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The Data Acquisition in Smart Substation of China

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1. Introduction

The construction of smart grid of China includes six segments which are power generation, transmission, transformation, distribution, utilization and dispatching, substation is one of the important parts belong to the transformation segment.. At present, the substation based on IEC61850 standard in China is called digital substation, new requirements are proposed by the construction of smart grid in China, and the combination resulted in the generation of smart substation. The smart substation is the use of advanced, reliable, integrated, low-carbon, environmentally friendly intelligent devices. Digital of all station information, network of communication platform and standardization of sharing information are the basic requirements to realize the automation of data acquisition, measurement, control, protection, metering, monitoring and other basic functions. The smart substation also supports the real-time automatic control, standardization, analytical decision-making online, collaborative interaction and other advanced functions.

The construction of secure and reliable smart substation is critical to the development of smart grid, the “Technical Guide for smart substation” is published by State Grid Corporation of China to guide the construction of smart substation in December, 2009. The data acquisition in electric power system is very important and includes a lot of areas such as substation. Smart substation is one of the key parts of smart grid and the network of process layer is an important foundation for smart substation which is related to the reliability and real-time of data acquisition and switch control. The type of message of process layer which include GOOSE (General Object-Oriented Substation Event), MSV (Multiple Sample Value) and synchronization with network will be the content of data acquisition in this chapter.

As the trend of development about the power system is along the large capacity, high voltage, extra-high voltage and the same about the device is along the small, smart and high-reliability, the electric transformer is widely used for its many advantages such as small size, light weight,

good capability of anti-electromagnetic, wide dynamic range which is not easy to saturation, simple insulation structure and easy to the transmission of digital signal, etc. The merging unit is connected with the electric transformer and is used to transmit the sample value to the Intelligent Electronic Device(IED).It is not only useful to simplify the design and reduce the cable and area of substation but also can promote the development of digital substation and provide strong support to the construction of smart grid. With the construction of smart substation, the requirements about the merging unit are increased and the urgent need to develop a new type merging unit to meet the requirements of the smart substation is generated.

In the early period of the use of the electric transformer, the merging unit is mainly based on the standard IEC60044-7/8 and IEC61850-9-1(shortened as 9-1).In the digital substation stage, the 9-1 is widely used as it is easy to achieve, but it is conflict with the concept of IEC 61850 standard and has been abolished. Subsequently, the standard IEC61850-9-2(shortened as 9-2) has become the only standard of data acquisition. As this standard is based on model and multicast services, the requirements of the performance is greatly improved and is bound to involve the re-development of the product rather than a simple upgrade. At the same time, this standard also requires that the manufacture should have a more in-depth understanding about the IEC61850 standard. The two aspects resulted in that the merging unit based on 9-2 is few.

As the planning of smart grid released by the State Grid Corporation of China in 2009, the smart substation which is one of the important nodes of smart grid present new requirements about the data acquisition, especially the publication of Technical Specifications of Protection for Smart Substation by the State Grid Corporation of China. The data acquisition of relay protection based on the 9-2 process bus is cautious in this specification and it specify that the data acquisition of relay protection should use the direct connection way which is also called peer to peer based on the standard IEC60044-8.This present the new requirements of the merging unit, not only the transfer protocol is extended, but also the number of net port which is used to transmit sampling value has been greatly increased.

As the traditional way of cable connection is canceled by the digital sampling of smart substation. The function of bus voltage parallel and switching falls on the merging unit. This promotes a higher demand about the merging unit. As the realization of bus voltage parallel and switching needs the state information of bus circuit breaker and switcher, this requires that the merging unit should get the status information. In addition, the function of data cascade is proposed by the smart substation which is used to receive the sampling value of other interval and integrated with itself. The series of new requirements call for the development of a new type of merging unit with multifunction to meet the construction of smart substation.

2. The data acquisition

2.1. The data acquisition of merging unit

The most important data acquisition in substation is the sampling of the voltage and current which is realized through the merging unit. As the new requirements about the merging unit, the sampling mode, protocol and design of the device are discussed.

2.1.1. The sampling model

The standard of IEC61850 is used to guide the construction of substation. The model is used to realize the information normative. IEC61850-9-1 is firstly used in substation but has been abolished by the IEC because it does not fit the requirement of model of the IEC61850 standard, but in the early period of the application of the IEC61850, this way is easy to realize.

As the IEC61850-9-2 has been used, the model about the data acquisition is applied in the substation. Fig.1 is the data model of data acquisition device which called merging unit. In the device, there are a LPHD(Logical Physical Device), a LLN0(Logical Node 0) and some other voltage logical node TVTR and current logical node TCTR. In theory, the number of TVTR and TCTR logical is not limited and can add for real demand but this is not convenient in the project, so the IEC publish the IEC61850-9-2LE which is used to guide the application of IEC61850-9-2 to give some guide in the project. The obvious character is that the voltage and current logical node TVTR and TCTR is fixed which are both four as the fig.1. This model is based on IEC61850-9-2 which can realize the share of the data acquisition.

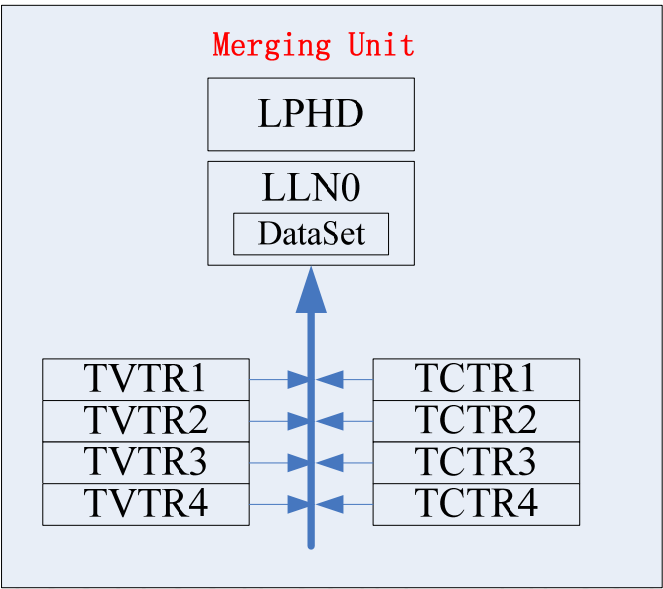


Figure 1. The structure of data model of merging unit

As the relay protect device in the smart substation of China is prudent to the sampling data getting from the network, the several segments of the communication add the risk to the relay protect device, so the new type model which called the extended IEC60044-8 standard is published by the state grid corporation of China to meet the sampling requirements of the relay protect device.

The extended IEC60044-8 standard still use the model of IEC61850-9-2, but add some new data attributes. In logical node LLN0, the logical device name(LDName) and nominal delay(DealyTRtg) is extended which used to meet the relay protect device and this way is called point-to-point.

The difference of configuration between 9-2 and IEC60044-8 is the configuration of dataset. The dataset in 9-2 not only includes the voltage and current , but also has the nominal time delay(DealyTRtg).In IEC60044-8 extend protocol, the header of packet include the nominal time delay(DealyTRtg) ,so it do not have to define it in the dataset. But the data attribute that logical device name(LDName) should be configured according the needs of project. So, the attribute LDName is expanded in the LLN0 to meet the actual demand and the value is 16-bit unsigned integer according to IEC60044-8.

The dataset of 9-2	The dataset of IEC60044-8
LLN0.DelayTRtg.instMag.i	None
TCTR1.Amp[MX].instMag.i	TCTR1.Amp[MX].instMag.i
TCTR2.Amp[MX].instMag.i	TCTR2.Amp[MX].instMag.i
TCTR3.Amp[MX].instMag.i	TCTR3.Amp[MX].instMag.i
TCTR4.Amp[MX].instMag.i	TCTR4.Amp[MX].instMag.i
TVTR1.Vol[MX].instMag.i	TVTR1.Vol[MX].instMag.i
TVTR2.Vol[MX].instMag.i	TVTR2.Vol[MX].instMag.i
TVTR3.Vol[MX].instMag.i	TVTR3.Vol[MX].instMag.i
TVTR4.Vol[MX].instMag.i	TVTR4.Vol[MX].instMag.i

Table 1. The dataset of merging unit

When the 9-2 sampling data transferred with the network, the dataset contains only voltage and current, But when the 9-2 sampling data transferred with the point to point way, it need contain the nominal time delay as this way does not have the time synchronization. So, the nominal time delay is extended in the logical node LLN0 and as the first data attribute in the dataset, as showed in table.1. The two ways of sampling data transmission are depend on the different chip, in network way, the packet is send by the MPC, but in the point-to-point way, the packet is send by the MCF. The data type of nominal time delay is SAV which meant that the type of DelayTRtg.instMag.i is 32-bit.But the same data transferred with IEC60044-8 is just 16-bit, so the device need use the low-rated 16-bit of the value of DelayTRtg.

Although the configuration of model is not real used while use the IEC60044-8 protocol to transfer sampling data to relay protection device through the point to point way, as it does not has the sample control block, but we can get the order of the sampling data through the model.

2.1.2. The transfer protocol

2.1.2.1. IEC61850-9-2

IEC61850-9-2 is the only protocol used in substation to realize the sampling data transfer. The table 2 is the control block which is part of the message.

The MsvCB is used to realized the sampling message control. But the message is as fig.2.

Element Name	MMS Type
MsvCBNam	ObjectName
MsvCBRef	ObjectReference
SvEna	Boolean
MsvID	Visible-string
DataSet	Object-Reference
ConfRev	Interger
SmpRate	Interger
OptFlds	
refresh-time	Boolean
sample-synchronized	Boolean
sample-rate	Boolean
Sample[1.....n]	Struct

Table 2. The structure of MsvCB

1. The header MAC

The destination address is defined in the standard of IEC61850-9-2 which is ranged from 01-0C-CD-04-00-00 to 01-0C-CD-04-01-FF.

The source address is the MAC of the sending device.

2. Priority tagged

TPID (Tag Protocol Identifier) Field: Indicates the Ethernet Type assigned for 802.1Q Ethernet encoded frames. This value should be 0x8100.

TCI (Tag Control Information) Fields:

User Priority: BS3; User priority value shall be set by configuration to separate sampled values from low priority busload. If the priority is not configured then the default values of Table 7 shall be used.

CFI (Canonical Format Indicator): BS1 [0]; A single bit flag value. For this standard the CGI bit value shall be reset(value = 0).

VID: Virtual LAN support is optional. If this mechanism will be used, the VLAN Identifier (VID) shall be set by configuration, if it is not used, it shall be set to zero (0).

3. Ethernet-PDU

Ethernet Type: In this standard, the sampling type is defined 0x88BA.

APPID: application identifier. The APPID is used to select ISO/IEC 8802-3 frames containing sampled value messages and to distinguish the application association. The value of APPID is the combination of the APPID type, defined as the two most significant bits of the value (as defined in Table 8), and the actual ID. The reserved value range for sampled values is 0x4000 to 0x7FFF. If no APPID is configured, the default value shall be 0x4000. The default

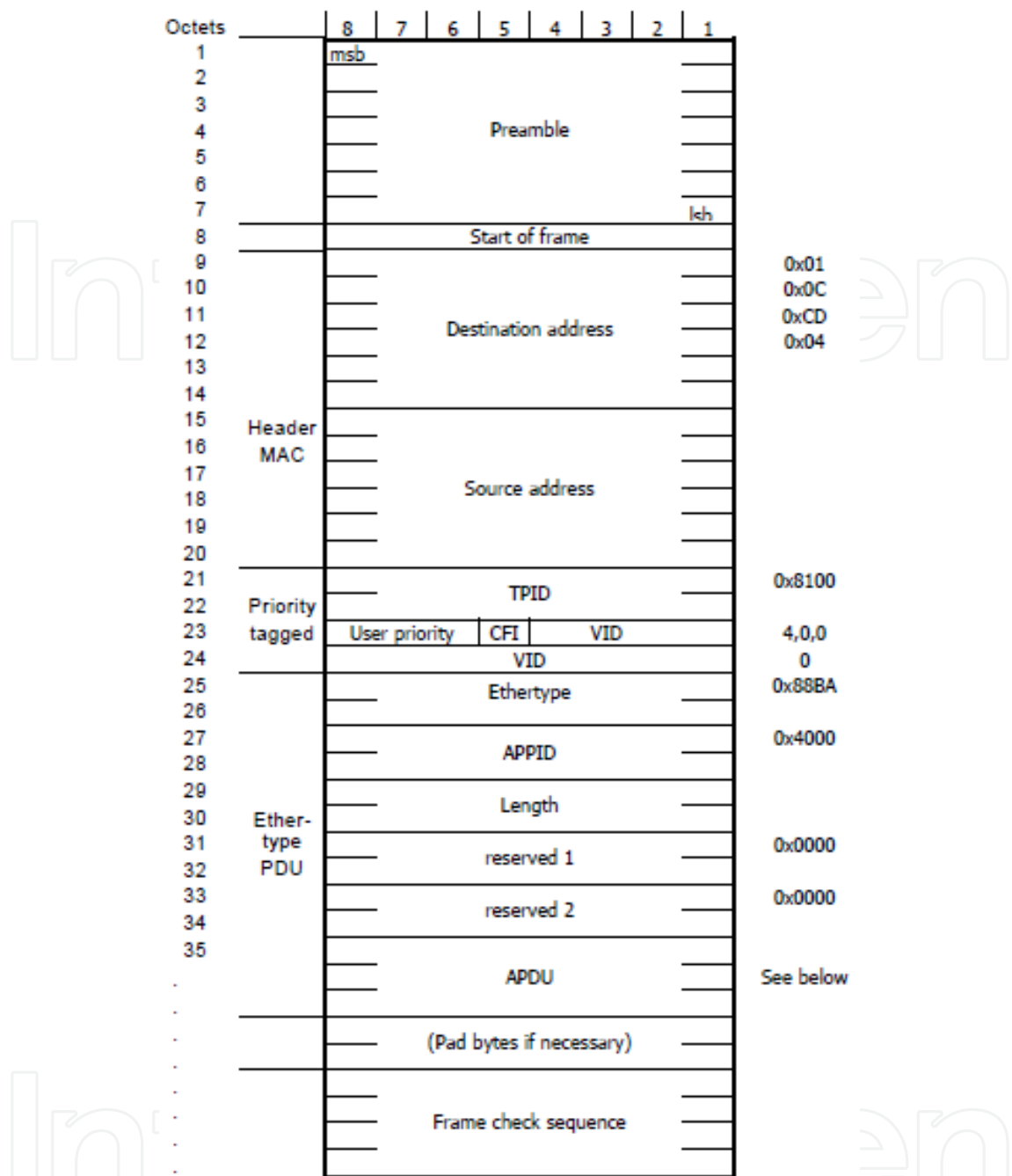


Figure 2. ISO/IEC 8802-3 frame format

Octets		8	7	6	5	4	3	2	1
0	TPID	0 × 8100 (as per 802.1Q)							
1									
2	TCI	User priority			CFI	VID			
3		VID							

Figure 3. The structure of tag header

Reserved 1 and Reserved 2: This is used to extend in future, and now the value are 0x0000;

APDU: The structure is as fig.4, it can contain several ASDU.

