Communication Modeling for Wide-Area Relay Protection Based on IEC 61850

GuoYan Chen*, Xianggen Yin, Kai Zhang
The State Key Laboratory of Advanced Electromagnetic Engineering and Technology, Huazhong University of Science and Technology, Wuhan, 430074, China
*corresponding author, e-mail: fzu_electric@163.com*

Abstract
Wide-area communication system is supporting platform for wide-area relay protection (WARP) exchanging information, which includes not only visible physical communication equipment and links, but also communication protocols and other upper communication services. WARP communication has become an important issue in WARP practical applications, but it has not been described in IEC 61850 standard. To solve this issue, this paper firstly presents the general steps of WARP modeling according to the layer upon layer modeling methods of IEC 61850 standard, then proposes a tree structure model of master station and affiliate stations with information interaction model between master station and affiliate stations following IEC 61850 by taking a 220kV smart substation and WARP algorithm based on fault voltage distribution for example, finally establishes a communication model of WARP that includes client/server transfer model, electrical value transmission model and logical status variables transmission model. The fundamental purpose of constructing the communication model is to implement the interoperability between WARP−IED (WARP−Intelligent Electronic Devices) and other IEDs in a smart substation.

Keywords: Wide-area relay protection, IEC 61850 standard, tree-structured model, data stream interaction model, information exchange service models

1. Introduction
With enlargement of the scale of power system and development of electric power market, the setting of relay protection is increasingly complex and difficult to coordinate. Power system blackout caused by incorrect action of relay protection has occurred [1-3]. Traditional backup protection based on single-ended information has serial issues such as setting is complex, action delay is long, and may be affected by power flow transfer [4-5]. The recessive fault because of the setting of relay will increase the power grid disturbance in the risk of instability [6]. In recent years, with the optical Synchronous Digital Hierarchy (SDH) technology continuing mature and the electric power communication network constructing and improving, WARP that collects multi-point information of power grid to recognize fault components and make comprehensive decision with the help of wide-area telecommunication network gains extensive attention and research by many scholars to solve the issues of the traditional backup protection. It results in various algorithms, which can be general divided into two types: (1) based on electrical information such as current, voltage [7-9]; (2) based on logical status information such as traditional protection action and circuit breaker position [10-12].

Wide-area information of the power grid collected for WARP by aid of wide-area communication system which needs to satisfy all sorts of WARP algorithms' function requirement. Here the communication system referred not only includes physical visible communication equipment and links such as WAMS system [13-14], but also includes the upper content that network used by communication protocols, services, and so on. With the promulgation of the IEC 61850 standard and implementation, it has become the only standard in a smart substation. But until now, IEC 61850 does not relate to communication modeling for WARP, which has become an important issue to be urgently solved in practical application of WARP. There are few articles about the WARP communication modeling so far. Only reference [15] has studied the method of the logical nodes (LNs) modeling and the logical devices (LDs) modeling based on the algorithm of wide-area current differential protection following IEC...
61850, but [15] didn’t propose the method of the information exchange service modeling and the unified communication modeling for satisfying the demand of all kinds of WARP algorithms.

The wide-area communication bandwidth between substations for WARP is limited (usually 2 Mbit/s), which is far less than 100 Mbit/s Ethernet bandwidth between IEDs in substation. Therefore, we should choose proper LNs and their data, data attributes to reduce the length of communication message, and should also establish proper wide-area information service model to reduce traffic and alleviate the processing burden of WARP decision-making center. In the meantime, wide-area communication network inevitably occurs fault for it is range, long distance and numerous network nodes. Therefore, in addition to strengthen communication network redundancy and the network protection of SDH ring, we should also establish high reliability wide-area information service model.

Wide-Area Protection System (WAPS) directly relates to WARP communication modeling. At present, scholars have propose three kinds of WAPS structure [10, 16] as follows: 1) Regional master station centralized WAPS, the scope of protective object is all primary equipment of regional power grid, and decision-making center is located at master station; 2) Substation centralized WAPS, the scope of protective object is all primary equipment in substation, and decision-making center is located at each substation. 3) Distributed WAPS, the scope of protective object is single primary equipment, and decision-making center is located at each scattered IED. The above three kinds of WAPS structures have something in common that decision-making centers requires to collect correlation information from the scope of protective object so as to achieve WARP function; The only difference is the range of protective object. Therefore, the three kinds of WAPS structures modeling are almost the same: decision-making center is master station, other substations which are in protection information domain of the master station are affiliate stations.

