

## Dependability Evaluation of Substation Automation System with Redundancy

HACHIDAI ITO<sup>\*+</sup>, KEIICHI KANEDA<sup>#</sup>, KOICHI HAMAMATSU<sup>#</sup>,  
TATSUJI TANAKA<sup>#</sup>, KOICHI NARA<sup>\$</sup>

\* Faculty of Engineering  
Ibaraki University  
Hitachi-Shi, Ibaraki 316-8511  
JAPAN

# Power Systems Control Dept.  
Toshiba Corporation  
Fuchu-Shi, Tokyo 183-8511  
JAPAN

+ Energy Automation Systems Engineering Dept.  
Toshiba Corporation  
Minato-Ku, Tokyo 105-8001  
JAPAN

\$ Fukushima National College of Technology  
Iwaki-Shi, Fukushima 970-8034  
JAPAN

*Abstract:* - Substation Automation Systems (SAS) are widely used for the purpose of control, protection, monitoring, communication etc. in substations to improve the reliability of the power supply. SASs adopting IT based solutions such as Ethernet LAN have recently become more common although hardwired control has been used in the past in earlier versions of SAS utilising simple communication methods. Moreover, IEC 61850 which is the international standard for communications within substations has been published, and the application of SAS based on IEC 61850 is increasing.

It is necessary to select each component and the configuration of the SAS from the viewpoint of dependability so that the dependability of the SAS, i.e. reliability, availability, and serviceability may have a very big impact in the stability of the power supply in the electric power transmission and distribution systems.

In this paper, we will describe the configuration policy of an IEC 61850 based SAS, its actual system configuration and the redundant configuration to improve dependability. In addition, we will explain some of the new functions not currently covered by IEC 61850 that we have developed to improve usability and availability. Following which we will present an evaluation of the dependability for MTTF (Mean Time To Failure), Availability, and FMEA (Failure Mode and Effects Analysis) for these configurations of SAS based on the dependability requirements for SAS.

*Key-Words:* - SAS, Substation Automation System, IEC 61850, Reliability, Dependability, Availability, System Architecture, Redundant System

### 1 Introduction

Substation Automation Systems (SAS) are widely used for the purpose of control, protection, monitoring, communication etc. in the substation to improve the reliability of the power supply [1]. SAS using IT such as Ethernet LAN has recently become more common although hardwired control has been used in the past in earlier versions of SAS utilising simple communication methods [2][3]. Moreover, IEC 61850 which is the international standard for communications within substations has been published [4], and the application of SAS based on IEC 61850 is increasing [5][6]. Furthermore, the method to transmit the current and voltage data at the process level using a network has

been developed and examined [7][8][9]. In addition the process bus has been standardized within IEC 61850.

However, it is necessary to select each component and the configuration of the SAS from the viewpoint of dependability so that the dependability of the SAS, i.e. reliability, availability, and serviceability may have a very big impact on the stability of the power supply in the electric power transmission and distribution systems. It is common to use various levels of redundancy within the equipment and the network used in a SAS to improve dependability. Moreover, it is often necessary to have sufficient level of redundancy in very important substations to achieve a high level of dependability, because the level of

redundancy implemented is usually decided based upon the trade-off between the importance of the substation in the power transmission network and the available budget. Since users such as electric power utilities and SAS manufacturers are interested in the dependability of SAS, various considerations on the dependability of SAS have been performed [10][11][12].

The main objective of recently published standard, IEC 61850 is to facilitate interoperability and it aims to enable logical configuration of the SAS by connecting various types of equipment from different vendors through an Ethernet LAN. However, the current version of IEC 61850 does not standardise the redundant configuration. Therefore each manufacturer uses different measures to realise the redundancy which results in different dependability levels and hence difficulty in ensuring interoperability. It is also a very important requirement to maintain interoperability between different manufacturers, different generations of equipment even from the same manufacturer, to enable easy configuration based on a common technology and to achieve better cost/performance.

In this paper, we will explain the concept of system configuration of a SAS using IEC 61850, its actual system configuration and approach to redundancy to improve dependability. In addition we will explain some of the new functions not currently covered by IEC 61850 that we have developed to improve usability and availability. Following which we have performed a dependability evaluation for MTTF (Mean Time To Failure), Availability, FMEA (Failure Mode and Effects Analysis) etc. based on the dependability requirements which are necessary for SAS.

