A Communication Networks and Systems in Substations (IEC 61850) Applied to Power Network Systems of Distributed Power Resources with Enhanced Web Function

IEC 61850, IEC 61400-25, Monitoring and control system, Web service, Photovoltaic power system, Smart grid

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Abstract

IEC 61850 is becoming known as a communication standard for a substation system. We developed a prototype of a communication server and tested its conformity to IEC 61850 series of the communication with a large-scale photovoltaic power system.

(1) We adopted IEC 61850 and IEC 61400-25-4 (a Web service communication standard) to transmit our equipment model data and our proprietary communication protocols.

(2) We made a Web client application for testing and conducted a conformity test to IEC 61850 over our model data and proprietary communication protocols.

(3) Test results confirmed that the communication server conforms to our model data and our proprietary communication protocols.

(4) The conformance of IEC 61850 to the operation of the solar farm was confirmed.

1. Preface

Recently, general interest in smart grids has increased due to heightened awareness of the impact of climate change by green house gases like CO_2 and the pursuit to improve power supply stability with the increase of renewable energy resources like solar power and wind power. In this situation, a smart grid system is required to operate interlinking of multiple power network systems equipment manufactured by various suppliers. Presently, each respective supplier's proprietary protocol is used for communication with another suppliers' equipment and compatibility is a major concern.

In order to maintain compatibility, the communication of monitoring and control systems with an international standard, IEC 61850[(1)-(5)] conformity (“Standard” hereafter), is receiving increased attention. Originally, this Standard was established to standardize internal communication among multivendor electric devices in a substation in order to assure compatibility among electric devices[(6)(7)]. Since the concept of the Standard is general and can be fully applicable to other fields of power network systems, it is becoming a core universal standard for smart grids.

Our Company conducted a joint research with Central Research Institute of Electric Power Industry (CRIEPI). We adopted the data model for a large scale photovoltaic power system as an energy source in the smart grid system and made a prototype for a monitoring and control system (Prototype System as follows) applied with IEC 61850. The development of the solar farm project became very active in Japan. The distributed power supply systems such as a large scale photovoltaic power systems are installed throughout a wide area, and as such, it is expected that they would communicate via the Internet. For this reason, our system development was not only simply focusing communication applied with IEC 61850 in our system, but also on manifesting communication over the Web. This communication method is stipulated in IEC 61400-25[(8)] for wind power based on IEC 61850. In addition, we prepared test communication client applications. Using these test communication client applications, the standard conformance test[(9)(10)] under IEC 61850 carried out the data model and communication protocols for the Prototype System. This paper introduces the developed Prototype System and its conformance test.

2. Application of IEC 61850 to a Large-Scale Photovoltaic Power System

The application of IEC 61850 for a large-scale photovoltaic power system was made by the following procedures.

2.1 Application Range of IEC 61850

In a large-scale photovoltaic power system, there are hierarchical communication layers between SCADA and control terminals, between control terminals and Power Conditioning Subsystem (PCS), and connecting points or measuring points. Because application possibility of the Web communications was the highest between SCADA and control terminals, we expanded IEC 61850 in reference to IEC 61400-25.

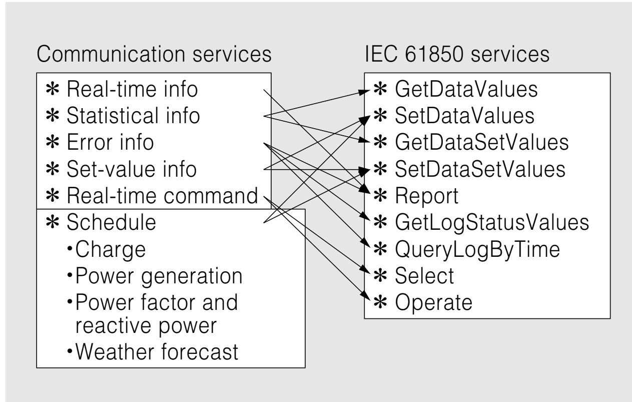

Fig. 1 Mapping to Communication Service
This compares communication services and IEC 61850 services.

2.2 Mapping to Communication Services

We extracted necessary functions for communication from the application functions of the large-scale photovoltaic power system and mapped it with a list of communication services defined in IEC 61850 as shown in Fig. 1 (including of IEC 61400-25 to apply the Web services as a communication protocol).