For convenient analysis, the paper takes the regional master station centralized WAPS structure as researching object to present general procedure of WARP modeling and concrete method by combining with WARP principle. The method includes how to modeling LN model, LD model, information interaction model and communication service model. The proposed unified communication model of WARP in the paper has the characteristics of small traffic and high reliable communication.

The rest of the paper is organized as follows. The general unified modeling steps for WARP following IEC 61850 are present in section II. The process of WARP modeling is addressed in section III by taking a 220kV smart substation and the WARP algorithm based on fault component voltage distribution [8] as example. Information interaction model and communication service model are developed in section IV and section V, respectively. Conclusion is in section VI.

2. The general unified modeling steps of WARP based on IEC 61850

Local Terminal Units (LTU) and Decision-making Units (RDU) are named for WARP-IED in affiliate stations and master station, respectively.

IEC 61850 is using the object-oriented modeling technology and the layer upon layer modeling method, which mainly includes four levels: the server modeling, the LD modeling, the LN modeling and the information service modeling. Following IEC 61850, this paper gives the general modeling steps of WARP as follow:

1) The LN modeling. Choosing LNs and their data and data attribute following IEC 61850 by decomposing the function of LTU, and if there are no relevant LNs or their data or data attribute in IEC 61850 for LTU, new LNs will be created following IEC 61850.

2) The LD modeling. From the view of master station, a basic unit of affiliate station is bay, and master station often monitors and protects a bay as an object in affiliate stations. So taking bay as a unit for LD modeling, and relevant function LNs make up a LD in a bay. Several shared LNs between each bay form several LDs according to relevant function.

3) The server modeling. Server describes externally visible or addressable behavior, which has at least one access point. For communication need, WARP-IED establishes four access points, which respectively applied for communication with SV net of the process layer, GOOSE (General Object Oriented Substation Events) net of the process layer, MMS net of the station layer and wide-area communication network.
4) The information exchange service modeling. Client/server model is established for associating bilateral application and transmitting management information like maintenance, diagnosis and configuration between RDU and LTU. Data set and report model are used to abnormal warning information transmission. The SV model based on IEC 61850-9-2 standard is used to electrical information (current and voltage) transmission. The GOOSE model is used to the transmission of logical status information.

5) RDU can acquire LTUs model by two ways: Static acquisition, namely reading the IED Configuration Description (ICD). But the approach is difficult to adapt LTU model change. Dynamic acquisition. After establishing bilateral application between RDU and LTU using Configuration Description (ICD). But the approach is difficult to adapt LTU model change. LTU sends updated request to RDU When LTU’s model changed, then RDU updates LTU’s model online. This method is able to update LTU model change in real time.

3. Model Building of WARP
3.1 Smart Substation Example
Combining with a 220 kV smart substation (see Figure 1) to study the process of establishing communication model of WARP based on the IEC 61850 standard.

![Figure 1. The diagram of a 220 kV smart substation](image)

In Figure 1, the substation consists of two voltage grades E1 (220kV) and D1 (110kV), and divides into six bays, namely one transformer bay (D1T1), one busbar bay (E1Q3), four electric line bays (D1Q1, E1Q1, E1Q2, E1Q4). The primary equipment includes circuit breakers, isolating switches, CTs, PTs and a transformer. The secondary equipment includes Merging Units (MUs), Smart Terminals (STs), relay protections, measurement & control equipment, etc. Here taking the same voltage level of line 1 and 2 for example to establish communication model are used to abnormal warning information transmission. The SV model based on IEC 61850-9-2 standard is used to electrical information (current and voltage) transmission. The GOOSE model is used to the transmission of logical status information.

