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A Software-Defined Networking Model for Smart Transformers with ISO/IEC/IEEE 21451 Sensors

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ABSTRACT
The IEC 61850-advanced smart transformer shows an improved performance in monitoring, controlling, and protecting the devices and equipment in smart substation. However, the heterogeneity, feasibility and network control problems have limited smart transformers in network performance. To address these issues, a software-defined networking model is proposed using ISO/IEC/IEEE 21451 networks. The IEC-61850 based network controller is designed as a new kind of intelligent electrical device (IED). The proposed data model and information model contributes to the network awareness ability and facilitates access of smart sensors from transformers to communication networks. The performance evaluation result shows an improved efficiency.

Index Terms: IEC 61850, ISO/IEC/IEEE 21451, Intelligent electrical devices (IED), Smart transformer.

I. INTRODUCTION

Smart grids improve environmental friendliness, reliability, efficiency, and safety for the traditional power grid infrastructure [1-2]. The IEC 61850-advanced smart transformer was proposed to replace the conventional transformer in substations which contribute to implementing the smart distribution system and the microgrid [3-4]. However, the current communication network in smart transformer was faced with new challenges as follows.

(1) Heterogeneity: Several different kinds of sensors are utilized in the transformer for specific functions such as the oil drain valve, Ultra High Frequency (UHF) sensors and so on. Meanwhile, large amounts of sensors are deployed utilizing various protocols. As a result, solving the heterogeneity problem attaches importance to developing the smart transformer.

(2) Network Quality of Service (QoS): The failure of the transformer affects the supply reliability of the utility electricity and may cause supply interruptions [5]. The communication between the transformer and the remote system also increases the communication complexity which demands a better network QoS.

To address the above issues, ISO/IEC/IEEE 21451 standard and software defined networking (SDN) architecture are two powerful methods. ISO/IEC/IEEE 21451-X Standards (previously known as IEEE 1451.x) is a family of standards which provides an application model to facilitate the access of transducers to a network [6]. To meet the industry’s needs and the growing demands for reliable sensing systems with higher performances, the standard allows smart transducers and sensors to join over a series of protocols such as the eXtensible Messaging and Presence Protocol (XMPP), TEDS, signal treatment, networks, Web services, RFID, and so on.

As a promising next generation network architecture, the Software defined network (SDN) separates control planes from the data plane. The programmable controller contributes to dynamically manipulation of network behaviors. Recognized as simple switches, network devices match packets against entries and look up corresponding actions [7]. The SDN provides an approach to solving QoS problems, such as bandwidth, delay, and packet loss.

In this paper, the Software Defined Smart Transformer with IEC 61850 and ISO/IEC/IEEE 21451 networks is proposed to achieve a better network QoS and address the heterogeneity problem. The limitations of the existing works are as follows: First, the current IEC 61850 based communication models sensors using Intelligent Electronic Devices (IEDs). How to access and model SDN controller to IEC 61850 network is still not solved. Second, with the software defined smart transformer, an integration model is also needed to bridge the gap between IEC 61850 and ISO/IEC/IEEE 21451 networks.

To overcome the above limitations, the data model and information model are discussed to address the new challenges. Network controllers are designed as controller IEDs to process and exchange control and monitoring data in the data model. A management information base (MIB) is designed in the information model. The remainder of the paper is organized as follows. Section II describes the preliminaries related to this paper. Section III presents the proposed system model. In section IV, the details of the proposed model are given, followed by the discussion as well as the performance evaluation in section V. Finally, we draw our conclusion and give the future work in section VI.