## 2 Overview of Substation Automation System (SAS)

In this section, we will provide an overview of the purpose, function and system configuration of SAS.

### 2.1 Background of SAS application

The SAS is a system that provides the automation functions for monitoring, control and protection within a substation and utilises recent improvements in the fields of electronics, information and communication technologies. Application of SAS has increased to fulfil a market requirement to decrease the total cost, including life cycle costs of substation

equipment, highly effective operation or near-limit operation of the substation equipment, and the optimization of maintenance costs etc.

Application of SAS to substations began in the 1980's, and systems applied in accordance with international standard specifications such as Ethernet and TCP/IP, etc. as well as systems that utilised proprietary methods from different manufacturers have been applied from the 1990's. IEC 61850 which is the international standard for communications within substations was established from 2003 to 2005 and has become very popular and its application has increased very rapidly in recent years.

A major break-through has been achieved with the application of the IEC 61850 standard. This is the realization of "Interoperability" which is also an objective of this standard. It is expected that the system will be easier to configure in answer to the market requirements by having flexibility in the system configuration. The new standard continues to have a large impact on the design and implementation of SASs and very positive active discussion has continued based on practical experience from manufacturers, system integrators and end-users. This has resulted in further improvements to the standard and this work continues.

Table 1 Overview of SAS functions

Basic functions	Typical examples of functions
Monitoring functions	<ul style="list-style-type: none"> <li>Monitoring of switchgear status, tap position and status of transformer and tap changer, status of protection and control equipment, etc.</li> <li>Monitoring of electrical quantities, e.g. current, voltage, frequency, power and reactive power, etc.</li> </ul>
Control functions	<ul style="list-style-type: none"> <li>Control for switchgear and transformer tap</li> <li>Synchronism check and interlocking</li> <li>Voltage regulating control and voltage-reactive power control</li> </ul>
Recording functions	<ul style="list-style-type: none"> <li>Recording the monitoring data and manipulation/control of facility/device</li> <li>Fault record of facility and device Disturbance fault record</li> </ul>
Protection functions	<ul style="list-style-type: none"> <li>Protection for Transmission line, Transformer, Busbar, Generator, Distribution feeder, Shunt reactor, Shunt capacitor etc.</li> </ul>

### 2.2 Basic functions of SAS

The basic functions of a SAS are categorised into 4, i.e. monitoring, control, recording and protection. Most

SAS systems have the functions described in Table 1, even though these may vary from project to project.

### 2.3 Basic system configuration

In this subsection we will describe improvements related to system configuration when applying IEC 61850, and the basic system configuration of SAS adopting IEC 61850.

#### 2.3.1 SAS before IEC 61850

Fig. 1 shows a basic system configuration example of SAS before IEC 61850 is adopted. This system configuration, which is still widely used all around the world is based on a distributed-bay configuration policy and utilises Ethernet and TCP/IP for the LAN in the substation. The substation LANs consists of a Station-level LAN and a Bay-level LAN. The Bay-level LAN can be separated into different voltage-levels which is one of the measures used to improve system reliability. Furthermore, a Standard Time Signal provided by GPS (Global Positioning System) is distributed to each BCU (Bay Control Unit) through a Time Distributor in order to realise an accuracy of 1ms for event recording by each BCU. Dedicated optical fibre is used for transmission of the Time Signal from the Time Distributor.