3.2 Logical Node Modeling and Extention for Warp
LN is the smallest unit of IED function decomposed. IEC 61850 defines about 90 LNs which cover all types of relay protection, measurement and control, other automation function in the smart substation. In general, a complete set of WARP-IED can be decomposed by function as following: current collection (TCTR), voltage collection (TVTR), measured values collection (MMUX), breaker position (XCBR), switch input and switch output (CSWI), traditional relay protections (PDIF, PDIS, PTRC), circuit breaker failure protection (RBFR), automatic reclosing (RREC), swing blocking (RPSB), fault location (RFLO), disturbance record (RDRE), fault record (IARC), man-machine interface (IHMI), equipment fault alarm (CALH), and WARP function. But IEC 61850 has not appropriate LN for WARP as it is a new relay protection. To ensure interoperability, we should extend a new LN according to its named regulations of IEC 61850. A new LN class name shall be created by use of the following conventions [17]:

"Communication Modeling for Wide-Area Relay Protection Based on IEC 61850 (GuoYan Chen)"
1) The first character shall be chosen in accordance with the relevant prefix of the LN group if applicable. The other characters shall be defined in relation to the English name of the new LN class name.

2) New LN classes shall be marked by a “name space attribute” according to the concept and rules given in IEC 61850-7-1 and to the attributes given in IEC 61850-7-3. After extending the new LN, we should add data and data attribute of the LN based on its function. When in a standardized LN, data are missing or for a new LN data are needed, the data names from IEC 61850-6 shall be used if applicable. If no standardized data fulfills the needs for a special instance of a standardized LN class, a “new” data may be created. In any case, the following rules shall be followed [17]:

1) For building the new Data name, the abbreviations of IEC 61850-4 shall be used if applicable. Only in other cases are new abbreviations out of the English name for the data allowed.

2) The data shall be assigned to any of the Common Data Classes (CDC) as defined in IEC 61850-7-3. If no standardized CDC fulfills the needs of the new data, an extended or new data class may be used.

3) Any data name shall be allocated to one Common Data Class (CDC) only.

Taking WARP based on fault voltage distribution [19] for example to introduce how to create a new LN. Wide-area fault voltage distribution protection is obviously the scope of protection. The first character should choose the protection function of LN group P, other characters selects related characters to English name of the new creating LN. So the new LN can be defined as PWAFCVD, as shown in Table 1.

Table 1. The New LN name of ‘wide area fault component voltage distribution protection’

<table>
<thead>
<tr>
<th>Items</th>
<th>First character</th>
<th>Second character</th>
<th>Third character</th>
<th>Fourth character</th>
<th>The new LN name</th>
</tr>
</thead>
<tbody>
<tr>
<td>character</td>
<td>P</td>
<td>W</td>
<td>A</td>
<td>FCVD</td>
<td>PWAFCVD</td>
</tr>
<tr>
<td>meaning</td>
<td>Protection</td>
<td>Wide</td>
<td>Area</td>
<td>Fault Component Voltage Distribution Protection</td>
<td></td>
</tr>
</tbody>
</table>

PWAFCVD has multiple LN instantiation as well as other LNs of protection. for example: E1Q1LD1PWACFVD, E1Q2LD2PWAFCVD, the first represents wide-area fault voltage distribution protection in the bay E1Q1 and LD is LD1, the second represents wide-area fault voltage distribution protection in the bay E1Q2 and LD is LD2.

After creating the new LN, We should add its data and data attribute based on the LN function. Wide-area protection algorithm based on fault voltage distribution uses measured current and voltage fault component on one end of line to estimate the value of fault voltage component on the other end, and uses the ratio of estimated value and measured value for the protection criterion. Data of PWAFVD should be extended according to the WARP algorithm because IEC 61850 has no such LN to inherit its data and data attribute for PWAFCVD. The data and attributes of PWAFCVD are shown in Table 2. The “Attr.Type” in Table 2 need not to extend because they can choose from existing CDC in IEC 61850.

Table 2. The data and attributes of PWAFCVD

<table>
<thead>
<tr>
<th>Data</th>
<th>Attr.Type</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common LN Information</td>
<td>LN shall inherit all Mandatory Data from Common Logical Node Class</td>
<td></td>
</tr>
<tr>
<td>Op</td>
<td>ACT</td>
<td>Operate</td>
</tr>
<tr>
<td>Measured Values</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VolRto</td>
<td>WYE</td>
<td>ratio of estimated value and measured value</td>
</tr>
<tr>
<td>Settings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z1Mod</td>
<td>ASG</td>
<td>Positive-sequence line impedance value</td>
</tr>
<tr>
<td>Z2Mod</td>
<td>ASG</td>
<td>Negative-sequence line impedance value</td>
</tr>
<tr>
<td>Z0Mod</td>
<td>ASG</td>
<td>Zero-sequence line impedance value</td>
</tr>
<tr>
<td>KSet</td>
<td>ASG</td>
<td>Protection action setting value</td>
</tr>
<tr>
<td>RsDITmms</td>
<td>ING</td>
<td>Reset Delay Time</td>
</tr>
</tbody>
</table>
3.3 Logical Device Modeling of WARP