As in fig.5, the APDU contain eight ASDU and the structure of every ASDU is the same. Every value will be coded with ASN.1 which is TLV type(Tag+Length+value).

In the figure above, the sample data is contained in the DataSet, the value can be struct or single. In Table 2-1, the model of sampling is only single value, the quality and time of the data can be send with the data. In real project, the value and quality are usually configured in the model , the time is not configured as all the time of the data in the same ASDU is same and can be get from the Frame. The fig.6 shows the parameter of quality.

....00 = validity: good (0)
....0.. = overflow: Not Set
....0... = outOfRange: Not Set
....0 = badReference: Not Set
....0. = oscillatory: Not Set
.... .. .0.. = failure: Not Set
.... .. 0... = oldData: Not Set
.... ..0 = inconsistent: Not Set
.... ..0. = inaccurate: Not Set
.... ..0.. = source: process
.... ..0... = test: False
.... ..0 = operatorBlocked: False
.... ..1. = derived: True

Figure 6. The parameter of Quality

The quality of the sampling value is bit-string, in 9-2 there are only 13 bit, but in 9-2LE which is used to guide the application of 9-2 and published by IEC, one bit is added which is called derived. This bit used to show whether the data is original value or calculated value.

2.1.2.2. IEC60044-8

The IEC60044-8 is the standard for ECT/EVT to send the sampling value. In the smart substation of China, this standard is extended to meet the relay protection as the State dispatch center of China is prudent about the sampling through the network.

The extended frame of IEC60044-8 is consist of four data module and the length of every module is 16.The structure of the frame is as fig.7:

		2 ⁷	2 ⁶	2 ⁵	2 ⁴	2 ³	2 ²	2 ¹	2 ⁰
字节 1	前导	msb	数据集长度 (= 62 十进制)						lsb
字节 2									
字节 3	数据集	msb	LNName (=02)						lsb
字节 4		msb	DataSetName						lsb
字节 5		msb	LDName						lsb
字节 6									
字节 7		msb	额定相电流 (PhsA.Artg)						lsb
字节 8									
字节 9		msb	额定中性点电流 (Neut.Artg)						lsb
字节 10									
字节 11		msb	额定相电压 (PhsA.Vrtg)						lsb
字节 12									
字节 13		msb	额定延迟时间 (t_{dr})						lsb
字节 14									
字节 15		msb	SmpCnt (样本计数器)						lsb
字节 16									

Data Module 1

字节 1	数据集	msb	DataChannel #1						lsb
字节 2									
字节 3		msb	DataChannel #2						lsb
字节 4									
字节 5		msb	DataChannel #3						lsb
字节 6									
字节 7		msb	DataChannel #4						lsb
字节 8									
字节 9		msb	DataChannel #5						lsb
字节 10									
字节 11		msb	DataChannel #6						lsb
字节 12									
字节 13		msb	DataChannel #7						lsb
字节 14									
字节 15		msb	DataChannel #8						lsb
字节 16									

Data Module 2

字节 1	数据集	msb	DataChannel #9	
字节 2				lsb
字节 3		msb	DataChannel #10	
字节 4				lsb
字节 5		msb	DataChannel #11	
字节 6				lsb
字节 7		msb	DataChannel #12	
字节 8				lsb
字节 9		msb	DataChannel #13	
字节 10				lsb
字节 11		msb	DataChannel #14	
字节 12				lsb
字节 13		msb	DataChannel #15	
字节 14				lsb
字节 15		msb	DataChannel #16	
字节 16				lsb

Data Module 3

字节 1	数据集	msb	DataChannel #17	
字节 2				lsb
字节 3		msb	DataChannel #18	
字节 4				lsb
字节 5		msb	DataChannel #19	
字节 6				lsb
字节 7		msb	DataChannel #20	
字节 8				lsb
字节 9		msb	DataChannel #21	
字节 10				lsb
字节 11		msb	DataChannel #22	
字节 12				lsb
字节 13		msb	StatusWord #1	
字节 14				lsb
字节 15		msb	StatusWord #2	
字节 16				lsb

Data Module 4

Figure 7. The frame of the extended IEC60044-8

In fig.7:

Length: The value is type of unsigned short and it is 62.

DataSetName: This type is ENUM8, The value is 1 or 0xFE. If the data channel is standard, the value is 1, else the value is 0xFE.

LDName: This type is unsigned short and the value is configured in the real project.

Nominal Phase Current(PhsA.Artg): The type is unsigned short.

Nominal Neutral Current(Neut.Artg): The type is unsigned short.

Nominal phase voltage and neutral voltage(PhsA.Vrtg): The nominal voltage is multiply with $1/(10 * \sqrt{3})$ kV, the nominal phase voltage and neutral voltage is multiply with $10\sqrt{3}$.

Nominal Delay(tdr): The type is unsigned short, the unit is us.

Sample Counter(SmpCtr): The type is unsigned short, The value will became zero(0) when receive the synchronization pulse, The value will invent if there is not synchronization. For example, if the sample rate is 4k/s, the range of SmpCtr is 0-3999

DataChanne#1 to DataChannel#22 : The type is short and the scale factor is different.

The scale factor of the phase current for relay protection is SCP, the scale factor of the neutral current is SCP, The scale factor of the measure current is SCM. The scale factor of the voltage is SV. The detail is as table 3:

	ECT for Measure (scale factor SCM)	ECT for protection (scale factor SCP)	EVT (scale factor SV)
nominal value(range-flag =0)	0x2D41H(11585)	0x01CFH(463)	0x2D41H(11585)
nominal value range mark (range-flag =1)	0x2D41H(11585)	0x00E7H(231)	0x2D41H(11585)
Reference:The ECT for protection should measure 50 multiple nominal current(0% offset)or 25 multiple nominal current(100% offset). The ECT and EVT should measure 2 multiple nominal value.			

Table 3. The scale factor and the nominal value

The status word#1 and status word#2 are used to show the status of every sampling channel, the detail is as table 4 and table 5

The two tables above show the status information from which we can know the status of every data channel.

2.1.3. The design of the merging unit

Considering the many requirements of smart substation about the multifunction merging unit, the mode that PowerPC+FPGA+MCF is designed as hardware architecture of the CPU board of the device.

Declaration			Comment
Bit 0	LPHD.PHHealth	0:goose; 1:warm	
Bit 1	LLN0.Mode	0:normal; 1:Test	
Bit 2	wake-up time indicator	0:normal; 1: invalid	Should be set during the wake-up time
Bit 3	The synchronization way of merging unit	0:no interpolation 1: interpolation	
Bit 4	The different merging unit of synchronization	0:samle synchronization 1:invalid	
Bit 5	DataChannel#1	0:valid; 1:invalid	
Bit 6	DataChannel#2	0:valid; 1:invalid	
Bit 7	DataChannel#3	0:valid; 1:invalid	
Bit 8	DataChannel#4	0:valid; 1:invalid	
Bit 9	DataChannel#5	0:valid; 1:invalid	
Bit 10	DataChannel#6	0:valid; 1:invalid	
Bit 11	DataChannel#7	0:valid; 1:invalid	
Bit 12	The output type of ECT	0:i(t); 1: d(i(t)/dt)	
Bit 13	RangeFlag	0:SCP=0x01CFH; 1:SCP=0x00E7H	
Bit 14	for future		
Bit 15	for future		

Table 4. The statue word#1

Declaration			Comment
Bit 0	DataChannel#8	0:valid; 1:invalid	
Bit 1	DataChannel#9	0:valid; 1:invalid	
Bit 2	DataChannel#10	0:valid; 1:invalid	Should be set during the wake-up time
Bit 3	DataChannel#11	0:valid; 1:invalid	
Bit 4	DataChannel#12	0:valid; 1:invalid	
Bit 5	DataChannel#13	0:valid; 1:invalid	
Bit 6	DataChannel#14	0:valid; 1:invalid	
Bit 7	DataChannel#15	0:valid; 1:invalid	
Bit 8	DataChannel#16	0:valid; 1:invalid	
Bit 9	DataChannel#17	0:valid; 1:invalid	
Bit 10	DataChannel#18	0:valid; 1:invalid	
Bit 11	DataChannel#19	0:valid; 1:invalid	
Bit 12	DataChannel#20	0:valid; 1:invalid	
Bit 13	DataChannel#21	0:valid; 1:invalid	
Bit 14	DataChannel#21	0:valid; 1:invalid	
Bit 15	for future		

Table 5. The statue word#2

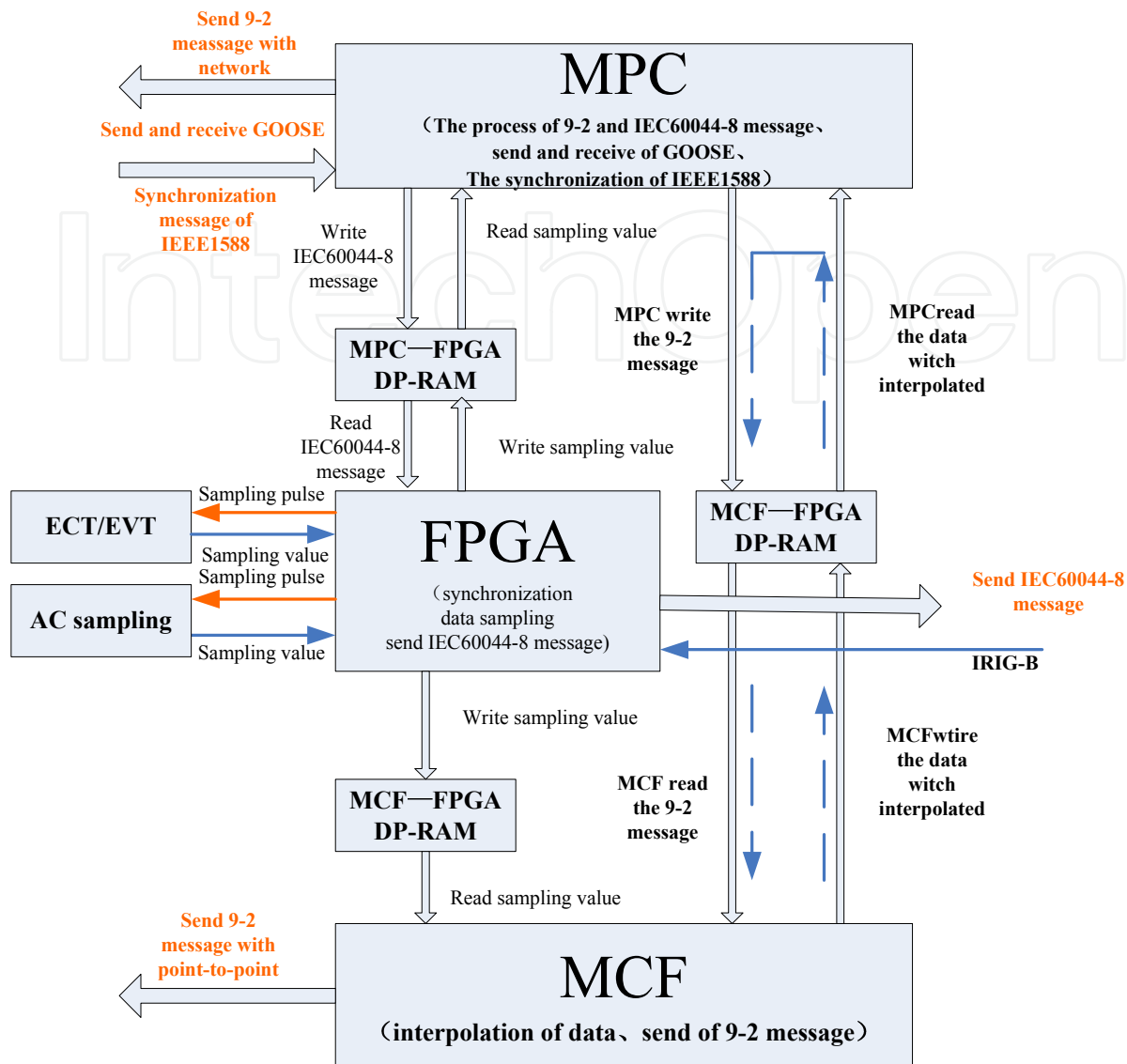


Figure 8. The hardware structure of the merging unit

The PowerPC is used to parse the model and realize the data processing which include that send the multicast sampling value packets, send and receive GOOSE message. The Freescale's MPC8313E chip which runs up to 333MHZ speed and 700MIPS performance is selected as the CPU chip. The most important factor is that this chip supports the synchronization of IEEE1588 and Gigabit Ethernet protocol for communication and these are very fit to the development of device.

The FPGA is used to send synchronous sampling pulse to electronic transformer and receive the data from the electronic transformer. In the signal processing and control system, the FPGA not only reduce the volume of circuit, improve the stability of circuit but also improve the signal process speed because it is based on the hardware circuit and the execution speed is nanosecond. The Spartan-3A devices of Xilinx Company which is based on the 90nm technology is used in FPGA module to realize the precise synchronization and timekeeping of merging unit. It can receive the second pulse of IEEE1588 and output the 5kHz to 10kHz

high-speed synchronization sampling pulse and time scale. The time clock error is less than 1 μ s and the time error between sampling pulse and second pulse just a few dozen nanoseconds.

MCF is designed primarily for the interpolation calculation and the point to point transmission of 9-2 messages. As the Vxworks system is running in the MPC, so the time delay of every packet is not fixed. The transmission time delay of 9-2 message through the network can be processed by the recipient, but while using the point to point transmission of 9-2 message, as there is no synchronization of the time, so the nominal transmission time delay should be stable. The time-interval of interrupt of DSP is fixed so it is most suitable to be used to send the 9-2 packet through the point-to-point way. And therefore, the MCF serial chip is selected under the consideration of performance and price of various chips.

As the merging unit may have the requirements that getting the status information. So the 16 channels are designed in the power board to get the switch status through the cable connection. Also, the device can receive the status signal from the intelligent operating terminal through the GOOSE network. The merging unit not only can receive the status signal, but also can send the alarm information. The status information of electronic current transfer(ECT) such as the circuit fault, A/D abnormality and the sampling data is not continuous can send with the sample data to merging unit, and this is part of the alarm information. Also, the internal fault of merging unit and the error during the data processing make up the other part of alarm information. These alarm information are transferred to the bay device through the GOOSE network. This function can improve the level of the station operation and maintenance and the safety and reliability of the substation effectively.