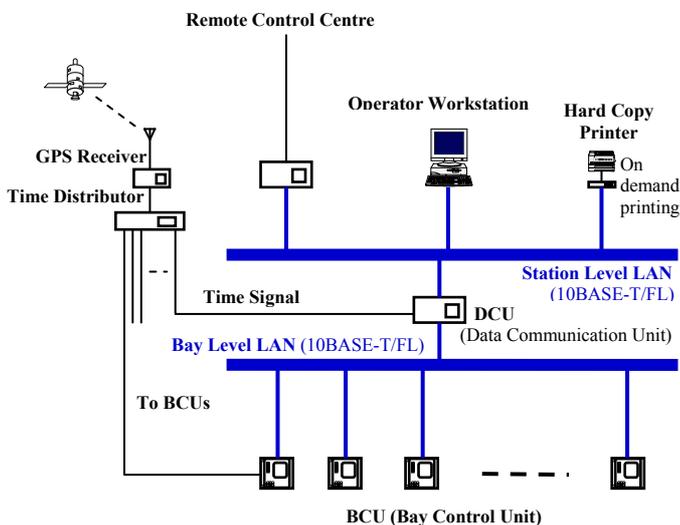


Fig. 1 Basic system configuration example of SAS without IEC 61850

#### 2.3.2 SAS adopting IEC 61850

A basic system configuration for a SAS having a distributed Bay approach adopting the IEC 61850 communication standard within a substation is shown in Fig. 2. In this configuration we have implemented the following improvement and simplification to the

system from the viewpoint of achieving higher system dependability, and a better balance between redundancy and efficiency.

- Unification of some devices to simplify system configuration (Integration of DCU, Gateway and Substation Server into one Station Computer). The result is a 30% reduction in hardware which in turn reduces the overall failure rate of the system.
- Integration/simplification of Station-level LAN and Bay-level LAN into Station Bus.
- Removed the dedicated communication lines for Time Signal by adopting IEC 61850 based SNTP (Simple Network Time Protocol).
- Instead of the Star topology LAN used in the past, we have adopted a Ring topology LAN which has the advantage of achieving a higher redundancy and shorter cable length. The system uses RSTP (Rapid Spanning Tree Protocol) for the Ring-topology LAN so that the system can remain less complicated and inexpensive whilst still providing a high level of redundancy.

Although this is the minimum configuration to achieve all of the SAS functions, the system still has sufficient flexibility in terms of maintenance and future expansion by using a Bay distributed configuration and ring LAN. This system configuration is in widespread application today.

An outline of the main system components is given below;

(a) Operator workstation:

This is an HMI (Human Machine Interface) device which is used to perform control and monitoring operations for the entire substation. Engineering tasks, such as database maintenance and relay setting can be equipped in this HMI device.

(b) Station computer:

The station computer is a substation server device providing control and monitoring functions, a remote control centre interface function, data recording function, etc. Moreover, as it is one of the most important devices in the system the hardware that is used is for industrial applications, with the emphasis on dependability.

(c) BCU (Bay Control Unit):

This is a multifunction control and monitoring unit equipped with a control and monitoring function at the bay level for a single line. BCUs are provided for each line and mounted in the LCP (Local Control Panel) or control device. The BCU executes control processing in response to commands from

the operator workstation or remote control centre under normal operational conditions. It is also provided with an LCD having a system display function. Local control from the BCU can also be achieved.

(d) Station bus:

This shows an intra-substation LAN which is compliant with the IEC 61850 standard for establishing connection with the various IEDs. The ring topology shown in Fig. 2 has the following features:

- Shorter total cable length
- Redundant communication path
- Prevention of data looping for broadcasting data using RSTP (Rapid Spanning Tree Protocol, IEEE 802.1w)

Therefore the ring-type configured LAN with the application of RSTP is more widely used. RSTP is a protocol through which communication paths are logically formed in a star configuration and controls the transmission paths in such a way as to prevent a

loop of multi-address transmission data. In addition, in the event of a failure in one of the transmission paths it also provides a function to reconfigure the paths at high speed. Even if a failure occurs in the communication paths, reconfiguring the paths through this protocol enables continuous transmission over the station bus and system operation to be performed. See Fig. 3.