II. PRELIMINARIES

A. IEC 61850 and 21451 networks

In order to collect, monitor, and process electric data, a large amount of Intelligent Electronic Devices (IEDs) are equipped with the smart transformer [8]. Several kinds of sensors are deployed in transformer including the oil drain valve, bushing transducer, UHF sensor, gas, switches etc. The corresponding IEDs are built to map and model the sensors as designed in IEC 61850 [9]. The applications such as power-quality (PQ) events and condition monitoring are realized through the IEDs and the communication network. ISO/IEC/IEEE 21451 sensor network provides an application model to facilitate the access of transducers to a network [8]. Network Capable Application Processor (NCAP) and Transducer Interface Modules (TIMs) compose a 21451-based transducer node. As a processor-based network node, NCAP works as a gateway to connect TIMs and application networks. However, the previous works cannot be directly utilized in IEC 61850-advanced network deploying ISO/IEC/IEEE 21451 sensors.

B. SDN in smart grids

With the rapid development of communication technologies, SDN has attracted attention in various areas including the smart grid. Compared with the traditional network architecture, SDN separates the control plan to make the network programmable using proposed network. In the previous network, self-configuring IEDs for smart substation are developed using SDNs in [10]. SDN-enabled networks adapt *Phasor Measurement Unit* (PMU) data rates to different receiver requirements in [11]. In a wide area of communication, SDNs are applied in *Multiprotocol Label Switching* (MPLS) in power systems [7]. Based on SDN, a smart grid can efficiently build a unified communication infrastructure which addresses the heterogeneous, resource optimization, and open issues [12-13]. However, the previous works do not provide a solution for building a software defined smart transform in IEC 61850 network.

III. PROPOSED MODEL

In this paper, the software-defined networking model for the IEC 61850-advanced smart transformer is proposed using ISO/IEC/IEEE 21451 networks. To enhance the interoperability between the transformer application and the network services with an improved performance, the requirements of the SDN-based network model are given briefly. Based on the requirements, the architecture of proposed model is given afterward.

A. Basic idea

With the development of the smart transformer, control strategies and communication systems have promoted the progress of the transformer. In the utilization of the transformer, efficiency and reliability are significantly taken into consideration in designing communication networks. To extend the SDN paradigm to the smart transformer, such requirements are the consequence of the transformer features. With the wild deployment of various sensors, the smart transformer is characterized by a heterogeneous network. To meet the industry's needs and the growing demands for reliable sensing systems with higher performances, the application model is required to facilitate the access of the transducers to the network as shown in Fig.1.

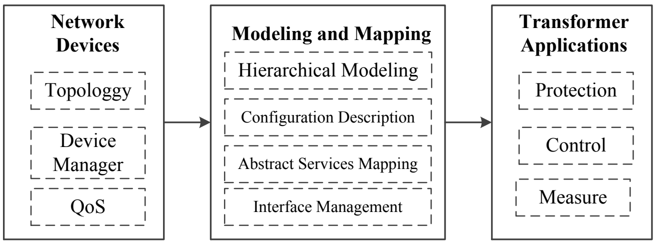

Figure 1. The basic idea of proposed model.

To build a networking model with improved programmability and flexibility, the designed network services are required to model and map based on IEC 61850 standards. The network services such as topology, device management, and QoS management are mapping to the Abstract Communication Service Interface (ACSI) in the IEC 61850-advanced smart transformer. Hierarchical modeling, configuration description, abstract service mapping, and interface management compose the critical parts in modeling and mapping network services. According to hierarchical network functions, the SDN controller is required to model based on IEC 61850. Besides, the SDN controller configures the SCD files of IEDS to implement the functions in the model. The designed network services should be mapping into ACSI services. The safety and high-efficiency of the proposed model is guaranteed in interface management to ensure the authority. What's more, protection, control and measure are achieved in the transformer application through the network services.

B. Architecture

To meet the requirements mentioned above, a software defined networking architecture for the IEC 61850-advanced smart transformer is proposed using ISO/IEC/IEEE 21451 networks as shown in Fig.2. Three parts are designed including TIM, NCAP, and the application side. The information collected by TIM is transferred to the application side through NACP. TIMs are the smart sensor nodes based on 21451 standards which run the data plane. NACPs works as the gateways implementing the control plane between TIMs and the application side. In the application side, the remote control center, engineering station, and other systems realize the control, monitoring, and protect functions throughout the network.