2.2. The data acquisition of status information

In smart substation, the status information such as the status of switch, the block signal are transferred through the GOOSE. GOOSE is shorted with the Generic Object Oriented Substation Event and is derived from the GSE(Generic Substation Event) which is defined in the standard of IEC61850. It is used to meet the requirements of fast transmission of the substation in IEC61850 and is based on the multicast communication through the Ethernet. In order to ensure the real-time and reliability of the transmission, the packet transmission do not require the receipt confirmation instead of using the order retransmission mechanism, so the performance of the network is critical to the reliability and real-time of GOOSE and has been widely used in substation.

GOOSE is used to trip in the digital substation which is based on IEC61850 standard. This technology and the associated network scheme have been tested in the worst-case condition and the GOOSE message can be able to send in real-time and ensure the reliability of the application of GOOSE in relay protection area. With the further application, the basic principles, the solution about the implementation and network have been researched. The research that the implementation of GOOSE, the structure of network and the double network control strategy are discussed in the reference which provide the technical guidance and promote the widely use of the GOOSE. The enable information of protection

function and the change information of the switch position are transferred through GOOSE, then it is used in the block among the bays, even used in the area of bus protection and video monitoring which are all based on Ethernet .

During the construction of digital substation period, the merging unit do not has the function of the acquisition of status signal and the alarm information can not send to the bay device. But during the construction of smart substation, the project propose the requirements that the data acquisition of switch status and the monitoring information about the every section of the sample. At the same time, the merging unit used in smart substation should send the alarm information through the network and GOOSE(General Object-Oriented Substation Event)is used to meet this requirement.

2.2.1. *The mechanism of the GOOSE*

The generic substation event model provides the possibility for a fast and reliable system-wide distribution of input and output values and is based on the concept of an autonomous decentralization, providing an efficient method allowing the simultaneous delivery of the same generic substation event information to more than one physical device through the use of multicast/broadcast services.

GOOSE supports the exchange of a wide range of possible common data organized by a data-set. The information exchange is based on a publisher/subscriber mechanism. The publisher writes the values into a local buffer at the sending side; the subscriber reads the values from a local buffer at the receiving side. The communication system is responsible to update the local buffers of the subscribers. A generic substation event control class in the publisher is used to control the procedure.

Fig.9 gives an overview of the classes and services of the GOOSE model. The message exchange is based on the multicast application association. If the value of one or several DataAttributes of a specific functional constraint (for example ST) in the data-set changes, the transmission buffer of the publisher is updated with the local service “publish”, and all values are transmitted with a GOOSE message. The data-set may have several members (numbered from 1 up – the numbers shall be called MemberOffset). Each member shall have a MemberReference referencing the DataAttribute with a specific functional constraint (FC). Mapping specific services of the communication network will update the content of the buffer in the subscribers. New values received in the reception buffer are signaled to the application.

The GOOSE messages contain information that allow the receiving device to know that a status has changed and the time of the last status change. The time of the last status change allows a receiving device to set local timers relating to a given event.

A newly activated device, upon power-up or reinstatement to service, shall send the current value of a data object (status) or values as the initial GOOSE message. Moreover, all devices sending GOOSE messages shall continue to send the message with a long cycle time, even if no status/value change has occurred. This ensures that devices that have been activated recently will know the current status values of their peer devices.

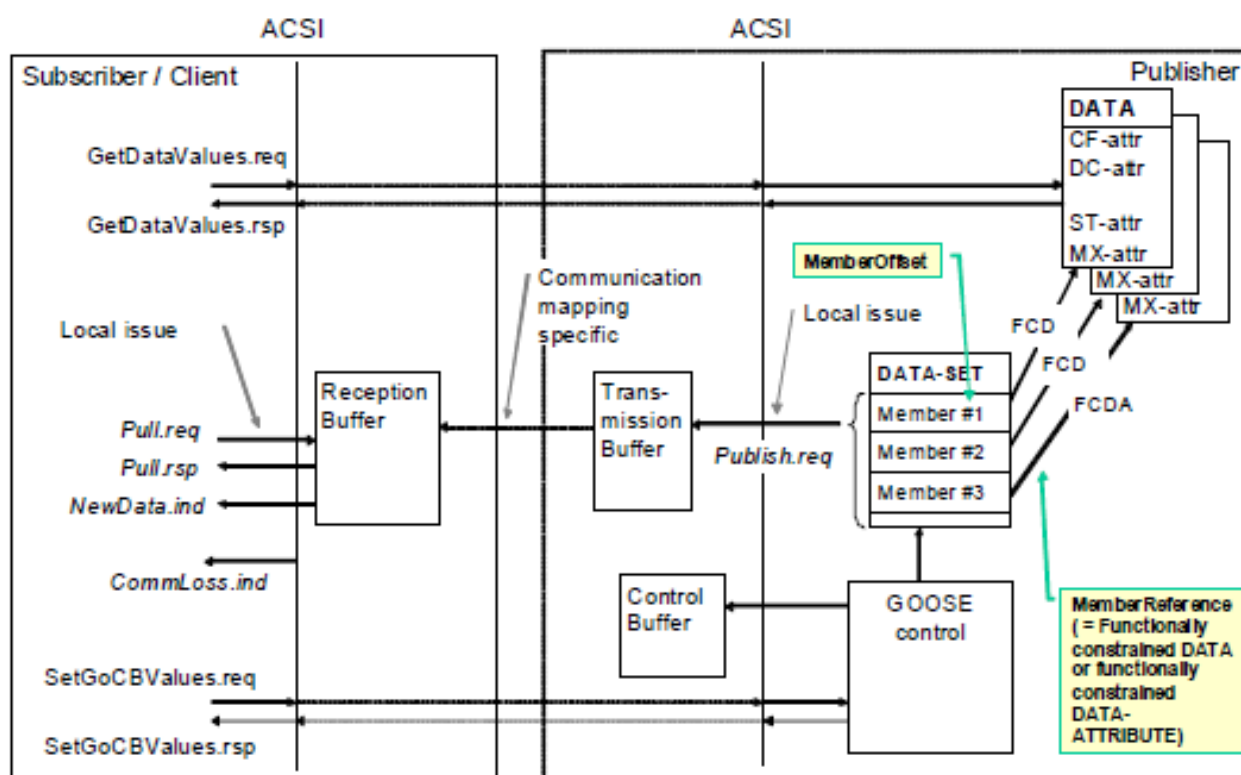


Figure 9. The model of GoCB

GoCB class			
Attribute name	Attribute type	r/w	Value/value range/explanation
GoCBName	ObjectName		Instance name of an instance of GoCB
GoCBRef	ObjectReference		Path-name of an instance of GoCB
GoEna	BOOLEAN	r/w	Enabled (TRUE) disabled (FALSE)
GoID	VISIBLE STRING129	r/w	Attribute that allows a user to assign an identification for the GOOSE message
DatSet	ObjectReference	r/w	
ConfRev	INT32U	r	
NdsCom	BOOLEAN	r	
DstAddress	PHYCOMADDR	r	

Services

SendGOOSEMessage
 GetGoReference
 GetGOOSEElementNumber
 GetGoCBValues
 SetGoCBValues

Table 6. The GOOSE control block class definition

The table 6 shows the GOOSE control block which is the content of the GOOSE message. In order to make sure the GOOSE message can be transferred in real time, a special mechanism is defined. Fig.10 is the message of GOOSE captured in the project. We can be easy to understand the structure of the message of GOOSE.

No.	Time	Source	Destination	Protocol	Info
23	4.992032	00:15:c5:02:d3:f2	09:00:00:00:00:02	IECGOOSE	GOOSE Request
24	5.053537	00:15:c5:02:d3:f2	09:00:00:00:00:01	IECGOOSE	GOOSE Request

Frame 24 (142 bytes on wire, 142 bytes captured)

Ethernet II, Src: 00:15:c5:02:d3:f2 (00:15:c5:02:d3:f2), Dst: 09:00:00:00:00:01 (09:00:00:00:00:01)

802.1Q Virtual LAN

IEC 61850 GOOSE

AppID*: 1287

PDU Length*: 124

Reserved1*: 0x0000

Reserved2*: 0x0000

PDU

IEC GOOSE

{

Control Block Reference*: gocbRef0

Time Allowed to Live (msec): 10

DataSetReference*: dataSet0

GOOSEID*: goId0

Event Timestamp: 2008-03-08 08:53.33.218000 Timequality: 00

StateNumber*: 1

SequenceNumber*: Sequence Number: 1

Test*: FALSE

Config Revision*: 0

Needs Commissioning*: FALSE

Number Dataset Entries: 18

Data

{

BOOLEAN: TRUE

BOOLEAN: TRUE

BOOLEAN: TRUE

BOOLEAN: TRUE

BOOLEAN: TRUE

BOOLEAN: TRUE

Figure 10. The message of GOOSE

2.2.2. The configuration of GOOSE

The key part of the application of GOOSE is the configuration which called the configuration of virtual terminal. As the GOOSE is the publish/subscribe model, so the message of the send is easier to realize. The different dataset should configure different GOOSE control block. But the subscriber should configure the terminal according the requirements. The sending data will be connected with the receiving data.

Fig.11 is one the project configuration view. The key part of configuration is the connection of virtual terminal. As the sender which is caller publisher does not know the requirements of receiver which is called subscriber, so the configuration is finished by the receiver. The receiver get the dataset which the publisher will send can choose the values needed and connect with the internal data. The fig.12 is the virtual connection of GOOSE . ExRef show that the data attribute which including iedName, ldInst, prefix, lnClass, lnInst, doName, daName come from the external device . The intAddr show that the value is internal of the receiver. The data attribute show be match and then the virtual terminal configuration is finished.

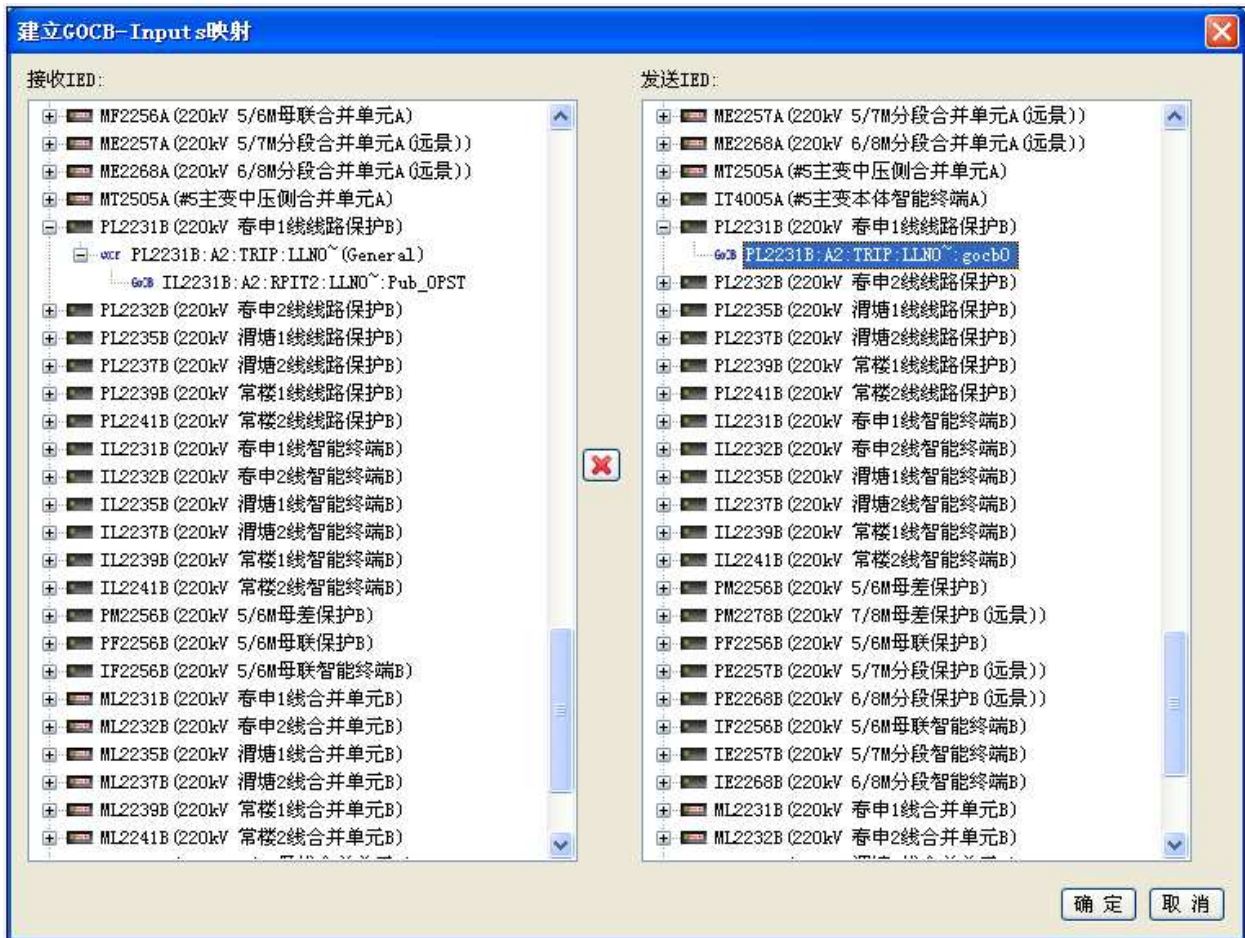


Figure 11. The configuration of the GOOSE

```
<ExtRefiedName="IT22097" IdInst="PI" prefix="GOOUT" lnClass="GGIO" lnInst="1" doName="Ind1" daName="stVal" mtAddr="GO GOINGGIO0.Ind10.stVal" />
<ExtRefiedName="IT22097" IdInst="PI" prefix="GOOUT" lnClass="GGIO" lnInst="1" doName="Ind2" daName="stVal" mtAddr="GO GOINGGIO0.Ind11.stVal" />
<ExtRefiedName="IT22097" IdInst="PI" prefix="GOOUT" lnClass="GGIO" lnInst="1" doName="Ind3" daName="stVal" mtAddr="GO GOINGGIO0.Ind12.stVal" />
<ExtRefiedName="IT22097" IdInst="PI" prefix="GOOUT" lnClass="GGIO" lnInst="1" doName="Ind4" daName="stVal" mtAddr="GO GOINGGIO0.Ind13.stVal" />
<ExtRefiedName="IT22097" IdInst="PI" prefix="GOOUT" lnClass="GGIO" lnInst="1" doName="Ind5" daName="stVal" mtAddr="GO GOINGGIO0.Ind14.stVal" />
<ExtRefiedName="IT22097" IdInst="PI" prefix="GOOUT" lnClass="GGIO" lnInst="1" doName="Ind6" daName="stVal" mtAddr="GO GOINGGIO0.Ind15.stVal" />
<ExtRefiedName="IT22097" IdInst="PI" prefix="GOOUT" lnClass="GGIO" lnInst="1" doName="Ind7" daName="stVal" mtAddr="GO GOINGGIO0.Ind16.stVal" />
<ExtRefiedName="IT22097" IdInst="PI" prefix="GOOUT" lnClass="GGIO" lnInst="1" doName="Ind8" daName="stVal" mtAddr="GO GOINGGIO0.Ind17.stVal" />
```

Figure 12. The virtual connection of GOOSE

2.2.3. The application of GOOSE in relay protection

GOOSE can be used in all areas of substation in theory and is widely used through the network. But in the smart substation, the situation has changed, especially for the relay protection. Considering the special nature of the protection device, all protection devices are required to trip directly not with the network is defined in the "Technical specifications of relaying protection for Smart Substation". This can improve the performance of security and reliability but brought some new problems such as the increase of net port and the configuration of port which take the change about the application of GOOSE in smart substation.