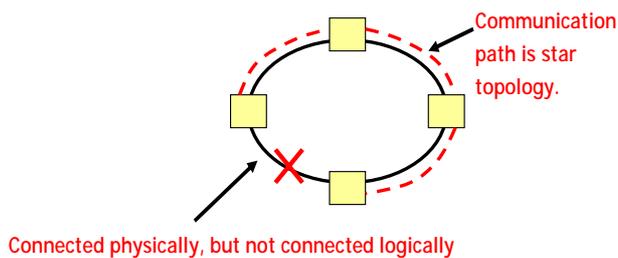


Fig. 3 Outline of RSTP

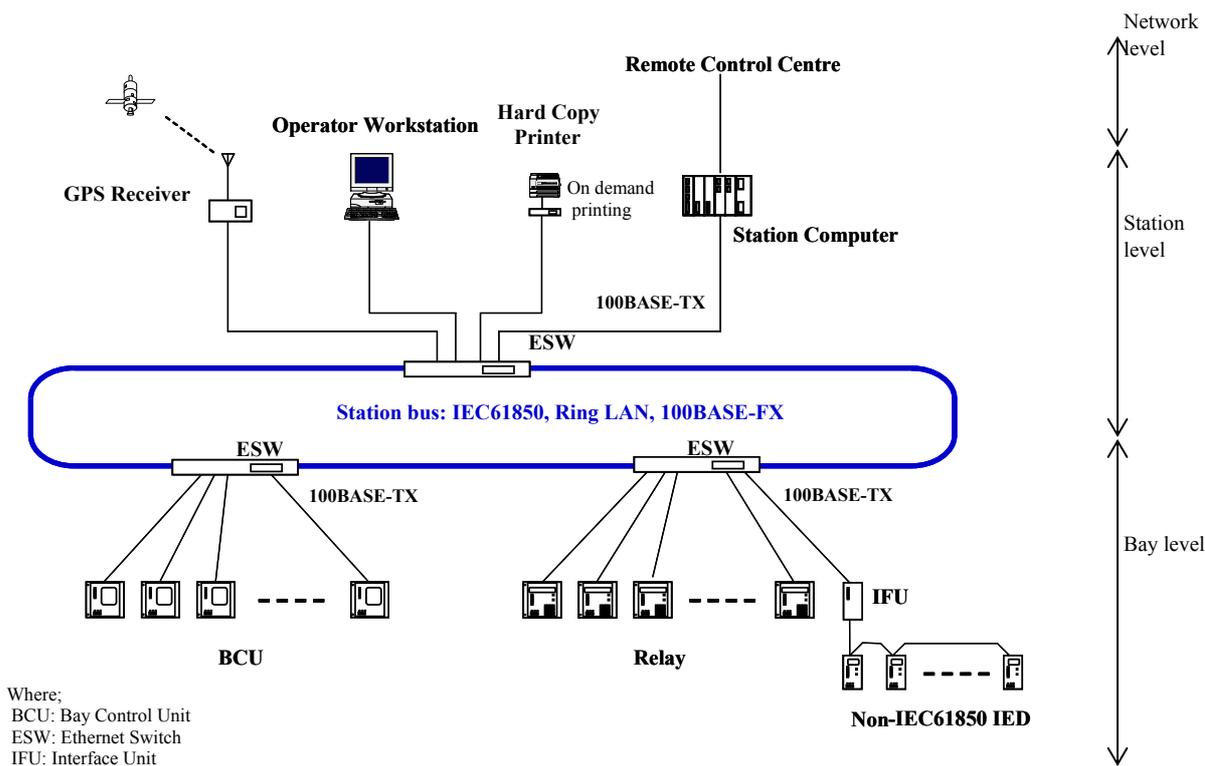


Fig. 2 Example of basic system configuration with ring network topology

2.4 Communication method

To ensure improvements in system maintainability and scalability, it is important to use a communication

method that is excellent with regard to it being open and being able to provide connectivity in accordance with the relevant international standards. In view of

this, the communication methods which are compliant with the following IEC standards are applied to the SAS:

- Communication between remote control centre and substation control and monitoring system: IEC 60870-5-101/104
- Communication between protection relay and substation control and monitoring system: IEC 60870-5-103/IEC 61850
- Communication within substation control and monitoring system (Station bus): IEC 61850

## 2.5 Further improvements to the system

In addition to the implementation of the IEC 61850, we have developed and implemented a number of functions to improve SAS in terms of usability and availability etc. The functions described in 2.5.1 and 2.5.2 out of those many functions we developed have important features in a highly reliable SAS. By utilising these functions the users of the system will be quickly informed as to the status of the system or be able to shorten the repair time when a failure occurs within the system. These improvements result in shorter MTTR (Mean Time To Repair) and higher dependability of the system.