The dotted arrows represent the flow of control data. As the SDN-based model separate control plane from data plane and the application plane, the protocol stack of the controller and network devices are described to implement the control plane. The solid arrow shows the data flow in the proposed network model. The data is transferred through network devices according to the flow table generated by the controller. A programmable network control is enabled which helps offer a solution to various use cases in the smart grid.

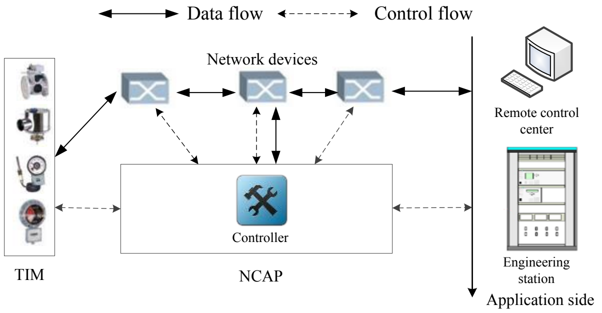

Figure 2. The architecture of the proposed model.

As designed in the proposed architecture, the SDN-based model accesses the sensors from the network using the XMPP protocol for the IEC 61850-advanced smart transformer. Based on 21451 standards, a unified communication network is built for heterogeneous sensors. In this section, details of major issues in the proposed network model are described. An integrated model is proposed for an SDN-based network with 21451 standards. Besides, the network controller is modeled as a controller IED to map and manage the network with programmability. The modeling and configuration facilitate access of the controller IED to the IEC 61850-advanced transformer. As many managed network objects are specified in the Management Information Base (MIB), the method of mapping MIB is also utilized in building the required network and information model.

IV. Details

A. XMPP based Communication

With the characteristics of instant messaging and scalability, XMPP is utilized to access the sensors from the network as designed in the 21451-1-4 and 61850-2 standard. Session initiation and protocol transport for sensors, actuators, and networked devices are provided in the ISO/IEC/IEEE 21451-1-4 XMPP Smart Transducer Interface which offers interoperability, high scalability, and security. With the development of information technologies, extending the IEC 61850 standard with XMPP) becomes a trend in solving the problem of exchanging non-time-critical data. IEC61850 8-2 has been a draft which complements the existing Part 8-1 Specific communication service mapping (SCSM) and maps SCSM to XMPP.

Signal treatment, conditioning, and data conversion is processed in TIM and TEDS are generated based on 21450 standards afterward. Data collected from sensors will be transferred to NCAP using a serial interface based on 21451-2. In NCAP, the network services like discovery and TEDS access services will process the collected data and form the basis for XMPP services. The communication between the application side and NCAP is based on client/server model using XMPP and mapping to the ACSI service. Service-oriented architecture (SOA) is utilized in the proposed model to meet the original design of the standards.

B. Data Model

The network controller is a key component in the software defined networking model. To access the IEC 61850 network, SDN controller is modeled as an IED to monitor and control network flow in station levels and process levels logically. Dynamic network policies are mapped into ACSI services in the data model.

Logical devices (LDs), logical nodes (LNs), data objects (DOs), data attributes (DAs), and data sets are the main parts in the data model. The corresponding application servers for the controller IED are deployed using a distributed method. Network functions including OpenFlow Driver, Services Abstract, and Orchestration are contained in LDs. Flow tables, links, data flows, and devices are included in LNs. Dynamic LNs provide fine-grained abstraction in networking. In DOs, network states, topology, services, and flow tables are presented by bandwidth, IP address, services level, size, and lifetime respectively. DAs are also a part in the controller IED. For example, Mps/sec is the metric for the bandwidth or throughput. Between clients and servers, the network data such as sensor data, and network logs are collected in Data Sets.