2.3 Mapping to the Data Model

According to the communication requirements defined in IEC 61850-7-4 and IEC 61850-7-420, we modeled information (equipment info and communication data) in the large-scale photovoltaic power system. IEC 61850-7-4 provides the data model for substation equipment while IEC 61850-7-420 provides the data model for distributed electric resources. There are some overlapping definitions for equipment under the both standards. In such a case, IEC 61850-7-420 is given priority.

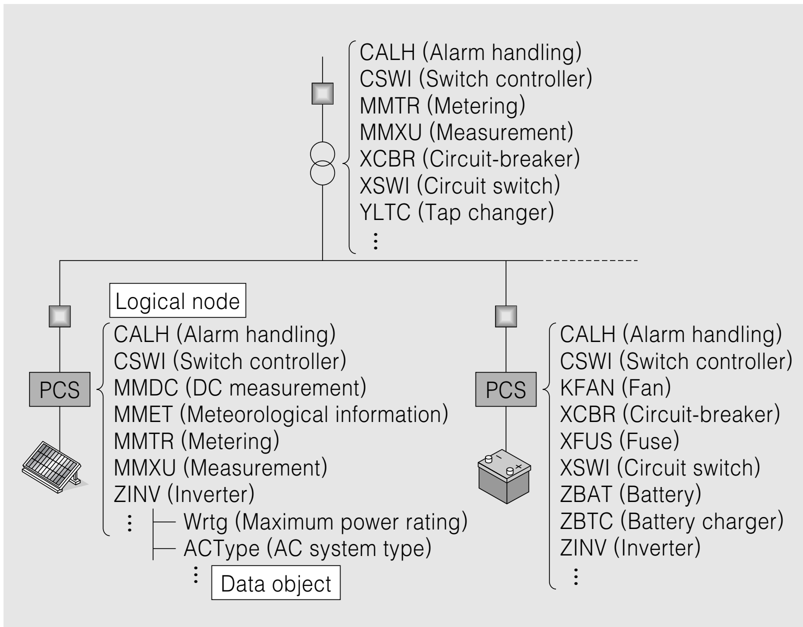

Fig. 2 Image of Logical Node Allotment for Photovoltaic Power Systems
An image shows the logical node allotment for photovoltaic power systems defined by IEC 61850.

Fig. 2 shows an image of mapping for the data model. As shown in Fig. 2, IEC 61850 defines a hierarchical data model. The data model is defined as logical node with hierarchical structure of the data object which is a component in IEC 61850. The Logical Node (LN) can be compared to a data container used by the application function. The Data Object (DO) specifies the method to provide the specific data type. (Actual values, such as measured values, are defined as the data attribute of the DO.) Table 1 shows a data allocation list for the equipment of the large-scale photovoltaic power system.

In the large-scale photovoltaic power system, the battery capacity is expressed in percentages (%) of the total capacity; but in the battery, corresponding DO which is defined as LN (ZBAT) does not exist in IEC 61850. As such, we defined three DOs as a calculable variable: internal voltage, internal current, and battery temperature. For the battery PCS, there are various control modes (for suppress fluctuation of power flow, and control mode for constant power transmission); in IEC 61850, however, no consideration is given to such modes. Therefore, following the rule on the IEC 61850 data object definitions which must be assigned to all power devices, we allotted the status variables of the modes in the DO (Loc: Local control behavior) of the LN (LLN0).

2.4 Installation of the Prototype System

Fig. 3 shows the configuration of the prototype system. The prototype system is constructed as Web service using the Common Gateway Interface (CGI) type. The gSOAP is used for the Simple Object Access Protocol (SOAP) library. This gSOAP is light weight for an engine of SOAP and can be used independent of the OS.

Since the prototype system performs Web services using the CGI type, a session is finished after a single processing of request and response between

Table 1 List of Logical Node Allotment for Photovoltaic Power Systems

This shows a list of logical nodes stipulated by IEC 61850. These nodes were allotted to the equipment of photovoltaic power systems.