LD is virtual device of IED, and is used for getting together relevant LN and data sets. One of the most important functions of LD is facilitating data access and communication. The composition of LD is usually following three methods: 1) the LNs divides into thirteen groups with similar function in IEC 61850, so each group can assemble a LD. 2) Taking bay as a unit, all LNs of a Bay assemble a LD. 3) For the convenience of communication and achieving reduced wide-area traffic, several LNs which have the same communication demand but in different bays can assemble a LD, and clustering data sets of all LNs send data through the LLN0 of LD together.

Figure 2. WARP-IED tree structure model of master station

Figure 3. WARP-IED server model

Tree structure model of RDU is shown in Figure 2. In Figure 2, The LTU server is the tree structure model of LTU. Owing to space limited, all LDs are not marked data and attribute and LLN0, LPHD of each node. The principle of the logical device LD1 and LD2 established is according to bay (LNs of LD2 is the same as LD1’s). The information of LTU sending to RDU based on fault voltage distribution protection mainly includes circuit breaker position, measured voltage vector and estimated voltage vector. They are respectively used to RDU realizing power grid network topology in a region and recognizing the fault line. And the information of RDU sending to LTU mainly includes control instruction which is used to trip the circuit breaker of the fault lines. In order to reduce communication traffic between LTU and RDU, voltage vector of each line in affiliate substation is periodically uploaded to master substation after voltage vectors of all lines are assembled into a frame. Therefore, the logical nodes MMUX of all lines in substation are composing a LD named LD3. At the meantime, for the purpose of reducing communication traffic as LD3, logical status value and circuit breaker position information of WARP are also composing a LD named LD4. The rest LNs belong to several bays shared. They are composing several LNs named LD5–LD7 based on similar function.

3.4 Server Modeling of WARP

Server describes a device externally visible or addressable behavior by setting an access point to support communication with external devices. The WARP server needs to support the communication of process level devices, substation level devices, and other substation WARP devices. Setting up access points should base on the attribute of the devices connected with the communication network. The process level network of 220kV voltage side of substation usually adopts optical fiber directly connected to transmit sample value (SV), and adopts GOOSE network to transmit relay protection tripping and circuit breaker position information. WARP server model is shown in Figure 3.
There are four access points for WARP-IED in Figure 3, which are used to support the SV transmission (access point M1), the GOOSE network (access point G1), the MMS network of substation layer (access point S1) and the wide-area communication network for WARP between substations (access point W1). The access point M1 uses IEC 61850-9-2 protocol to transmit current and voltage sample value information, and it contains LNs which are as follow: TCTR, TVTR, MMUX, etc. The access point G1 uses the GOOSE network transmission mode to transmit relay protection tripping and circuit breakers position information, and contains LNs which are as follow: GGIO, PTRC, RREC, etc. The access point S1 adopts MMS protocol to interactive monitor and management information with monitor host, and it contains LNs which are as follow: PDIF, PDIS, RREC, MMUX, etc. The access point P1 adopts IEC 61850-9-2 protocol, GOOSE protocol and MMS protocol to interactive information between LTU and RDU, such as electrical information, relaying action information, circuit breaker position information, related ACSI services, etc. The P1 contains LNs which are as follow: PDIF, PDIS, RREC, MMUX, etc.

4. Information Exchange Communication Service Modeling for WARP

4.1 Information Interaction Model between RDU and LTU

Information exchange communication service model of regional substation centralized WAPS includes: information exchange between LTU and other IEDs in substation, LTU and RDU between substations. Taking line 1 in Figure 1 for example, this paper gives information interaction model of wide-area fault voltage distribution protection, which is shown in Figure 4. Bracket of LN is its data. In order to show data flow clearly, RDU and LTU only show related LNs and LNs’ data of wide-area fault voltage distribution protection.

