center of the energy network. The control instructions are given to the wide area network software defined switch and local controller, so as to ensure the service quality of the information flow transmission in the wide area network.

7. Energy flow

The energy flow is actually controlled by the information flow. The basic steps are as follows:

7.1 Firstly, the whole topology (primary system structure) of the energy network is described by SCL at deployment time. The local controller in the substation reads the SCL configuration file to obtain the topology of the energy network in the substation and the connection between the managed energy routers and other energy routers. The energy control center reads the SCL configuration files of the entire network to obtain the energy network topology of the entire network.

7.2 Each IED device, including load and energy routers, uses a IEC61850 based demand side response protocol to exchange demand and supply for energy, which are distributed through Ethernet multicast to the corresponding message group. Software defined switches in the substation forward the message of the corresponding message group to the local controller according to the configuration. In this way, the local controller's energy routing module can know the load situation inside the substation and report it to the energy network control center. The protocol used between the local controller and the energy network control center needs to be able to represent the energy flow status information, so the original Openflow protocol needs to be extended. It adds energy stream messages containing multiple attributes of the current node ID, neighbour node ID, and the link to the neighbour node, which include the transmission overhead of the link itself, the load connection on the link, and so on.

7.3 After receiving the energy flow status report from the local controller, the energy network control center gets the load of each energy router and the state of the link between the energy routers. The energy network control center obtains the energy network state information of the whole network, reads the energy network system structure obtained by the SCL configuration file, executes the energy interconnection routing algorithm, determines the scheduling information of the energy flow, and finally sends it to the local controllers of all substations.

7.4 After receiving the scheduling instructions from the energy network control center, the substation local controller sends the control instructions to the corresponding energy routers through the IEC61850 protocol, which completes the actual energy flow control

8. Routing strategy

The topology information inside the substation is automatically detected and sent to the local controller by the internal software defined switch. Knowing the topology of the internal communication network, the local controller sends instructions to the software defined switch. The information of the energy flow inside the substation is aggregated to the local controller through two ways. One way is to load the internal energy network topology configuration file of the substation when the local controller starts, and the other is to get it through the demand side response protocol.

Because of the method of software defined, the local controller can make decisions based on the internal energy flow information and the interface information using traditional control algorithms or new control algorithms. Then the control instructions are sent to the internal IED devices through the IEC61850 interface to determine the internal energy flow. The local controller can also report the internal energy flow information to the upper energy control center. Energy control center uses the appropriate control algorithm to make decision according to the global information within the scope of its jurisdiction.

The local controller, the energy control center and the higher level energy control center can not only freely distribute the energy network topology and traffic information to a higher level according to the actual situation, but also put the internal information together and publish it to a higher level. Energy Internet routing architecture based on software defined uses a logical centralized control method, which can adopt the traditional power flow calculation method used in traditional power grid or some new method of power flow calculation.

9. Conclusion

In this paper, we discuss a software defined wide area energy internet routing architecture. The implementation approach is proposed. The compatibility of power devices with smart grid standards such as IEC61850 and flexible software defined innovative application deployment are both considered. In the future, the security of software defined wide area energy internet will be further researched.

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