	Grid connection	PV PCS	Battery PCS
CALH (Alarm handling)	○	○	○
CSWI (Switch controller)	○	○	
MMET (Meteorological information)		○	
MMDC (DC measurement)		○	
MMTR (Metering)	○	○	
MMXN (Non-phase-related measurement)	○	○	
MMXU (Measurement)	○	○	
KFAN (Fan)			○
XCBR (Circuit-breaker)	○		
XFUS (Fuse)			○
XSWI (Circuit switch)	○		○
YLTC (Tap changer)	○		
ZBAT (Battery)			○
ZBTC (Battery charger)			○
ZINV (Inverter)		○	○

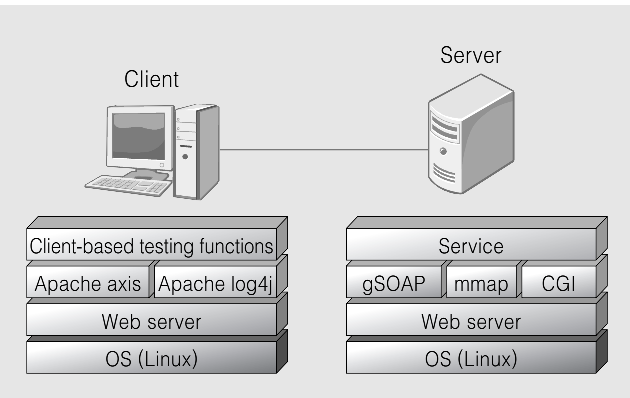

Fig. 3 Configuration of the Prototype System

This shows a configuration of hardware and software for the Prototype system.

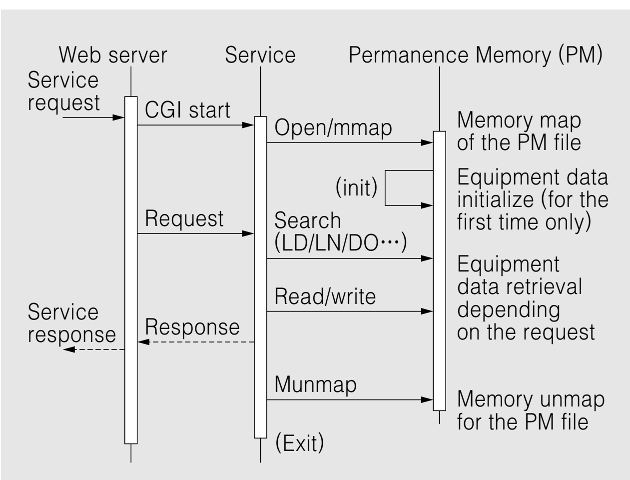

Fig. 4 Operation Flow of the Server

An operation flow diagram is shown for the SOAP server software.

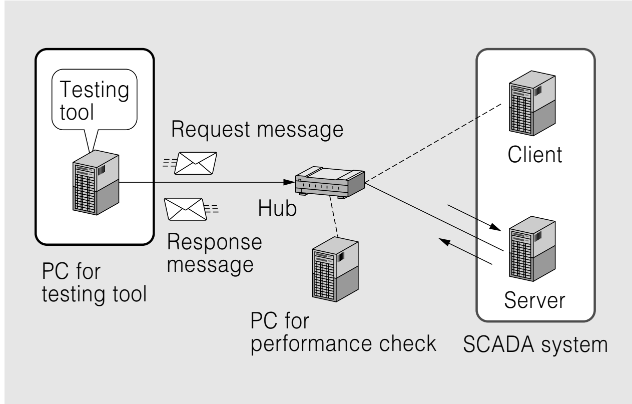

Fig. 5 Configuration of the Conformance Testing System

This shows the system configuration for IEC 61850 conformance test.

client and server, and no session information is shared between sessions. To solve this problem, files were mapped to memory space for maintaining information in the server. Fig. 4 shows the operation flow.

3. Conformance Test

For the functionality and performance of the prototype system, we designed a testing system as shown in Fig. 5 to implement the conformance test for IEC 61850.

We constructed a function test device (communication client for examinations) and a performance test device for a test system. We inspected a monitoring control function by the Web service in the function test device and measured the response time of the communication service in the performance test device. The result of testing satisfied the requirements of the standard. The contents of testing are described below.

3.1 Functional Verification

We carried out the functional verification categorized into two verification items; one is the data model verification that verifies whether the data model conforms to the LN and DO data structures defined by IEC 61850 and the other is the communication service verification to verify the servicing response resulted by the effect of normal or abnormal parameters.

(1) Data model verification

Under the prototype system, the testing subjects are about 2000 items of LN and about 12,000 items of DO (each one LN item involves 6 DO items on average.). All LN items, however, do not always hold different DO patterns, and some LN items may have shared DO patterns. Utilizing this feature, we improved the verification work in a more efficient manner by introducing verification procedures described below.

(a) All LN items held by prototype system are acquired and classified LN by the respective DO patterns.