### 2.5.1 Dedicated logical node for IED failure

Logical nodes of physical devices or logical devices defined in the current version of IEC 61850 have only "Health" attributes to show the status of the system. As a consequence the attribute can only show the difference in the status of normal, light failure or heavy failure conditions. This results in the SAS operator only being informed of which IED has failed. In this case the operator will have to replace the complete IED unit which usually takes about 4 to 6 hours, even after obtaining the new IED, including re-wiring, re-configuration of the IED, confirmation tests etc. The user may also inspect the IED in location in order to determine which part inside the IED has failed, but it also may take hours.

We developed and implemented dedicated logical nodes and mechanisms within our IEDs to notify the operator which circuit board has failed. In order to maintain as high a level of interoperability as possible when an IED has failed, the logical node is implemented as a "GGIO (Generic Process I/O)" logical node as defined in IEC 61850. This dedicated logical node is used to inform the operator of where the failure has occurred in order that it is only necessary to replace the failed circuit board rather than

the complete IED. With this approach the repair time of the system is dramatically shortened to about 10 minutes for an I/O board up to 1 or 2 hours maximum for a more complex CPU board which requires re-configuration etc.

### 2.5.2 Usability improvement by unselect report

The SBO (Select Before Operate) control method is used in IEC 61850 and most SASs. The state transition of SBO control is shown in Fig. 4. When an unselect condition occurs after entering the "Ready" state, a method of how to notify the unselect state from an IED to the HMI is not defined in the current version of IEC 61850. Although the "stSeld" attribute is provided in IEC 61850, it will notify only "Select" or "Unselect". With this notification alone, i.e. without any reason for the "Unselect" condition, the operator has to find out why it has occurred by him/herself.

To improve this situation, we developed and implemented a dedicated logical node utilising "GGIO" to notify the type and reason for the "Unselect" error in the IED. With this mechanism, when an unselect state occurs within the IED between the ready state and the operate state, e.g. IED failure, interlock condition unsatisfied, control privilege unsatisfied etc., the type and reason for the error, i.e. unselect, can be notified immediately to the operator.

Without this function, the operator must investigate the reason of the unselect. Since there are nearly 20 possible reasons, it may take about 10 minutes or more for the operator to find out the real cause of the error. The new feature we implemented assists the SAS operator in improving availability and shortening the repair time of the system.

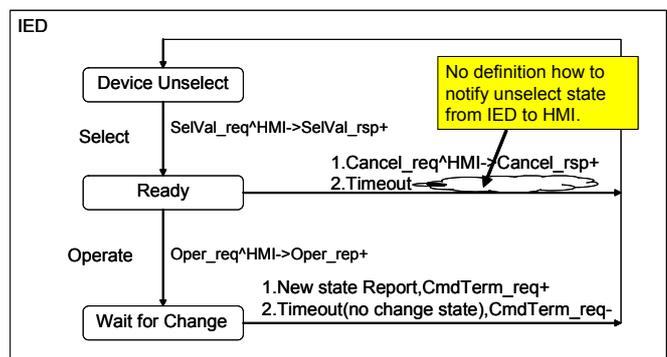


Fig. 4 SBO Control state transition

### 3 System Architecture for SAS

Investigation into optimisation of dependability and connection between substation equipment and devices using IEC 61850 is shown in this section.

#### 3.1 Concepts of system configuration

When IEC 61850-based SAS is applied to a substation, the following two points should be considered by system integrators;

- (a) To avoid system unavailability due to a single point of failure
- (b) To provide an integration solution for non-IEC61850 devices/signals in an equipment/substation

Item (a) is very important and should be carefully considered in order to ensure dependability of operation for the substation. However, too much emphasis on dependability may cause complexity in system configuration and result in an increase in costs. Therefore a system integrator must propose an appropriate configuration for a particular system.

The point covered in (b) above is an issue to be considered because not all IEDs are IEC 61850 compliant since IEC 61850 is a rather new standard. Furthermore (b) is important for instances where the input information required is only available via mechanical contacts. Generally contact information is captured at the BCU and translated into IEC 61850 information. But inputs to the BCU may not be allowed in order to separate control functions from protection functions by users. In addition, minimising the cable length for contact inputs may be a consideration.