![Diagram](image)

Figure 4. Information interaction model of wide area protection between master station and affiliate substation in a region

Normal background flows include: 1) ACSI (Abstract Communication Service Interface) information between RDU and LTU (data flow 0_1). 2) Merge Unit periodically transmits sample value data to relaying IEDs, measurement & control IED and LTU (data flow 0_2). 3) Measurement & control IED periodically sends sample value which is just received from MU to
man-machine interface IHMI on substation layer (data flow 0_3). 4) LTU sends WARP information to RDU through wide-area electric power communication network, the information includes: measured voltage vector value, estimate voltage vector value and circuit breaker position. 5) Fault anomaly detection, if detecting WARP-IED is abnormal, LTU will send fault detection results to RDU immediately (data flow 0_5). Communication gateway following IEC 61850 in master substation or affiliate substation completes IP address conversion between the Intranet and Internet.

Assuming that line 1 had happened permanent one-phase ground fault, and main relay protection and fast backup relay protection (such as the distance 1 section) had not operated to clear the fault for some reasons. Then the process of information interaction of WARP is as follows:

1) RDU sends a WARP operation instruction to the LTU of affiliate substation 1 by the electric power communication network transmission (data flow 1, GOOSE information) when LN PWAFCVD detects line 1 has happened one-phase ground fault.

2) The LTU of affiliate substation 1 receives the WARP operation instruction. The logical node PSCH of the LTU makes comprehensive decision after coordinating traditional main relay protection, back-up relay protection, circuit breaker position and the WARP instruction from RDU. Then PTRC sends the tripping message of line 1 circuit breaker to smart terminal (GGIO) and automatic recloses (RREC) (data flow 2, GOOSE). At the meantime, LTU reports the comprehensive decision result to RDRE & RFLO of recorder equipment and monitor host (CALH) (data flow 3, report), which are respectively used for starting disturbance record and fault alarm.

3) ST receives the circuit breaker tripped instruction from PTRC, and sends a tripped command to the circuit breaker (data flow 4, GOOSE), and then the circuit breaker sends displacement information to ST When its position become “off” from “on” (data 5, GOOSE). Then ST sends displacement information of circuit breaker to traditional relay protection IED, LTU, then automatic recloses (RREC) (data flow 6, GOOSE) and reports this information to switch controller LN CSWI of measurement & control equipment (data flow 7, report). LTU needs to send the circuit breaker displacement information to RDU when receiving the information from ST (data flow 8, GOOSE). At the meantime, CSWI reports the displacement information to IHMI (data flow 9, report) for monitor host displaying.

4) When receiving the displacement information, RREC sends a reclose instruction with value to ST for reclosing the circuit breaker (data flow 10, GOOSE), and sends the report of circuit breaker reclosing (RREC.Op = 1) to IHMI (data flow 11, report).

![Figure 5. Information exchange service model of WARP](image1)

![Figure 6. The Ethernet frame format of report information](image2)
5) ST sends a reclosing message with value to XCBR (data flow 12). The circuit breaker fails to reclose because this is a permanent fault and sends a message of reclosing failure to ST (data flow 13, GOOSE). ST sends the information to RTRC, RREC and LTU (data flow 14, GOOSE) when receiving the information from the circuit breaker, and also reports the information to CSWI (data flow 15, report). Then LTU sends the reclosing failure message to RDU (data flow 16, GOOSE). At the meantime, CSWI reports this information to IHMI (data flow 17, report). That is the whole process of WARP information interaction.

From the above process information interaction model of regional master substation centralized WARP, we know that the mainly interactive information is as follows: 1) ACSI information, such as bilateral application association, maintenance, configuration, alarm. 2) Electrical information, such as measured voltage vector, estimated voltage vector. 3) Logical status information, such as circuit breaker position information, control instruction of RDU. For the above three types of interactive information, we can adopt the client/server model, the publisher/subscribe model, the bilateral or multicast application relation model, data set model and report model to implement their communication, they are shown in Figure 5.

4.2 Transmission Model of ACSI Information

The ACSI information adopts client/server transmission model following IEC 61850, and it can be mainly divided into two classes are as follows:

1) The ACSI service about information management class mainly includes as follows: bilateral or multicast application association service, reading and writing server directories, LDs, LNs, data, data sets services, reading and writing control blocks service, etc. IEC 61850-7-2 has given detailed specifications about them.