(b) All DO items of a single LN item were acquired from the classified LN group.

(c) For each DO, conformance to the standard was confirmed.

As a result, the LN items that are the objects of verification are integrated into about 50 items. For each LN and DO, we confirmed that they were correctly allotted.

(2) Communication service verification

We verified the communication services for the survey and operation of equipment in the trial system plus the acquisition of present values. Following the verification procedures shown below, the capability of the correct exchange of request and response messages conforming to the standard was confirmed.

(a) The request messages where normal and abnormal parameters were defined were transmitted from the client to the server.

(b) The response messages from the server were checked to confirm whether they were applicable to the sent request messages.

3.2 Performance Verification

For performance verification, the equipment monitoring (Report) and operation (Operate) of the prototype system, as well as the acquisition of present values (GetDataValue), were investigated. We measured the processing time with the server when the server transmitted its message to the client (Fig. 6) and the amount of message data exchanged at that time (Fig. 7). The processing time is the average value obtained from ten measurements. The amount of message data is a value at the Transmission Control Protocol (TCP) level.

Regarding the processing time, it was confirmed that it did not exceed 200ms, which is the required processing time stipulated by IEC 61850 (Fig. 8). Regarding the transmission time, it was confirmed that the required transmission time used (Fig. 8) was kept within 100ms if a line of 256kbps or faster. In regard to the equipment monitoring (Report), however, the request parameter for that service was capable of specifying a particular data size to be included in the response message. Therefore, it is necessary to keep the transmission speed in proportion to the size of the data.

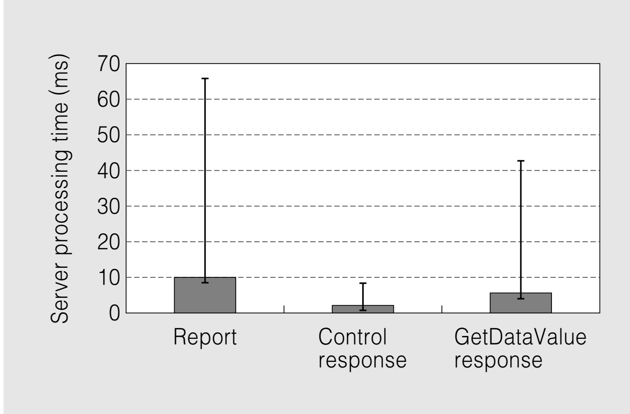

Fig. 6 Service Processing Time
This shows the server side processing time for each service IEC 61850 communication service.

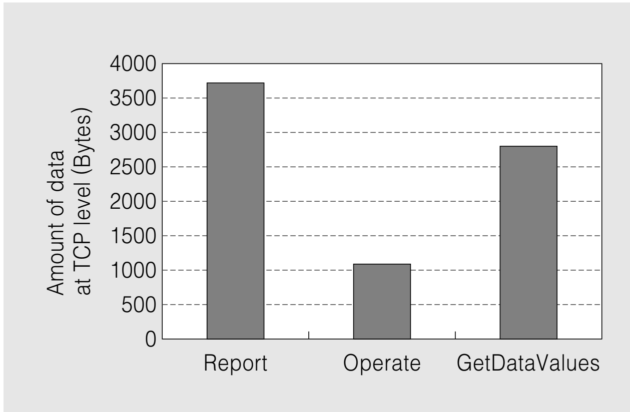

Fig. 7 Amount of Service Message Data
The amount of communication data is shown for each IEC 61850 communication service.

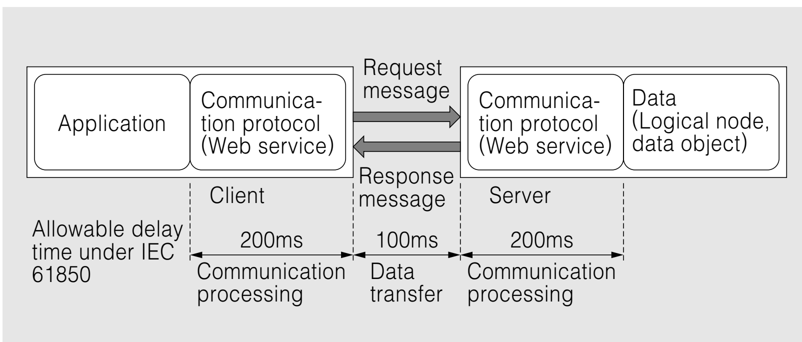

Fig. 8 Allowable Delay Time under IEC 61850
This shows the allowable delay time under IEC 61850 at each communication point.