2.2.3.1. *The sending port of GOOSE*

In the period of digital substation, the sending and receiving of GOOSE is realized through the network and the redundancy mode of double-network is widely used and there are only two network ports in maximum. The realization of the GOOSE is different from the different manufacturers. The sending port of GOOSE is fixed in some manufactures and the sending port can be configured according the requirement in other manufactures which mean that the mode of single network or double network is can be selected.

The requirements of the point-to-point way of the smart substation mean that the same protection device need to have more Ethernet port to trip. The direct connection mode generates the new problems, because there are many net ports, the ports witch the same GOOSE message will send must be configured with a flexible way to meet the complex engineering requirements. Take the smart terminal for example, this device may receive the trip command from several protection and send the status information of switch change to many protection devices. If the same message can be send from the multiple ports will be a good solution of the problem, the configuration of the net port can realize this function. Also, there is another way that does not need to support the configuration of the net port can solute the problem just through the creation of several datasets with the same data attributes. This way can meet the actual needs but have to increase the overhead of the device the workload of configuration. At the same time, the configuration of the net port is equipped with the hardware and do not impact the performance of the device, so it can improve the efficiency and flexibility of debugging and reduce the workload of the engineering application.

2.2.3.2. *The receiving port of GOOSE*

The receiving ports of the GOOSE messages are fixed in the mode of single network or double network. As the receiving port is limited and the receiving GOOSE messages have many types, the upper application program will extract the GOOSE message from the different net port. The content parsed from the message will be compared with the configuration of GoCB such as the APPID(Application Identification), Control Block Reference, DataSet Reference, GOOSE ID, only all the content are matched then the data from the message will be assigned to the associated data of the device. This way that compare the data attribute one by one will reduce the overall efficiency of the device, especially when the device have many number of GoCBs .

The receiving device has a lot of port in the direct connected mode of the smart substation. The port which the different packets will enter is uncertain. If the port is fixed, once the port is in trouble the device cannot receive the GOOSE message and must replace the board of the device and can not meet the actual needs of the project. If the port is optional, the device will extract the message and compare the content with configuration of every port which can avoid the compare with all the GoCB and save the overhead and improve the efficiency of the device.

2.2.3.3. The alarm about the GOOSE network

As the mechanism of GOOSE is based on the retransmission without the feedback through the network, the interruption of the network is detected by the receiving device. The alarm signal of the interruption will be generated by the receiving device when it can not receive the packet of GOOSE in twice the timetolive time. A device can receive many different GOOSE packets from one device or several other devices and the receiving port is the same. If one of the GoCB report the alarm of interruption while others not, the port is normal which can be sure, otherwise, the other GoCB will send the alarm of interruption also. So, the alarm of the interruption is identified with the GoCB in the network mode. Such as the fig.13, as the receiving port is fixed, the six GoCBs of the receiving device is matched with the external six GoCBs of different device according the configuration and can be adjusted also. So, once the alarm of interruption about GOOSE is generated, the GoCB should be identified with the configuration.

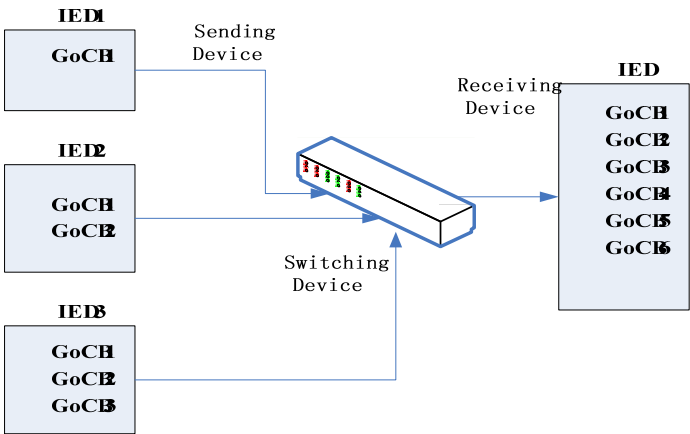


Figure 13. The mode of network about GOOSE interruption alarm.

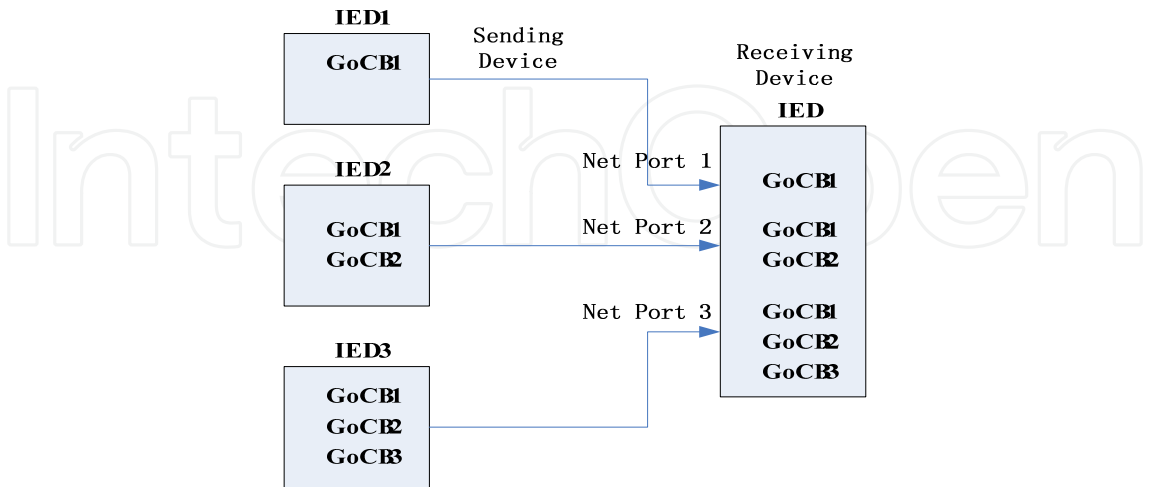


Figure 14. The mode of direct connection about GOOSE interruption alarm.

The principle of the direct connection mode of the smart substation is the same with the network mode, just the detection of the interruption distributed to each port. When the

alarm of interruption is generated, the reason may not be the device which including the GoCB but the port of the receiving device, especially the sending device only has one GoCB. In fig.14, the sending devices are connected with the different port of the receiving devices, so there will be limitation if the alarm of interruption about GOOSE is judged with the GoCB, because the receiving port is different. So, when alarm of interruption about the GOOSE is generated, we need to find not only the device and the GoCB, but also the access port, because the abnormal of the port may be the reason of the alarm. So, if the detection of alarm is according to the GoCB is still possible but must based on the normal of the device, if we subdivide the GoCB further that the alarm is depend on the GoCB and the port number, the whole process will be more reasonable and compatible, this way is compatible with the old way which according to GoCB because the port is fixed in the old way. As the direct connection mode, each port is connected with the different device, so the port number is corresponded to the device, the alarm of the interruption become the "[IED name]+[GoCB number]", this alarm information is more detailed and is helpful to find the fault. This new way is corresponded with the configuration of receiving port, if the receiving port can be configured, this new way will be easily realized.

2.2.4. The analysis of the further application of GOOSE

As the application of GOOSE in project, the problems are growing generally. The mode of the data processing of the GOOSE, the isolation measures for the maintenance with GOOSE, the configuration and design of the project which have support the guide to the construction. The practical problems are not only these, some other problems about the application of GOOSE are analyzed in this paper.

2.2.4.1. The define about the connection of virtual terminal

The mechanism of the GOOSE is publish/subscription. The receiving device should be pre-configuration to realize the internal data associated with the external data. The current series of standards and specifications define how to configure data model and how to regulate the name, but not specific the data association and this will be discussed in this paper.

2.2.4.1.1. The match of the sending and receiving data

The data of GOOSE message are just fully meet the requirements of the receiving device which meant that all the data are matched. This mode is widely used in the most of the project and the system integrator need to coordinate the sending device and receiving device, in order to match fully, the workload of configuration of the both are very large, because they need to edit the sending data or receiving data.

2.2.4.1.2. The mismatch of the sending and receiving data

As the dataset can be flexibly defined, so the same device may send the GOOSE message to multiple devices. If the requirements of the data are the same, the sending device only needs to define one GoCB to meet the need. However, the project is complex and the requirements of the receiving device are not the same but only small differences in most case.



Figure 15. The define of dataset

In fig.15, DA1-DAN are defined as the Common Data,DA01, DA02 and DA03 are different data attribute used to meet the different requirement of different device. There are seven different datasets to meet the different requirements which are DA01+Commondata, DA02 + Common Data, DA03 + Common Data , DA01 + DA02 + Common Data, DA01 + DA03 + Common Data, DA02 + DA03 + Common Data, DA01 + DA02 + DA03 + Common Data and resulting the 7 associated GoCBs. This is not only increase the load of the device, more importantly, it increases the workload of configuration of the field especially in the case of small amount data. So, we suggest that the dataset should be one with DA01+DA02+ DA03+Common Data and the sending device only have one GoCB in case of the difference of data requirements of the device is little, the receiving device only get the needed data to associated with internal data, the small account data can be associated to the data of the device which are not used. This way is the indirect application of the mode of matching discussed above and can meet the requirements of the project and reduce the workload and complexity of configuration.

2.2.4.1.3. Differential receiving

The two modes above are directly or indirectly using the match mode which the sending data just meet the requirements of the receiving device. There is another mode called differential receiving which have more compatibility. In this mode, the sending data do not need to meet the requirements of the receiving device and the receiving device can recognize their own need data from the message of GOOSE according to the configuration of virtual terminal. This mode is more complex but can meet all the requirements of the project flexibly.

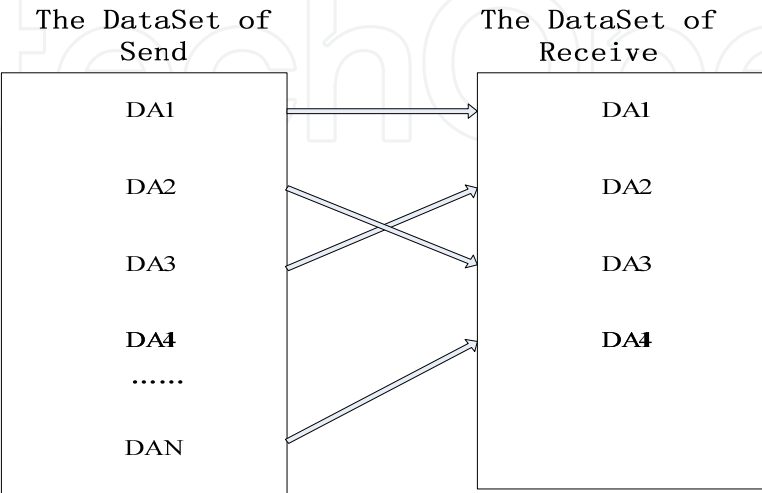


Figure 16. The configuration about virtual terminal

As the fig.16 shows, the sending data do not just match the requirements of the receiving device. The receiving device just need to choose the data needed from the receiving message which the other devices send. The other data which do not need are not be treated. This way can meet the requirements of the project and reduce the workload of configuration. The chart above is just for a sending device associated with multiple receiving devices. If multiple sending devices associated with one receiving device, the advantage of this mode is more obvious because it can avoid the sending device to send the data which must just match the requirements of the receiving device and the modification of the datasets and related GoCB. This mode is compatible with the two mode discussed above and is more intelligent.

2.2.4.2. The check of virtual terminal

The configuration of GOOSE is finished by the system integrator which has powerful system configuration tool and is responsible for the configuration of the station, including the configuration of GOOSE virtual terminal in current pilot project of smart substation. As the performance of different system configuration tool is different and the final configuration file is not be tested rigorously, so the device often generate the alarm of the configuration error after the configuration file is downloaded to the device which increase the difficulty of debugging. If the GOOSE virtual terminal can be checked immediately when the configuration is finished, the configuration error will be detected and modified which can improve the efficiency of the test of the project.

2.2.4.2.1. The check about the data attribute

In the configuration of the virtual terminal, the engineer may be careless to result the error of association of virtual terminal, especially in the configuration of IntAddr, the logical node number is easy to make mistake and resulting the Boolean type data of the sending device is associated with the int type or doubling point type data of the receiving device. These errors can be easily detected according to the model validation and comparison of data attribute and modified in time.

2.2.4.2.2. The check about the configuration of GoCB

The error is easily to generate in the virtual terminal configuration about GoCB such as the APPID and multicast address. Take the configuration of multicast address for example, the range of GOOSE multicast address is from 01-0C-CD-01-00-00 to 01-0C-CD-01-01-FF while the range of MSV multicast address is from 01-0C-CD-04-00-00 to 01-0C-CD-04-01-FF. These two type multicast address are often confused by the engineer of the project which is responsible for the configuration. This type of error is often find by the tester who analysis the message grabbed from the sending device and it slows the progress of test. If the configuration tool has the function of check, this type of error will be corrected quickly.

2.2.4.2.3. The check about the association of virtual terminal

The table and the wire splice are used in the association of virtual terminal and the way of wire splice is more convenient and is popular with the designer. It is easy to generate

mistake when there are many virtual terminal need to be associated such as the virtual terminal of the receiving device is not connected or the same terminal is connected will several sending data. This type of error is hard to find only when the device cannot receive the need data and there are many reasons to result in it, the omission of the check of the virtual terminal increases the complexity of the test. If the configuration tool can check the configuration file and give the warning in time, it can effectively ensure the correction of the virtual terminal association and avoid this type error.