2) The ACSI service of fault detection alarm (data flow 0_5) is adopted dataset and report model. The mainly function is alarm detection of device failure, DC power disappear, communication abnormal and synchronous clock abnormal. LTU firstly establishes an instance of Buffered Report Control Block (BRCB) which can effectively prevent data loss for communication interrupt or other reasons. RDU sets RptEna field of BRCB to be TRUE by the SetBRCBValues service after finishing bilateral application association between RDU and LTU. The event monitor of BRCB constantly monitors cited data of report data set to determine whether LTU occurring internal event, such as data changes (dchg) or quality change (qchg), or data value refresh (RDUpd). Once internal events happen, BRCB triggers a report which includes report name and data values in data sets. The definition of data set is an orderly muster for data and data attribute of LN. The data set of fault alarm detection is shown in Table 3.

Selecting LN CALH for fault alarm detection whose data GrAlm of public data classes SPS can't represent a number of different alarm information, so we extend SPS by creating new attribute MultiStVal whose data type is definition of CODED ENUM, and its length is one byte. Therefore, each bit of the attribute MultiStVal can express different types of fault alarm, and from the first bit to fourth bit respectively expresses device failure, DC power loss off voltage, communication abnormal and synchronous clock abnormal. Then selecting other necessary attribute q (data quality) and t (fault alarm time) from SPS for data GrAlm.

<table>
<thead>
<tr>
<th>attribute name</th>
<th>attribute value</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>DName</td>
<td>AlmRpt</td>
<td>Data set name</td>
</tr>
<tr>
<td>DRef</td>
<td>LD6/LLN0. AlmRpt</td>
<td>Data set Reference</td>
</tr>
<tr>
<td>DMemberRef</td>
<td>LD6/ CALH.GrAlm</td>
<td>Fault alarm</td>
</tr>
</tbody>
</table>

The client/server model adopts TCP transfer protocol. Taking report message for example, Its Ethernet frame format is shown in Figure 5. Master substation distinguishes the source of report information through the source MAC address and the RptID field of the frame.
4.3 Transmission Model of Electrical Information

Wide-area communication bandwidth is limited, so LTU is not suitable to upload sample value information to RDU for samples value of single protected line is generally 5.472Mt/s. To reduce LTU uploading communication traffic and release processing burden of RDU, the paper adopts following measures: 1) LTU uploads electrical vector value to RDU. 2) The corresponding start elements will take action when primary protected equipment is fault, therefore LTU only needs to upload electrical information of protected primary equipment whose start element have been set. 3) All uploading electrical information of all primary protected equipment are assembled as a frame.

Transmission model adopts publisher/subscriber model and IEC 61850-9-2 data set mode to send current, voltage electrical vector values. For the case of LTU sending electrical information to a RUD, LTU adopts bilateral application association model TPAA (point-to-point). For another case of LTU sending electrical information to several RDUs, LTU adopts broadcast application association model MCAA (point-to-multipoint). Taking point-to-point mode for example, LTU builds a Single Transmission Control Block (USVCB). After establishing bilateral application association between RDU and LTU, RDU sets fields of USVCB (vEna, Resv, UsvID, Con|Rev, SmpRate) through the SetUSVCBValues service, and after the enable property (SwEna) of USVCB is set positive, LTU uses the SmpRate frequency to periodically sent data set of electrical value to RDU by the SendUSVMessage service. Because the period of electrical value information uploading to RDU is short (usually 5ms/packet), it can be used for detecting whether the communication between master substation and substation is abnormal real-time. Taking wide-area fault voltage distribution protection for example, its electrical value includes: measured voltage vector value and estimated voltage vector value. LTU establishes a permanent data set instance of electrical value of line 1-2 shown in Figure 1, there is shown in Table 4.

<table>
<thead>
<tr>
<th>attribute name</th>
<th>attribute value</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSName</td>
<td>AllAnalog</td>
<td>Data set name</td>
</tr>
<tr>
<td>DSRef</td>
<td>LD3/LLN0. AllAnalog</td>
<td>Data set reference</td>
</tr>
<tr>
<td>DSMemberRef</td>
<td>LD3/E1Q1LD3MMXU1.Phv</td>
<td>measured voltage vector of line1</td>
</tr>
<tr>
<td></td>
<td>LD3/E1Q1LD3MMXU1_1.Phv</td>
<td>estimated voltage vector of line2</td>
</tr>
<tr>
<td></td>
<td>LD3/E1Q2LD3MMXU2. Phv</td>
<td>measured voltage vector of line1</td>
</tr>
<tr>
<td></td>
<td>LD3/E1Q2LD3MMXU2_1. Phvestimated voltage vector of line2</td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Data set about electrical value (LD3/LLN0. AllAnalog)

Figure 7. The Ethernet frame format of electrical quantity based on IEC 61850-9-2

Three-phase and zero sequence voltage vector value is selected from the Common Data Class WYE for the data Phv, and choosing necessary data attributes cVal (phase value), q(data quality) from common data class CMW for the WYE.