4. Prototype System: Problems and Countermeasures in Applying IEC 61850

For application of IEC 61850 to the large-scale photovoltaic power system, there were some difficulties in understanding the implications of the standard terms. Some examples are described below:

(1) Acquisition of a value while a sub-DO is present

As described previously, DO is defined as a subject of LN in IEC 61850. In some cases, another type of DO (sub-DO) may be defined beneath the hierarchical layer of DO. In IEC 61850, there is a service of GetDataValue to acquire the DO value. In regard to this service, there is a stipulation of "Use GetDataValue to acquire the data property of the reference (designated) DO" available in IEC 61850-7-2. As a result, if the DO having a previously mentioned sub-DO is used as an object of operation for this "GetDataValue" service, it is unclear how to move forward in such a case.

For our prototype system, we realized that it is possible to acquire only the data property of DO that is an object of operation for the GetDataValue service.

5. Postscript

We developed a prototype system to evaluate the conformance to IEC 61850 for the large-scale photovoltaic power system. In this system configuration, we applied IEC 61850-7-2, 7-3, 7-4, 7-420 to the equipment data model and its communication protocols for data transmission, while we applied IEC 61400-25-4 as the Web service communication standard. For the prototype system, a conformance test was implemented based on IEC 61850-10. The test result indicates that the prototype system conforms to the standard in both the data model and its communication protocols. We confirmed that IEC 61850 is applicable to the large-scale photovoltaic power system.

It is anticipated in the industry that IEC 61850 will be applied to the field of utility grids in a variety of environmental conditions and that the standard itself will be evolved for further developments and better content. Under such circumstances, we will actively take part in various standard technical committees and meetings so that we can contribute to the solution of challenges arising at the time of application of the standard.

Note: 1. Association: A process to establish a session between client and server or a session itself

《References》

(1) IEC: "Communication networks and systems in substations-Part 7-2: Basic communication structure for substation and feeder equipment – Abstract communication service interface (ACSI)," IEC 61850-7-2 Ed.1, 2003

(2) IEC: "Communication networks and systems in substations-Part 7-3: Basic communication structure for substation and feeder equipment – Common data classes," IEC 61850-7-3 Ed.1, 2003

(3) IEC: "Communication networks and systems for power utility automation-Part 7-4: Basic communication structure – Compatible logical node classes and data object classes," IEC 61850-7-4 Ed.2, 2010

(4) IEC: "Communication networks and systems for power utility automation-Part 7-420: Basic communication structure – Distributed energy resources logical nodes," IEC 61850-7-420 Ed.1, 2009

(5) IEC: "Communication networks and systems in substations-Part 10: Conformance testing," IEC 61850-10 Ed.1, 2005

(6) Yuki Deguchi, Takayuki Koyama, Teppei Hagiyama, Hideki Kitahara: "Development of a Substation Monitoring and Control System Applying IEC 61850," The Institute of Electrical Engineers of Japan, Workshop PPR-10-41, 2010, pp.87-92

(7) Yoshihisa Sumida, Kazuto Fukusima, Shigeki Katayama, Rei Takahashia: "Application of the IEC 61850 Standard to Automated Substation Automation Systems and its Challenges," Papers for Workshop of The Institute of Electrical Engineers of Japan, PPR-10-43, 2010, pp.99-103

(8) IEC: "Wind turbines-Part 25-4: Communications for monitoring and control of wind power plants – Mapping to communication profile", IEC 61400-25-4, 2008

(9) Yasuyuki Hoshi, Takanori Hayashi, Yoshimichi Okuno, Yutaka Arai, Tetsuo Ohya, Hiroyuki Usa, Masayuki Senke, Eiji Ohba: "Application of IEC Communication Standards to Large-Scale Photovoltaic Power Plant Systems – Development of Web Service Type Systems –," Papers for 2011 Meeting of The Institute of Electrical Engineers of Japan, 6-211, 2010

(10) Hiroyuki Usa, Tetsuo Ohya, Masayuki Senke, Eiji Ohba, Yutaka Arai, Yoshimichi Okuno, Takanori Hayashi, Yasuyuki Hoshi: "Application of IEC Communication Standards to Large-Scale Photovoltaic Power Plant Systems ~ Prototype for IEC 61850 Conformance Testing Tool~," 2011 Meeting of The Institute of Electrical Engineers of Japan, 6-210, 2010