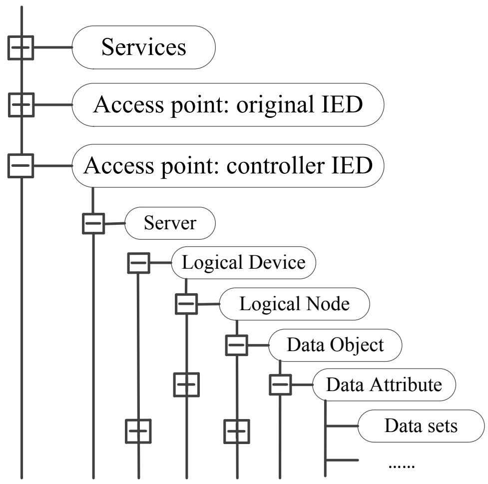

Figure 3. The architecture of the Data Model.

C. Information Model

To facilitate the access from transducers to the IEC 61850 based smart transformer, it is an efficient way to establish information model with mapped MIB. As a virtual database, MIB has specific network objects for monitoring in the network. A tree hierarchy is organized in MIB, in which organizations or functions consist nodes and managed objects consist of leaves. The hierarchy is conceptually organized as a tree.

In MIB, there are four different types of managed objects, including object type, notification type, object group, and sequence [4]. As basic data types, the object type, and notification type define single object instances and are mapped to DO in the IEC 61850 information model. With multiple related object instances in a tabular object, the sequence is mapped to an LN grouped in a table. As a complex data type, object groups are mapped to data sets with an ordered group of single objects. Considering the modeling principle, a switch can be regarded as a specific IED with a server. Based on the functionality decomposition, the LN model can be established. By mapping the MIB, the DO model can be obtained for many managed objects defined in MIB. Several data sets are established for the various communication services with enhanced access efficiency.

V. Evaluation and Discussion

In the evaluation, we select the bandwidth fluctuation performance to show the efficiency of proposed model. The requirement of bandwidth is dynamically changed in the IEC 61850 networks in the smart transducer. In the simulation experiment, we model a simple fixed network topology with one client, one server, and an end-to-end link. The current model allocates bandwidth with timing control. The proposed model with SDN model can dynamically allocate bandwidth with improved performance as shown in Fig.4. Bandwidth fluctuation is utilized to measure the volatility of occupancy rate of bandwidth. With the proposed SDN based model, networking policies of dynamic bandwidth configuration are achieved with better QoS.

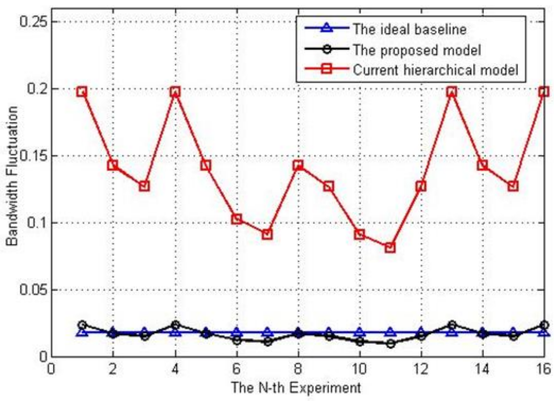

Figure 4. The performance in bandwidth fluctuation.

Deploying ISO/IEC/IEEE 21451 sensors, heterogeneity issue is solved with improved interoperability. The modeled programmable controller contributes to the dynamically manipulation of network behaviors to solve QoS problems. In the case of above simulation, the network policy is achieved through programming using modeled network controller. According to the behaviors and the real-time states of the networks, bandwidth configuration is performed in SDN controller in a distributed way. For the time-variant and continuous traffic flows, bandwidth resources allocated for each request are assigned in real time. As a result, bandwidth resource was configured for each traffic dynamically.

VI. Conclusion

In this paper, a software-defined networking model for an IEC 61850-advanced smart transformer is proposed using ISO/IEC/IEEE 21451 sensors. Network-aware abilities and access efficiency are improved with the designed data model and information model through protecting, monitoring, and measuring the network devices. The evaluation result shows an improved efficiency of the proposed software-defined smart transformer with the 21451sensors.

Acknowledgments

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