_EIC 61850 (GuoYan Chen)_

**Communication Modeling for Wide-Area Relay Protection Based on IEC 61850**
The Ethernet frame format of electrical value based on IEC 61850-9-2 is shown in Figure 7. RDU distinguishes the source of electrical value information through the source MAC address field and APPID field. In Figure 6, the type of Control block ID field is string, which varies depending on system modeling. Its maximum length is 65 bytes. Adding the ASN.1 tag and length field, the total length of control block ID becomes 67 bytes. So, the length of a message frame which comprises of electrical value of all lines whose start element taking action is 44+148×n bytes, n represents the number of lines whose start element taking action. The assumption that start element of line 1 and line 2 are taking action, then n = 4. Thus, the communication traffic of electrical information reduce by 44×(n-1) bytes compared with the amount of electrical information traffic of each line separately transmission (the number of ASDU is one and the total traffic is 192×n). And the communication traffic of electrical information of all lines composed of one frame to send reduce by 0.201Mbi/s by assuming the frequency of electrical information is 200packets/s. When the number of start element action is increasing such as a busbar fault, the reduction of communication traffic will be more obvious.

4.4 Transmission Model of Logical Status Quantity

Logical status information mainly contains traditional relay protection action status, circuit breakers position, and WARP action instruction from RDU to LTU. Following IEC 61850, such type of transmission model adopts the GOOSE transmission model and publisher/subscriber mechanism. GOOSE is based on event-driven and the variable interval time of retransmission mechanism which is: when no event occurs, GOOSE message repeats transmission with a long interval time (1024ms). But when an event occurs, GOOSE message repeats transmission with relatively short interval time as 1ms, 2ms, 4ms and gradually increasing to 1024ms. So the total repeating number of a GOOSE message in a second is 11 frames.

When power grid fault happens, especially busbar fault, LTU may instantly upload many sudden GOOSE messages of traditional relay action or circuit breaker position information to RDU. It will seriously impact on network delay and jitter of other types of messages, even may block the wide-area network from LTU to RDU. Therefore, in order to reduce the sudden data flow of GOOSE message, this paper takes the following measures: All of traditional relay protection action and circuit breakers' position information are made into one frame to send to RDU. Relay protections and circuit breakers here specifically refer to the operated relaying and the position changed circuit breaker. The main function of WARP is to resolve the issues of traditional relaying that setting is complex with power grid expending and often happen the misoperation or refusing action phenomenon. The speed constraint of WARP is between the traditional longitudinal master relay (20ms) and the distance II segment (0.5s). So the requirement of speed for WARP is lenient. In order to reduce the sudden of GOOSE message, this paper modifies the GOOSE transmission mechanism which is: When an event happens, GOOSE message repeats transmission every 5ms, and LTU counts the number of frames sending. When some new events of relaying action or circuit breaker displacement occurs during the period, LTU assembles all events as a frame to send, and each event is sent 11 times.

Because the possibility of multiple fault of regional power grid is tiny at the same time, the WARP control instruction of GOOSE message has lesser communication traffic. So LTU remains adopting GOOSE transmission mechanism based on IEC 61850.

<table>
<thead>
<tr>
<th>attribute name</th>
<th>attribute value</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSName</td>
<td>LD4STATUS</td>
<td>Data set name</td>
</tr>
<tr>
<td>DSRef</td>
<td>LD4/LLN0. LD4STATUS</td>
<td>Data set reference</td>
</tr>
<tr>
<td></td>
<td>LD4/ E1Q1LD4PWAFCDV1.Op</td>
<td>PWAFCVD of Line 1 taking action</td>
</tr>
<tr>
<td></td>
<td>LD4/ E1Q1LD4XCBR1.Op</td>
<td>Breaker 1 displacement</td>
</tr>
<tr>
<td></td>
<td>LD4/ E1Q1LD4PWAFCDV2.Op</td>
<td>PWAFCVD of Line 2 taking action</td>
</tr>
<tr>
<td></td>
<td>LD4/ E1Q1LD4XCBR2.Op</td>
<td>Breaker 2 displacement</td>
</tr>
</tbody>
</table>