2.2.4.3. *The test about the virtual terminal*

Most of the configuration tool is off-line, the configuration file generated by the configuration tool is downloaded to the device and is tested by the external sending device or simulation testing device. These two modes are widely used in smart substation to test the correction of the configuration file but they are not comfortable. In former mode , although the message is send by the device but the data of the packet is generated by the external device which mean that the sending device need the external input signal to realize the data send. This way is inconvenient and less efficient. The other mode do not need the external device to generate the signal and can simulate the data flexible, but it need finish the configuration of GoCB and the datasets, this increase the workload of the test. If the configuration tool can send GOOSE message directly which mean that it can get the GoCB from the model of the device, it will avoid the configuration of the GoCB and dataset, if the data can be set according to the configuration tool, it will be comfortable to sending GOOSE message to realize the check of the configuration file about the association of the virtual terminal and improve the efficiency of debugging greatly.

In addition, most of the data in the GOOSE message are Boolean or double-point status information, if the configuration tool can set the time interval to control the every data change of the dataset automatically, it will be reduce the workload of the test and truly reflect the intelligent character. Some manufactures have developed this type configuration tool and have been used in pilot project of smart substation which improve the efficiency and realize the automatic test.

2.3. The synchronization with IEEE1588

IEEE1588 is a precision time protocol (PTP) standard for the networked measurement and control systems, the synchronization accuracy can reach sub-microsecond range. The application of IEEE1588 in the merging unit based on IEC61850-9-2 will be presented. The type of clock and the core algorithms of IEEE1588 will be introduced. The principle of high precision clock synchronization will be analyzed. The strategy of synchronization for process layer devices will be discussed. At last, The implement of GMRP protocol is analyzed.

The electronic transformer is connected through optical fiber with merging unit. The merging unit based on IEC61850-9-2 can realize the data sharing.. but this way has a key

problem to solve which is synchronization especially to the cross-interval data sharing.. The bus protection will face this problem in project. There are two important type information transmission on the process lay which are sampling and the trip command. The sampling is realized through the merging unit and the trip command is realized through GOOSE. There are three levels synchronization accuracy in the standard of IEC61850 which are T3, T4 and T5. The T3 grade requirements for 25us used in the distribution of the line protection. T4 grade requirements for 4us used in transmission line protection. T5 grade requirements is 1us which is used in metering. It can be seen that, the synchronization with GPS can not meet the requirement of T5 because the accuracy only reach 1ms. At the same time, This way need additional wiring which increase the cost and reduce the reliability of the whole substation. Considering the IEEE1588 can reach 1us accuracy and is synchronized with network, so the application of IEEE1588 in merging unit is researched which can improve the reliability and sampling precision.

2.3.1. The principle of IEEE1588

The mode of the synchronization of IEEE1588 is master-slave which defines four multicast clock packets:(1)synchronization packet, shorted Sync;(2)following packet, shorted Follow_UP;(3)delay request packet, shorted Dealy_Req ;(4) response packet, shorted Dealay_Resp., the detailed is as follow:

During the synchronization, the master clock will send synchronization message periodically (typically 2 seconds). All the PTP terminal equipments which are in the same network with master clock will receive the Sync message and record the receiving time. The Sync message contain the timestamp which describes the expected sending time. As the expected time of the Sync message is not the real sending time, so the master clock will send the Follow_Up message after the Sync message which record the accuracy sending time of the Sync message. So the slave PTP terminal can calculate the the time offset between the master clock and slave clock through the return time in Follow_up message and the receive time in Sync message. As the transmission delay of the master clock and slave clock is unknown in the initialization stage, so the offset contain the network transmission dealy. Subsequently, the slave clock will send Dealy_Req message to master clock and record the the accurate sending time. The master clokc will record the accuracy arrival time of the Dealy_Req message and send the Dealay_Resp message to the slave clock which contain the accuracy arrival time of the Dealy_Req message.. The time offset between master clock and slave clock and the network transmission delay can be calculated through this "Ping-Pong" way.

In Fig.17, when the time is t_1 in master clock , the relative time of slave clock is T_1 which can be seen that the time offset need to be compensated. However, as the calculation of slaver terminal is based on the local clock, so the return time of the Follow_up message is the send time of the Sync message but is stand on the view of the slave clock. So

$$t_2 - t_1 = \text{Delay} + \text{Offset} \quad (1)$$

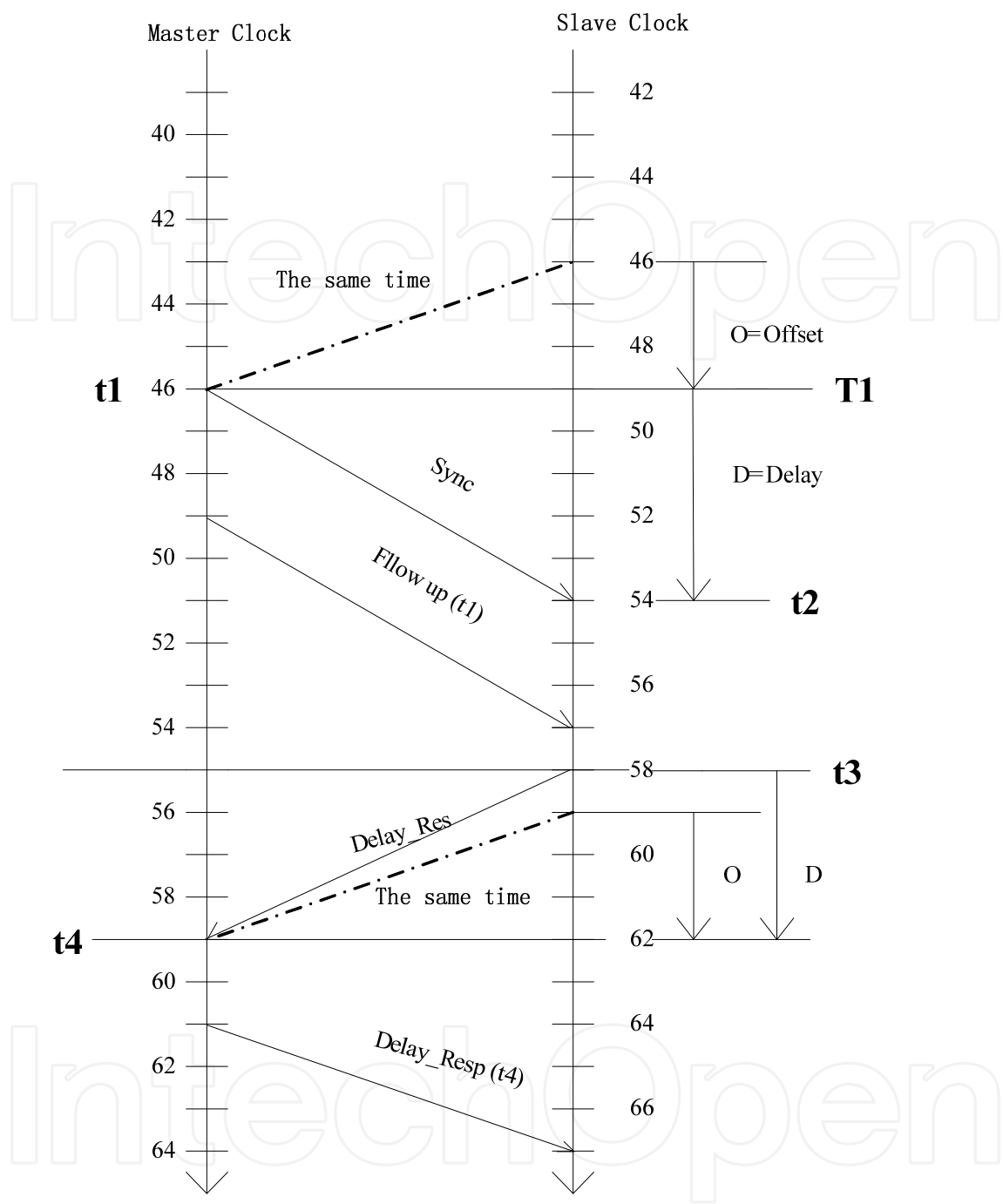


Figure 17. Synchronized principle of IEEE1588

The time offset between master and slave clock and the network transmission delay can not be calculated from the equation (1) . so, the slaver terminal will send the Dealy_Req message after receive Sync message. The slave terminal will record the the accuracy sending time of the Dealy_Req. The master clock will record the accuracy arrival time of the Dealy_Req and send the Delay_Resp message to the slave termila. So,

$$t4 - t3 = Delay - Offset \tag{2}$$

According to the equation (1) and (2), we can calculate the time offset and network transmission delay, as equation (3) and (4):

$$\text{Delay} = ((t_2 - t_1) + (t_4 - t_3)) / 2 \quad (3)$$

$$\text{Offset} = ((t_2 - t_1) - (t_4 - t_3)) / 2 \quad (4)$$

2.3.2. The realization of synchronization of IEEE1588

Considering the synchronization with IEEE1588 can reuse the communication network of substation and simplify the structure, also the synchronization accuracy can reach 10ns-100ns which not only can meet the requirements of sampling but also can meet all the requirements of automation system of substation. The IEEE1588 used in the merging unit which is to make sure the high accuracy of data acquisition is discussed.

2.3.2.1. The design of the hardware

As the synchronization of IEEE1588 is based on the MAC layer which should mark the timestamp so this way propose the higher requirements to the hardware. The Freescale's MPC8313E is chosen as the CPU of the merging unit which can up to 333MHz and 700 MIPS performance. The most important character of this chip is that it can support IEEE1588 protocol and gigabit ethernet network which is very useful to the development of the merging unit. In order to send high precise sampling pulse the FPGA is implemented. In signal processing and control of the entire system, FPGA can not only reduce the size of the circuit to improve the stability and the logic based on lookup table structure and the parallel processing way can improve the signal processing speed, as the realization is based on the hardware circuit essentially, so the speed of execution is nanosecond. The FPGA module chooses the Xilinx's Spartan-3A device which is based on 90nm technology to realize the synchronization and timekeeping. The FPGA receives the IEEE1588 second pulse and outputs 5kHz and 10kHz high speed synchronization sampling pulse and marks the timestamp. The time error is less than 1μs and the time error between the sampling pulse and second pulse is only a few nanoseconds.

2.3.2.2. The realization of the software

The time offset and delay calculated in the principle of IEEE1588 is based on the round-trip delay which are the same (i.e., the delay that the packet from the master clock to the slave terminal and the packet from the slave terminal to the master clock is the same), in fact, these two delay times are different to exactly the same. Considering the network traffic is relatively fixed in real project, so the time is considered being equal. The realization is as follows:

In fig.18, the master clock sends the synchronization message every two seconds while the merging unit sends the delay request message every ten seconds, the specific time can be configured according to the project. This way is based on the relatively fixed network time delay which is not changed and can reduce the network traffic.

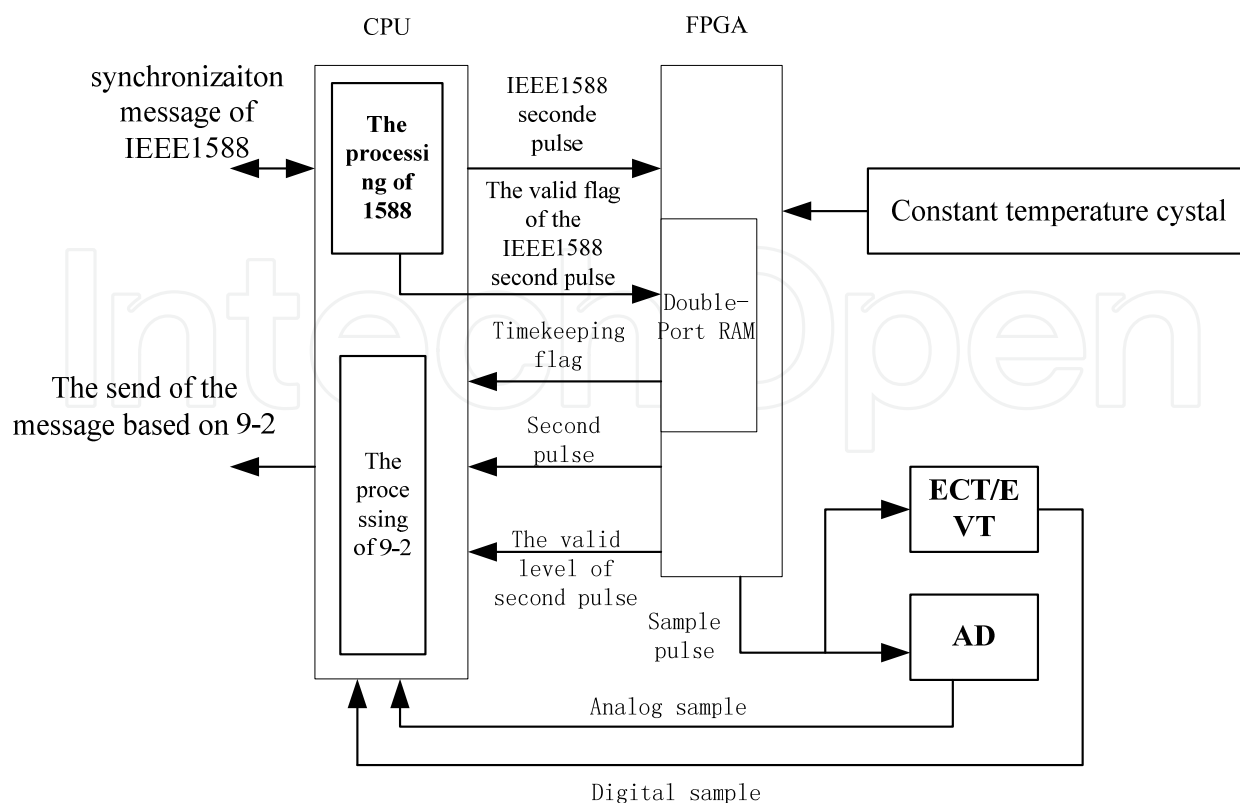


Figure 18. The process of IEEE1588

When the merging unit receives the synchronization message first time, the synchronization started. The process of synchronization need many times in order to reduce the time error less than 1 μ s. If the merging unit calculates the time deviation within 1 μ s in five continuous time then the device can be considered be synchronized with the master clock . The merging unit send the second pulse to FPGA through the I/O pin and write the 1588 second pulse valid flag to the double-port of FPGA. When the FPGA detects the flag it will inform the processing of sampling and then the smpSynch will be set to True in the sampling message which is based on the 9-2.