#### 3.2 Solutions for system configuration

System integrators need to propose solutions based on the concept of the system configuration described in Subsection 3.1.

This is especially important to minimise the effect of one failure, the redundant architecture described below can have a large impact;

- (a) To adopt redundant configuration of the station computer and operator workstation, these are the common devices at the station level in order to prevent the loss of the total system due to one failure.
- (b) To ensure communication reliability by adopting a redundant configuration of Ethernet switches at the station level connecting the station bus with

the station computer and operator workstation which are redundant as mentioned in (a).

- (c) To ensure redundant paths by adopting a ring topology with redundant feature for the station bus. Furthermore separating the ring configuration into several rings can also improve the dependability.
- (d) Ethernet switches at the IED side are used by several IEDs in common. Failure of the power supply will have the greatest impact as it will result in the total loss of function of the switch itself. Therefore it would be better that the power supply for each switch were redundant to increase reliability.

Information exists on non-digital devices or non-IEC 61850 devices in the substation or in protection relay panels. To integrate this information into the system, an IFU (Interface Unit) can be used which has interface functions for serial communication and binary inputs/outputs.

It will be possible to optimise system configuration and cost by paying heed to the measures described above.

#### 3.3 A system configuration

Fig. 5 shows the actual system configuration adopting the concept and solutions described in Subsection 3.1 and 3.2. The main features of the system are as follows;

- (a) Redundancy in equipment at station level enables higher dependability. The Ethernet switches are redundant because they are used to connect equipment at station level to the station bus.
- (b) To minimise the effect of device failure, a distributed bay configuration is used for IEDs such as the BCU or protection relays.
- (c) The most suitable number of Ethernet switches at the IED side is selected based on the number of IEDs and ports per switch. When considering the number of switches to be employed it is necessary to consider the impact on the system at the time of failure of the switch and optimisation of the cost. However, there are possibilities to use several independent switches for control IEDs because of the importance of communication for control when compared to than for protection. The same issue may apply to the ring configuration of the Station bus, and then it is possible to have several separate ring LANs instead of a single ring LAN.
- (d) An IFU is used when it is necessary to integrate mechanical contact information and/or protection

relays which are not compliant with IEC 61850 or analogue-type relays.