Table 5. Example of data set (LD4/LLN0. LD1PWAFVD)
LTU establishes a GOOSE-CONTROL-BLOCK (GoCB) for all lines in the region. After establishing multicast application association between RDU and LTU, RDU sets GoCB fields GoEna enable through the SetUSVCBValues service, and then LTU can send GOOSE message to RDU by SentGOOSEMessage service. LTU sets up a permanent GOOSE dataset instance of all lines. Table 5 shows the data set instance of PWAFcvD action and circuit breakers' position information of line 1-2 shown in Figure 1.

Necessary attributes from Common Data Class ACT is selected for Data Op, which are: fault type (general, phsA, phsB, phsC), q (data quality), t (action time).

<table>
<thead>
<tr>
<th>ocbRef</th>
<th>Time</th>
<th>Allowed</th>
<th>goID</th>
<th>stNum</th>
<th>sqNum</th>
<th>test</th>
<th>Conf</th>
<th>Rev</th>
<th>Nds</th>
<th>Com</th>
<th>numDatSetEntries</th>
<th>alldata</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 8. Packet format of APDU for logical status data

The Ethernet transmission packet format of logical status message is similar to electrical message, and the only difference is APDU which is shown in Figure 8. The each field of APDU's first row shown in Figure 7 are required by the ASN.1 encoding, so the length of each field plus 2, the "2" indicates the bytes of ANS.1 tag and length summation. The type of ocbRef, DatSet and goID fields in APDU is string, and their maximum length is 65 bytes. The k and q in Figure 7 respectively represent the number of WARP action and the number of displaced circuit breakers. So the maximum length of a GOOSE message uploading to RDU is 291+15×(k+q) bytes. Taking Table 5 for example, k=2, q=2, So LTU uploads a GOOSE message which is the maximum length of 351 bytes per frame to RDU, and the maximum communication traffic is 0.029Mbit/s. But adopting that each event separately sends to RDU, the maximum length of a GOOSE message is 306 bytes per frame, and the maximum communication traffic is 0.103Mbit/s. Thus, the proposing transmission mechanism of GOOSE message in the paper can greatly reduce traffic and the sudden of GOOSE information.

5. Conclusion

By analyzing IEC 61850 modeling method, this paper presents the general modeling steps of the WARP-IED, and proposes the unified modeling approach with the LN model, the LD model, the tree structure model, the information exchange model and the information service model of WARP. The modeling approach has the following characteristics:

1) The modeling approach has wide adaptability. The approach can be applied to various WAPS structure. This approach is also applicable to other types of WARP algorithm besides PWAFcvD algorithm. The only difference is the specific instance, and we can modify the model presented in this paper according to the specific instance based on the approach, such as extension of the LN based on the new WARP algorithm, LDs establishment for communication need like LD3, LD4 is shown in Figure 2.

2) Information service model has the characteristics of small communication traffic. All of the current and voltage electrical information in substation are assembled as one frame to upload to RDU, which can greatly reduce the wide-area communication traffic. The GOOSE transmission mechanism of IEC 61850 is not suitable for transmitting logical status information because wide-area communication bandwidth is small related to the Ethernet in substation and the traffic of GOOSE information is large and has strong sudden
characteristic. Therefore, the improved method of the GOOSE transmission mechanism proposed in this paper can greatly reduce wide-area traffic and the GOOSE sudden. The advancement of communication traffic can also reduce wide-area communication delay of information.

3) Information service model has strong transmission reliability, in particular that: A number of electrical information frames losing in transmission does not affect the WARP fault identification because electrical information is periodically uploaded to RDU for 5ms/packet and the speed of WARP is not very strict (only faster than 0.5s) because WARP is a backup protection. GOOSE message retransmits 11 frames per second, which has strong reliability. The ACSI services transmission adopts TCP protocol, and TCP is connection-oriented and ensures the reliability of the transmission.

Acknowledgments
This work was financially supported by the National Natural Science Foundation of China (50837002, 50877031).

References