The FPGA will be into punctual stage when the 1588 second pulse valid flag be detected for continuously for 32 seconds and then the FPGA will adjust the clock time of the device and write the 1588 punctuality flag in the double-port RAM. In the punctuality stage ,the FPGA always adjust the clock time according the 1588 second pulse in last 32 seconds. In this stage, the merging unit can make sure the accuracy of 1 μ s even the FPGA detect the 1588 second pulse is invalid, so the smpSynch flag is still ture in sampling message of 9-2. The time of timekeeping can be tested and the device we developed can sustain 2 hours and the real time can be set according to the project. In fact, the substation which use the IEEE1588 synchronization often has two main clock or the slave clock will become the main clock once the main clock is failed. In the other time, once the failure of network of IEEE1588 is detected, the substation will alarm immedeliatly, the operator on duty will solve the problem. Once the timekeeping time exceed the set value the smpSynch flag will be set false.

When the time deviation between master clock and slave clock exceed 1us,the FPGA will write the 1588 second pulse invalid flag to the double-port RAM and then the smpSynch flag of 9-2 message will become false.

2.3.3. The network of the IEEE1588

As most of the device in substation can not support the IEEE1588 which have the higher requirements of the hardware, so the synchronization of IEEE1588 is used in process layer device such as merging unit. But in the pilot project of smart substation, the device of bay layer also support IEEE1588, the structure of the network is as follow:

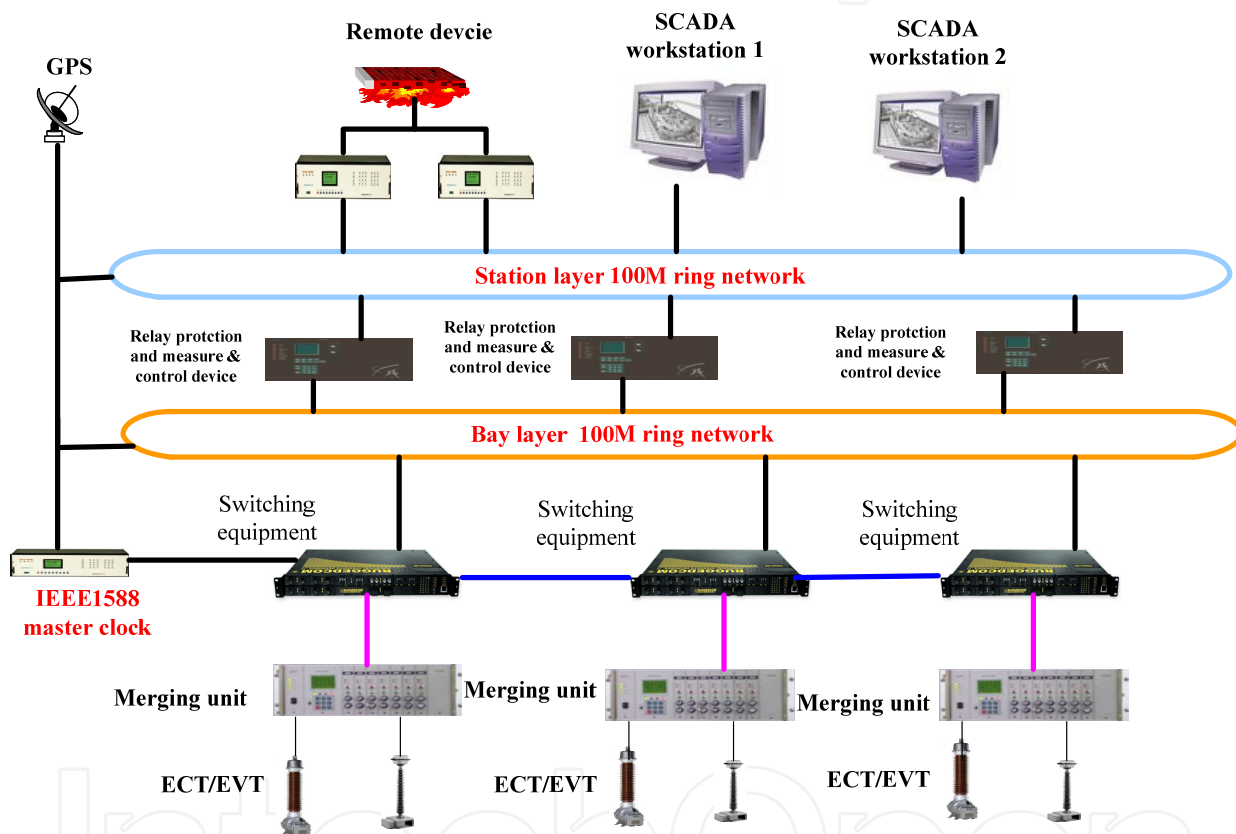


Figure 19. The structure of IEEE1588 network

The fig.19 is network of IEEE1588 of a 500kV substation. The voltage measurement of 500kV is still using the traditional electromagnetic voltage transformer but the current measurements using the optical-electrical transformer. The merging unit is based on 9-2 and the sampling frequency is 80 point per cycle which means 4kHz/s. The main clock of IEEE1588 is increased in the process layer which is used to send the synchronization message. The process layer switching equipment using the RUOGGECOM 2288 as the boundary clock which not only can be as the slave clock of the main clock but also can send synchronization message as the main clock of the merging unit. The merging unit receive the synchronization as the ordinary clock. The intelligent operation terminal which is used to close or open the switch through the GOOSE is also the process layer device, but as it does not have the

requirement of high accuracy of synchronization so it does not include in the figure. According to the trend of IEEE1588, the process layer network will realize the IEEE1588, 9-2 sampling message and GOOSE in the same network. Although the IEEE1588 used in bay layer device is not suitable so the bay layer device have a large quality and overall cost of investment about the update is very high, it may be the direction of development. Now, the SNTP time network can be able to meet the bay layer and station layer requirement, so it can be a good way to solve the synchronization at this stage.

The fig.19 is the simple structure, the real project is more complex. In smart substation, the relay protection require the sampling using the point-to-point way. The synchronization structure is the same as the fig 19 above because every merging unit still retain the network port which is used to send 9-2 message and this port can be used receive the synchronization of IEEE1588.

Therefore, whether process layer network is a ring structure or bus structure, whether it is digital substation or smart substation, the scheme of synchronization is basically the same which through adding the master clock. All the merging unit are as the boundary clock and this is the most reliable and economical way.

3. The network of data acquisition

3.1. The introduction

The process layer involves data transmission and control of primary equipment such as data sampling and trip of protection. The research about the scheme of network structure of process layer is important and it determines the stability and reliability of smart substation.

The type of message of process layer which include GOOSE (General Object-Oriented Substation Event), MSV (Multiple Sample Value) and synchronization with network will be generalized. The scheme of process layer network with different combination of the GOOSE and MSV will be discussed. The unite scheme of GOOSE, MSV and synchronization with IEEE1588 is researched, the scheme of hybrid mode which fits the requirements of relay protection of smart substation will be presented in detailed. The VLAN and GMRP technology which is used to divide the network of process layer to reduce the load of network will be proposed.

3.2. The message in process layer

The devices of process layer in smart substation include electronic (optical) transformer, merging unit, intelligent operation device (intelligent switch). The typical messages are GOOSE, MSV (multiple sample value) and synchronization with IEEE1588 may be included.

The sampling message in substation mainly based on the standard of IEC60044-8/7, IEC61850-9-1 (shortened with 9-1), IEC61850-9-2 (shortened with 9-2). The digital substations constructed earlier are mainly based on 9-1 which is abolished now. The 9-2 which is flexible and convenient to meet the requirements of the project but need the higher performance of

the device becomes the unique standard of the sampling in process layer. The IEC60044-7 / 8 standard is also in use, primarily in accordance with the “Technical Specifications of Relaying Protection for Smart Substation” which require the transition of sampling data from the merging unit to protection device through the direct connect which like point to point .

The tripping network in smart substation is GOOSE. The principle and implementation are the same with the digital substation. The difference is that the transition of GOOSE is through direct connection not the network which is used to meet the requirements of standard of “Technical specifications of relaying protection for Smart Substation”.

The network of IEEE1588 is included when the synchronization with IEEE1588 is used. This network can be attached to the network of GOOSE or MSV and need no additional electrical connections. The only requirement is that the switch should support the standard of IEE1588 and the master clock should be provided separately.

The topology of process layer network is the same with the bay layer which can divide three types such as star network, ring network and bus network. Among these three types, the reliability and cost of the bus network is the lowest but the delay is large. The delay of star network is the lowest and the reliability and cost is medium. The cost and reliability of ring network is the highest and the delay is very large also. According to the pilot project of digital substation in China, most of them choose the star network as the topology of process layer to achieve the optimization of performance and cost. The star network is also used in most high voltage substation.

3.3. The scheme of the process layer network

The communication of process layer include the digital sampling which involves the use of electric transformer and merging unit and the network of GOOSE which involves the use of intelligent operation device or smart switch. The process layer network which concerns the data source and the control of switch play a important part in the stable operation of substation. There is a need of the research of process layer network to choose the most safe, stable and economical scheme to make sure the security and stability of the substation. The main scheme is discussed in detailed:

3.3.1. *The direct connection of MSV and GOOSE*

The direct connection of MSV and GOOSE (also known as point to pint) is similar to the cable connection in traditional substation. The difference is that the cable is replaced by the fiber. The principles of MSV and GOOSE are remaining the same and the switching equipments are saved. The specific of fig.20 is as follow:

The scheme of fig.20 can ensure the reliability of data transmission but the sample value can not be shared. The direct connection needs the IED provide more network ports or optical ports and more fiber, the cost is very high. If the merging unit or intelligent operation device are installed beside the primary device, this scheme is suitable, but if the devices are

centralized in the supervision room, this scheme is not suitable. At present, this scheme is not used in the project.

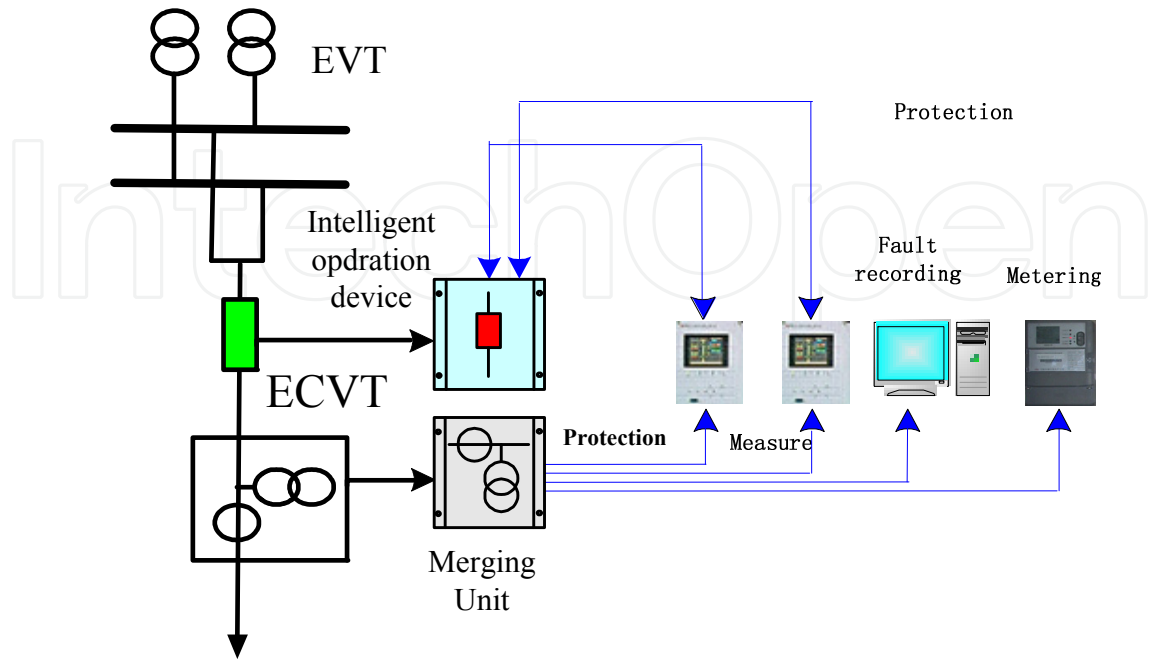


Figure 20. The structure of direct connection of GOOSE and MSV

3.3.1.1. Direct connection of MSV and network of GOOSE

This scheme has higher degree of automation than the scheme of fig.21. The discussion is followed:

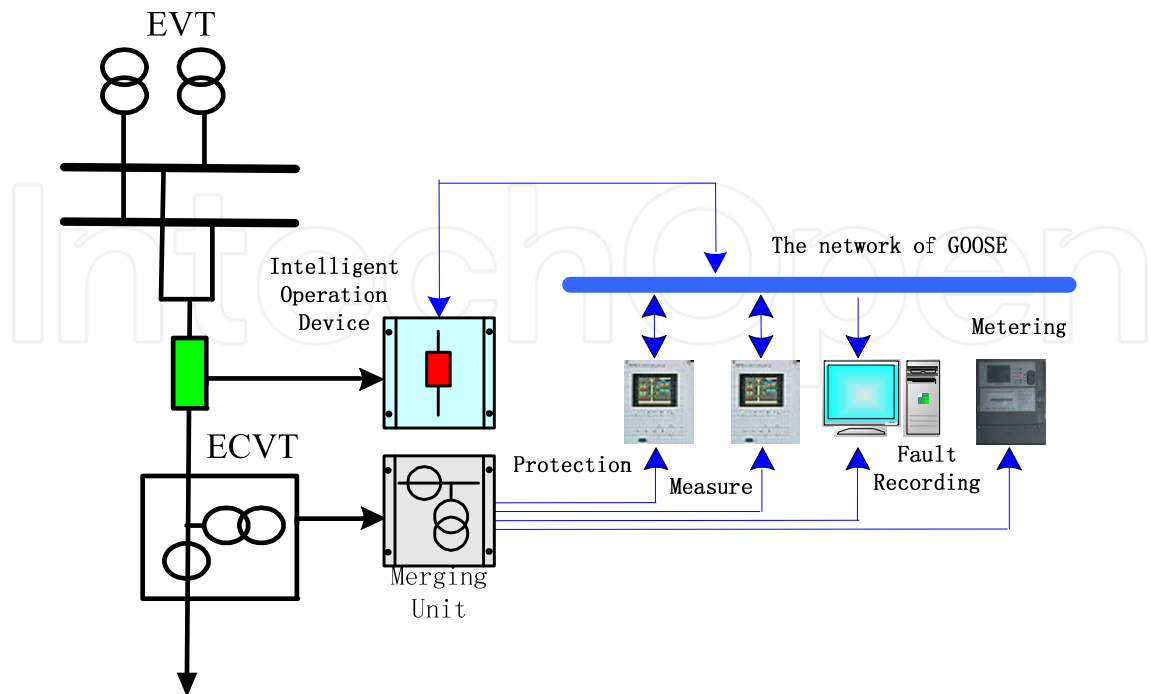


Figure 21. The structure of GOOSE network and MSV direct connect

The scheme cannot realize the sharing of sample data but can reduce the use of fiber as the trip is realized through the network of GOOSE. It meets the requirements of the standard of IEC61850 and the trend that the trip of intelligent switch through the network of GOOSE. It reflects the commonality and expandability of the standard of IEC61850. This scheme is widely used in the digital substation constructed earlier especially the substation of 220kV. The practical test show that the trip through the network of GOOSE can meet the requirements of real-time even in the heavy load.