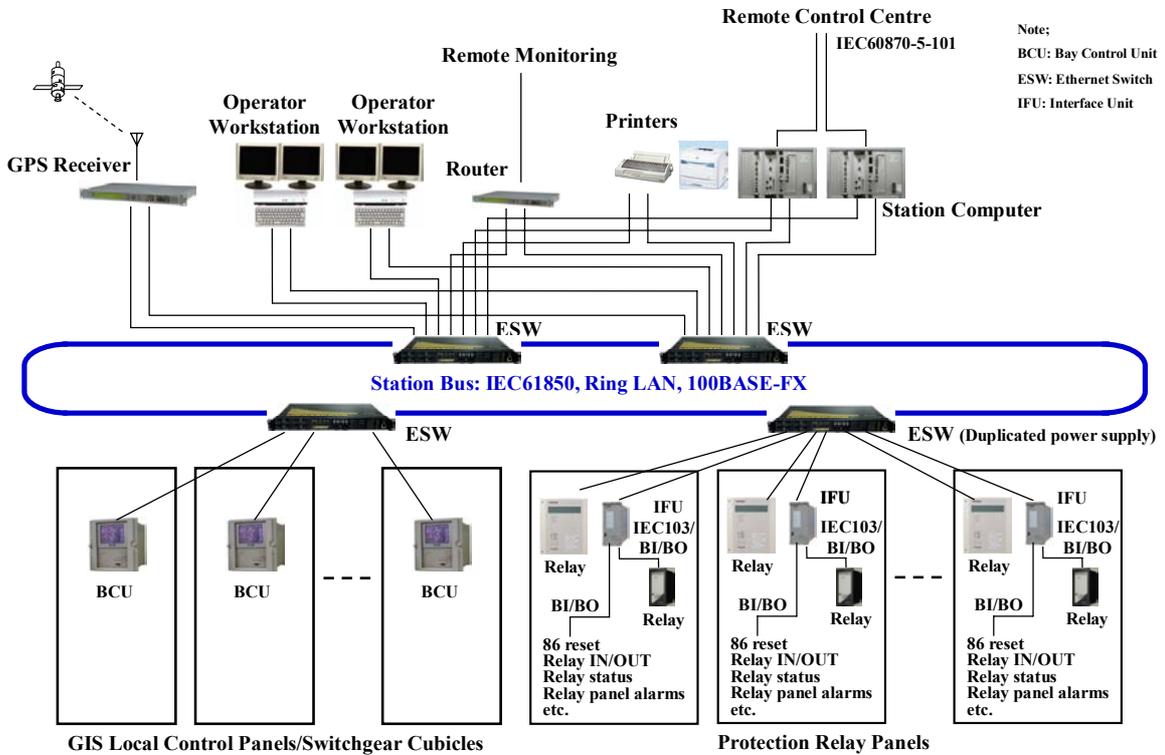


Fig. 5 Example of redundant system configuration

### 4 Dependability Evaluation

As one of the indicators that can be used to evaluate a SAS, dependability evaluation is described in this section.

#### 4.1 Dependability calculation method

Formulae to calculate MTTF, MTTR and Availability which are parameters that can be used to evaluate the dependability of a system as follows [13][14];

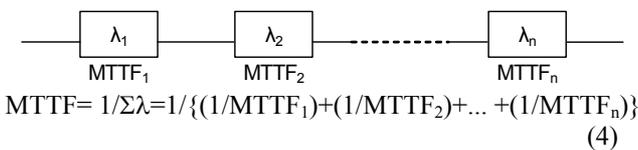
$$MTTF = 1 / \lambda \tag{1}$$

$$MTTR = 1 / \mu \tag{2}$$

$$Availability = MTTF / (MTTF+MTTR) \tag{3}$$

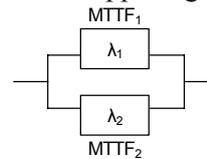
where  $\lambda$  is failure rate and  $\mu$  is repair rate.

MTTF of the serial model below is calculated as follows;



$$MTTF = 1/\Sigma\lambda = 1/\{(1/MTTF_1)+(1/MTTF_2)+... +(1/MTTF_n)\} \tag{4}$$

MTTF of the redundant model (parallel model) below is calculated as follows supposing  $\lambda=\lambda_1=\lambda_2$ ;



$$MTTF = (3\lambda + \mu) / 2\lambda^2 = (3MTTF/2) + (MTTF^2/2MTTR) \tag{5}$$

#### 4.2 Dependability calculation

We evaluated the dependability of the basic configuration of the SAS shown in Fig. 2 and the redundant configuration shown in Fig. 5. For the dependability of the system, we evaluated the Availability of monitoring and control system in one bay. Table 2 shows the MTTF of the main components of the system. These MTTF values were calculated from the supply experience of Toshiba SASs.

Table 2 MTTF for main components

Components	MTTF (year)	Remarks
Station Computer	41	With HDD for historical data recording
Bay Control Unit (BCU)	154	
Ethernet switch	12	16 optical ports

The average repair time is 4 hours based on our experience and with the new features described in 2.5 to improve repair time. Therefore an MTTR = 4 hours is used in the following calculation.

During remote control operation, the basic and redundant configurations can be modelled as depicted in Fig. 6 and 7 when focusing on one of the bays.