3.3.1.2. The network of MSV and direct connection of GOOSE

This scheme only focuses on the network of sampling and can realize the share of sampling value.

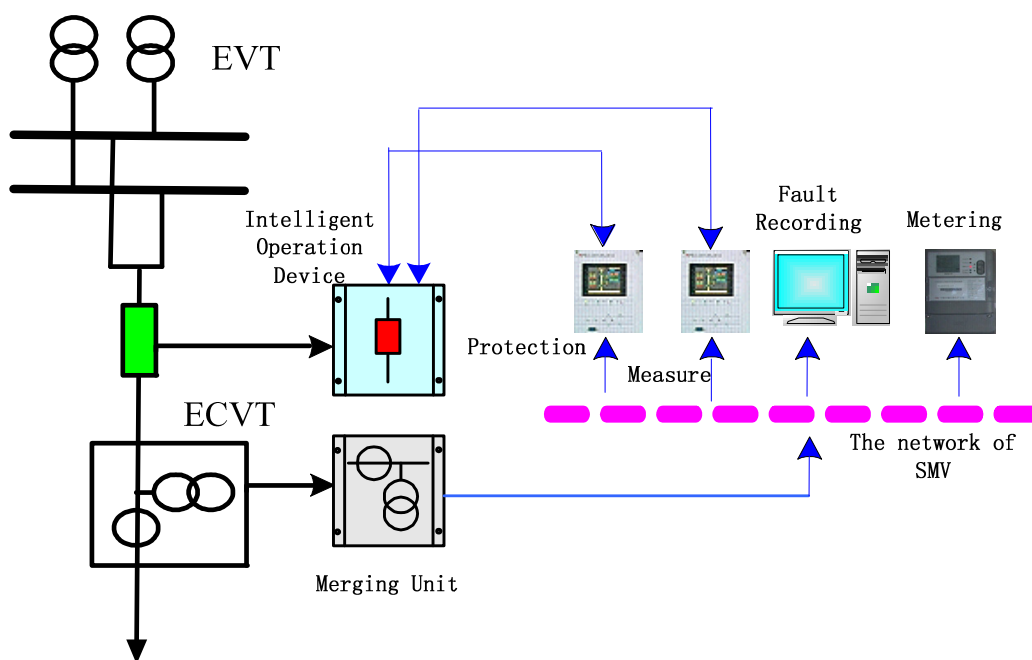


Figure 22. The structure of network of MSV and direct connection of GOOSE

This scheme is widely used in the digital substation constructed in early stage because of the GOOSE is not widely promoted as the performance and reliability of GOOSE is not tested by the project. In early stage, the focus is on the application the electronic transformer. Now, during the construction of smart substation, this scheme will be used in the upgrade of traditional substation.

3.3.1.3. The network of MSV and GOOSE

The scheme of the network of sampling data and GOOSE meets the requirements of process layer communication in the standard of IEC61850.

The network of sampling which can realize the sharing of data and the network of GOOSE which can realize the trip through the network can meet the development of substation automation and the requirements of process layer of smart substation. The structure of this scheme is complicated and the number of switch required is large especial the network is

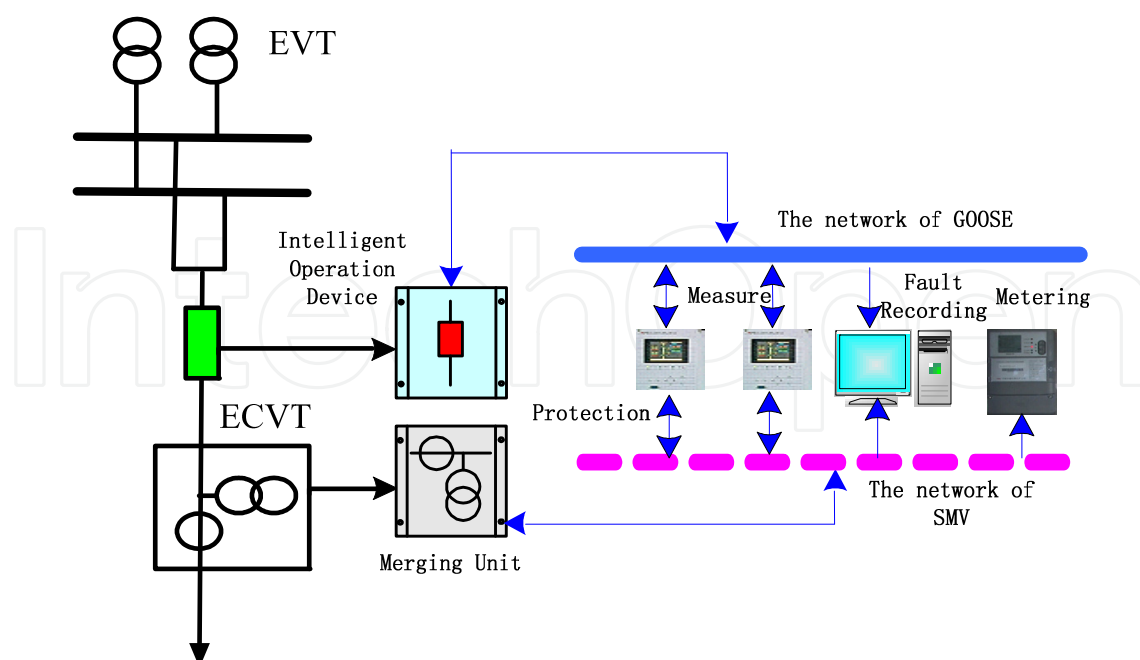


Figure 23. The structure of network of GOOSE and MSV

redundant which will increase the investment. The type of switch which meets the requirements of the standard of IEC61850 is few and the networks of MSV and GOOSE have the higher requirements of performance. The switch used in process layer is expensive and this is the reason that the cost of digital substation is large. At present, the scheme is widely used in digital substation and there is a lot of practical experience. The synchronization of IRIG-B is used in this type of substation.

3.3.1.4. The unite network of MSV, GOOSE and IEEE1588

This scheme is similar with the scheme of fig.23 except the synchronization. The accuracy of synchronization with IEEE1588 is less than 1 us and can meet all the requirements of substation. The realization of synchronization with IEEE1588 through the network has no requirements of additional connections which can reduce the cost. The type of synchronization with IEEE1588 is promoted and will be the trend of synchronization in smart substation.

This scheme has the higher requirements of performance of switch equipment which should support the function of IEEE1588 and process layer device which should have the higher processing power and support the synchronization of IEEE1588. The bandwidth of 100M can not meet the requirement of this scheme and the gigabit Ethernet will be the best choice. The implementation of this scheme needs the process layer device to be updated and the type of switch which fit the requirements is few, the product which is more expensive is new produced and the stability and reliability need verification in project. This scheme is already used in substation of 110kV of DaLv in ZheJiang province and substation of 220kV of MaShan in LiaoNing province.

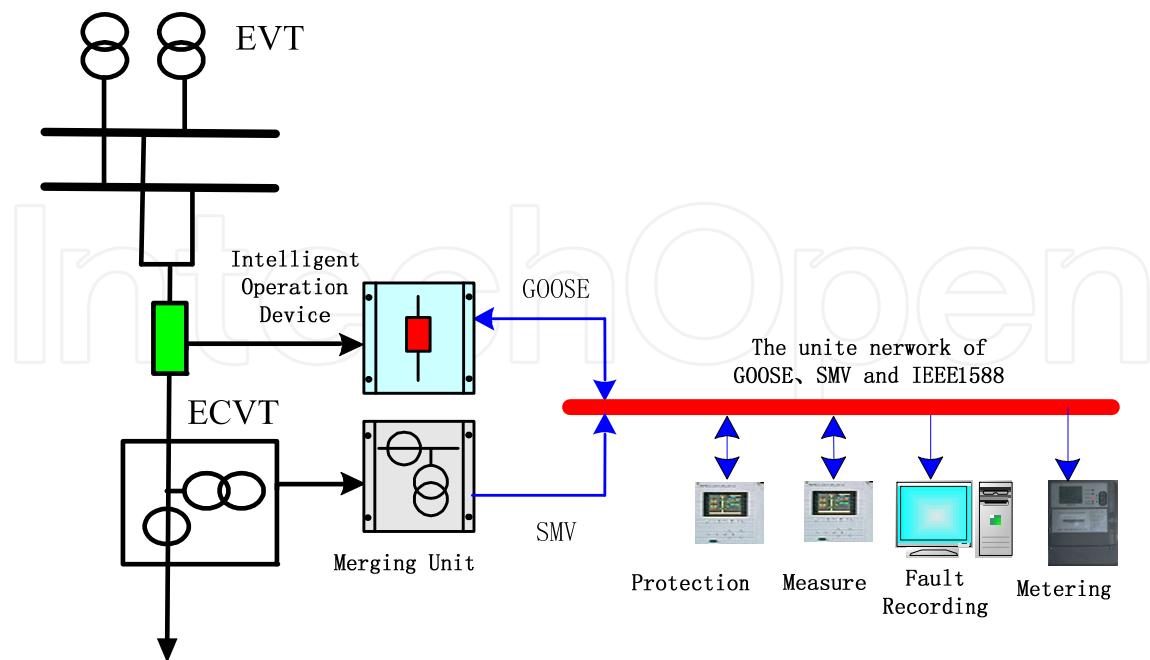


Figure 24. The structure of unite network of GOOSE, MSV and IEEE1588

3.3.1.5. The hybrid mode network

This scheme which the sampling and trip used for protection through the direct connection and the other implementation such as measure and metering through network is a hybrid of schemes discussed above and is generated according to the practical implementation of project.

This scheme is mainly on the consideration of the requirements of security and reliability of protection to avoid the failure of protection caused by the network and is also defined in the "Technical specifications of protection for smart substation" published by State Grid Corporation of China. This method has the high requirements of devices in process layer and bay layer. The merging unit and intelligent operation device should add a lot of net ports to meet the requirements of direct connection. At present, the fiber ports need eight at least and the other devices such as bus protection need more. The devices which meet the requirement of process layer and bay layer are in developed and have not used in the project. But the first batch of smart substation is designed according this scheme.

This method which meets the requirements of standard of State Grid Corporation of China and the basis of digital information, standardization and network while improving the security and reliability of protection will be the major scheme in future.

3.3.2. The implementation of packets filter

The communication in process layer which includes the transmission of sampling value of current and voltage, the status information of primary device and the signal of protection

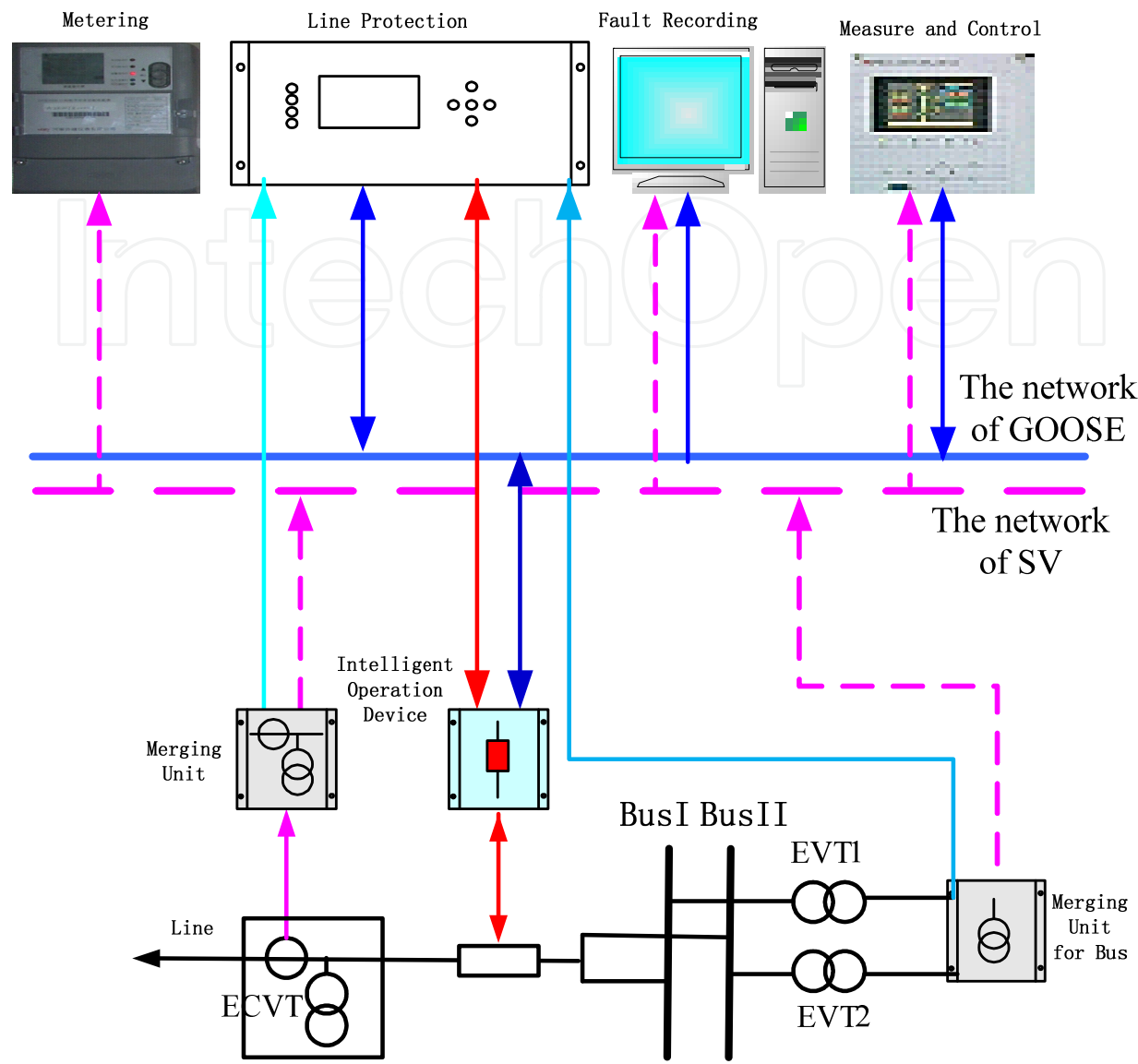


Figure 25. The structure of hybrid mode network in smart substation

and control device is real-time and has large information. In order to reduce the load of switch, to improve the security of network and increase the flexibility of management, convenience of maintenance and the expansion of substation, the virtual LAN should be implemented to filter the packets of the port which are not needed. The VLAN (virtual local area network) and GMRP (Group Multicast Registration Protocol) are the two methods widely used.

3.3.2.1. The implement of Virtual LAN

The load of the network of sampling value is very heavy especial when the sample rate is high, in order to reduce the number of packets retransmitted by the switch and to improve the reliability of the network, the devices in process layer should be divided into several virtual LAN. The unite network of MSV, GOOSE and IEEE1588 is also need to be divided in

order to avoid the master clock receiving the other messages which are not synchronization message of IEEE1588.

The technology of VLAN is widely used to filter packets in digital substation but the configuration of switch is complicated which increase the complexity of construction and maintenance. Once the structure of network changed such as reduce or add device the virtual LAN should be configured again.

3.3.2.2. *The implement of GMRP*

GMRP is a multicast registered protocol based on GARP (Generic Attribute Registration Protocol) which is used to maintain the multicast registration information of switch. The basic principle is: when a host wants to join the multicast group. It will send the join information. The switch receives the message and joins the port to the multicast group and sends broadcasting to the group of VLAN and then the multicast source will know the existence of new member. All the switches which support the GMRP can receive the register information from the other switches to update the local register information dynamically and can send the local register information to other switcher also^[6-8]. This kind of mechanism about information exchange can make sure the consistency of register information of the devices which support the GMRP in the same network. It suitable to the sampling based on the mechanism of publish/subscribe and IEC61850-9-2 and the transmission of GOOSE. Compared with the VLAN, the implement of GMRP do not need the configuration of switch but the switch should support the GMRP. This method is more flexible compared with VLAN and can reduce the difficulty of construction and maintenance.

Generally, the realization of VLAN which only need the configuration of switch is easy, but once the structure of network changed the VLAN should be divided again and the maintenance is complicated. Although the realization of GMRP involves the device and switch which should support the GMRP, it is more flexible and convenient to the construction and maintenance.

4. The introduction of the application in project

The construction of smart grid of China includes six segments which are power generation, transmission, transformation, distribution, utilization and dispatching, substation is one of the important parts. At present, the substation based on IEC61850 standard in China is called digital substation, new requirements are proposed by the construction of smart grid in China, and the combination resulted in the generation of smart substation. The smart substation is the use of advanced, reliable, integrated, low-carbon, environmentally friendly intelligent devices. Digital of all station information, network of communication platform and standardization of sharing information are the basic requirements to realize the automation of data acquisition, measurement, control, protection, metering, monitoring and other basic functions. The smart substation also supports the real-time automatic control, standardization, analytical decision-making online, collaborative interaction and other advanced functions.

The construction of secure and reliable smart substation is critical to the development of smart grid, the “Technical Guide for smart substation” is published by State Grid Corporation of China(shorted as SGCC) to guide the construction of smart grid in December, 2009. As there is not experience about the construction of the smart substation, the SGCC select different areas and different voltage level substation as the pilot. The data acquisition of the four smart substation of the pilot projects are introduced..

4.1. Shan-xi 750kV Yan-an substation

This substation is the highest voltage level substation in all the smart substations. The data acquisition is using the typical way which the data acquisition is through the network and the sampling network(SMV)and GOOSE network are separate. The detail is as fig.26:

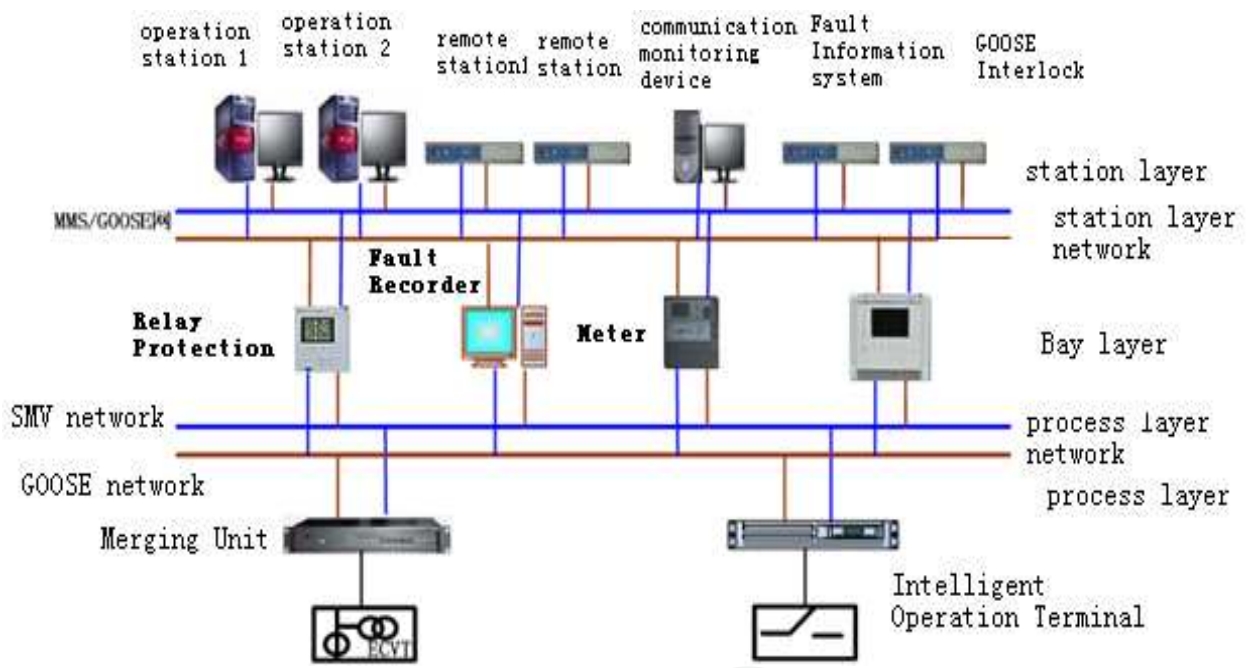


Figure 26. The structure of network

4.2. Ji-lin 500kV Chang-Chun substation

This substation is new constructed with many new technologies, the data acquisition is also through the network. This network is different with Shan-xi 750kV Yan-an substation. Although the merging unit and intelligent operation terminal is used but the sampling and GOOSE are in the same network and the network is redundant as A network and B network.

At the same time, the process layer network support the synchronization of IEEE1588. As the travel wave fault location need the requirements of high-speed sampling and the merging unit cannot meet it. So a separate high-speed sampling module is add in the CT/VT to realization the high-speed data acquisition.

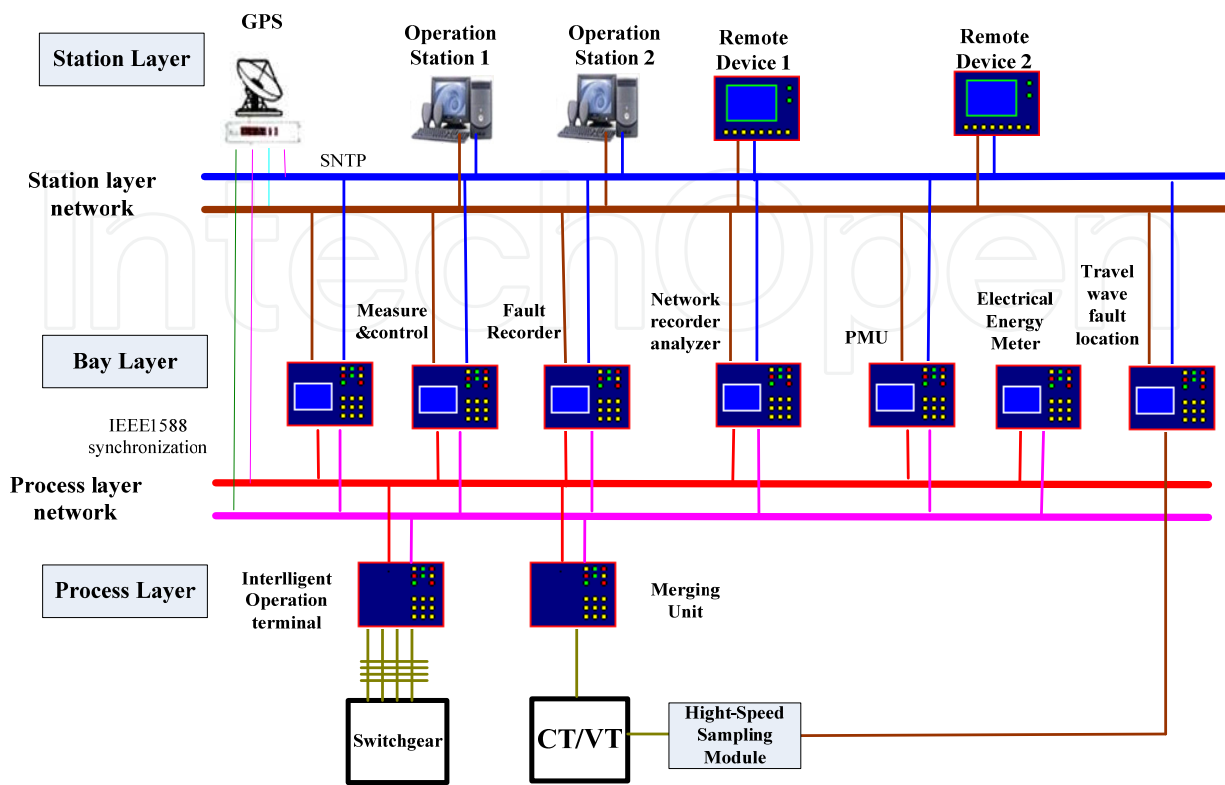


Figure 27. The structure of the network

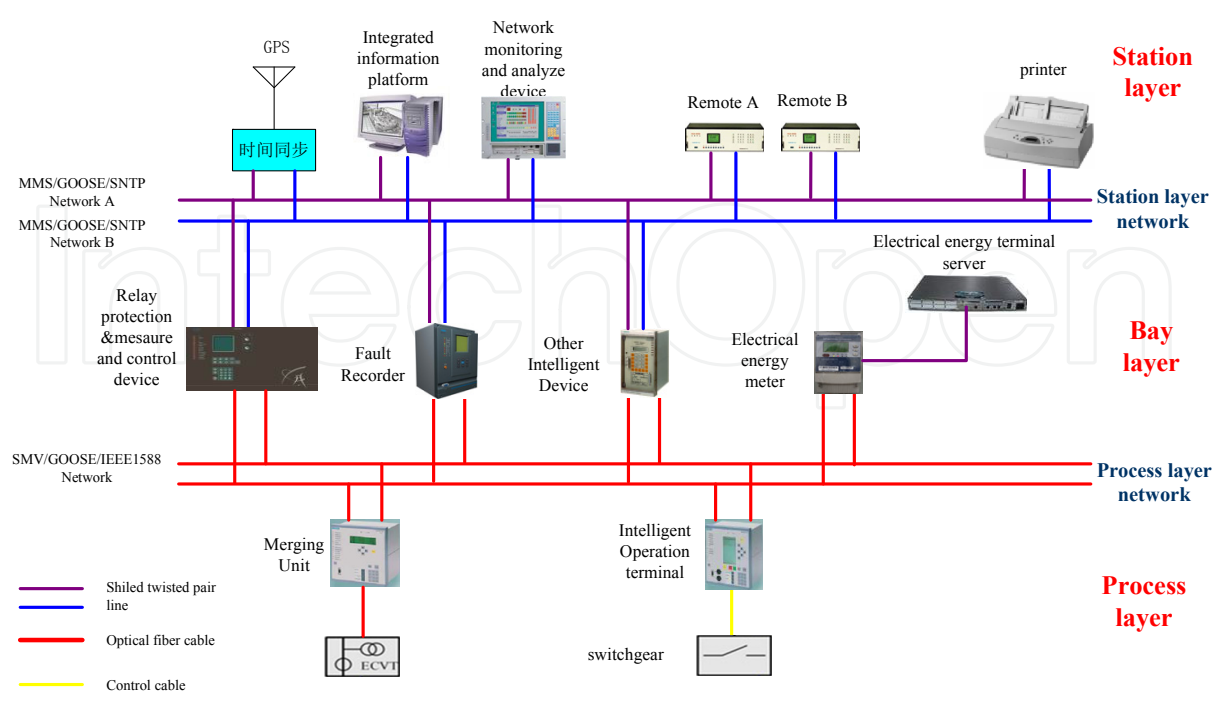


Figure 28. The structure of the network

4.3. Jiang-su 220kV Xi-jing substation

This substation is typical and many new devices and technologies are used. The data acquisition of this substation is also through the network but the SMV network which is based on 9-2, GOOSE network and IEEE1588 network are united which compose the process layer network which the data are full. The detail is as fig.28.

5. Conclusion

The construction of the first pilot projects of smart substation in China is developed and the plan of the second pilot projects is accomplished already. There are 41 new constructed substations have been operated until 2011.

The data acquisition in smart substation is very important to the security, reliability and economy of smart substation. The real-time data acquisition about the sampling value, status information and synchronization are introduced in this chapter. The sampling model and protocol based on IEC61850 and IEC60044-8 is widely used and the merging unit developed upon is now used in many smart substations. The mechanism of GOOSE and the configuration of the virtual terminal is the useful ways to make sure the status information transmit reliable. The principle of IEEE1588 and the realization of synchronization with IEEE1588 in merging unit is discussed which can make the error of synchronization below 1us and it has been used in pilot projects of smart substation.

The scheme of process layer network about the data acquisition which including the MSV, GOOSE and IEEE588 is significant to the security, reliability and economy of smart substation. The various solutions are compared and analyzed; it will be useful to the construction of the smart substation especially to the design of the process layer network.

According to the experience of the pilot project of smart substation of China, the smart substation will be constructed in large-scale in China and the plan that 6000 smart substations will be constructed in China until 2015 is publish by the Status Grid Corporation of China. The key technology of the data acquisition introduced in this chapter will play important role in the future.

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