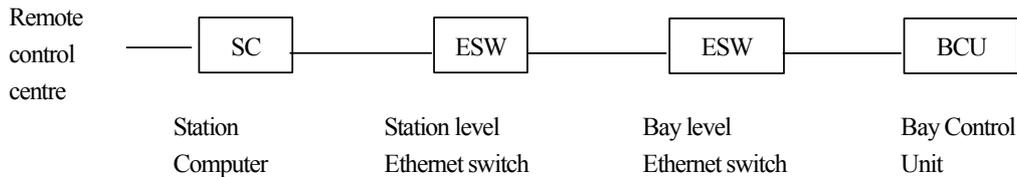


Fig. 6 Dependability calculation model for basic system configuration

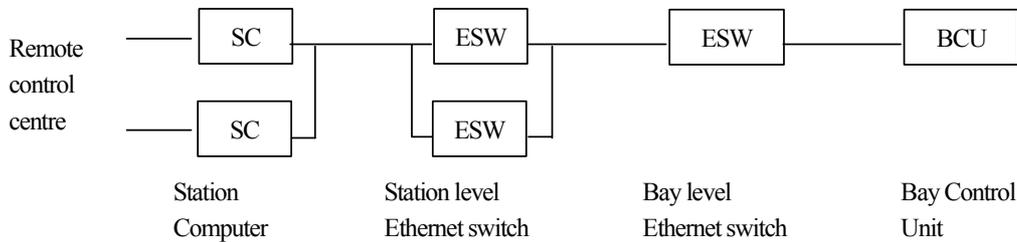


Fig. 7 Dependability calculation model for redundant system configuration

The Availability for the basic system configuration (Case 1) is 99.9820% based on the calculation using formula (4), MTTF in Table 2 and MTTR=4 hours.

On the other hand, the redundant system configuration results in a much higher Availability, since the station computer and the Ethernet switches, which are common parts in the system, are redundant. The Availability for the redundant system configuration (Case 2) is increased, being 99.9918%.

Table 3 summarises the availability evaluation described above. Generally, users of SAS, i.e. electric power utilities, require Availability higher than 99.98% for the SAS. Both cases in Table 3 satisfy this criterion.

Table 3 Availability calculation

Case	Availability (%)
Case1: Availability for basic system configuration	99.9820
Case2: Availability for redundant system configuration	99.9918

### 4.3 Dependability consideration

It is important to conduct an FMEA for critical systems such as SAS. The basic system configuration has a risk that one failure in the system may affect the

whole system from the FMEA point of view. Therefore it is preferable to configure a redundant system for important or large substations. Ethernet switches have to be highly reliable because they are the key components that make up the LAN. Thus we have to select a switch which is compliant to the relevant IEC standards and is applicable in the harsh environment that is encountered in substations. As for a port failure in Ethernet switches, the MTTR can be shortened, i.e. Availability can be improved by preparing spare ports in the switch.

From the view point of FMEA, other redundant measures can be possible, such as the use of a redundant LAN or distributed Ethernet switches, for example additional switches for every Voltage level or individual switches for protection devices and control devices etc. However these redundant measures may increase system cost, maintenance cost or may decrease system capacity. Therefore it is not a simple decision. The redundancy level of the system should be considered and decided based on the overall consideration with respect to power system utilities' policy on SAS, importance and size of the substation, etc. The SAS configuration shown in Fig. 5 is one of the optimum solutions achieving a good balance between redundancy and its benefit.

Needless to say the use of high reliable devices, it is also other measures to improve dependability in wider meaning to use redundancy explained already, to use distributed system, to simplify system and/or functions, to adopt fail-safe and/or fool-proof design etc. These measures can reduce human errors and need to be considered in designing a system or equipment.

## 5 Conclusion

In this paper, we have described the configuration policy for a SAS applying IEC 61850, the system configuration and the redundant configuration to improve dependability. Also, we have explained some of the new functions that we have developed, in order to improve usability and availability which are not currently covered by the IEC 61850 standard. Then we presented a dependability evaluation for MTTF, Availability, and FMEA for these configurations of SAS based on the dependability requirements for SAS. Generally, users of SAS, i.e. electric power utilities, require Availability higher than 99.98% for SAS. Both of two cases of SAS configurations that we evaluated in this paper satisfied this criterion. Further, we need to choose the appropriate redundancy for the SAS to be applied in an actual substation from the view point of FMEA. It is important to apply devices which have a high enough dependability.

A substation automation system configured in accordance with the redundant system architecture described in this paper is scheduled for commercial installation in an EHV (Extra High Voltage) substation early 2009. We will propose this type of SAS system to various electric power utilities.

### References:

- [1] Klaus-Peter Brand et.al., *Substation Automation Handbook*, Utility Automation Consulting Lohmann, 2003
- [2] Keiichi Kaneda, Koji Igarashi, Koichi Hamamatsu, Shigekazu Morita, *Modern Substation Control and Monitoring System*, ICEE, Hong Kong, 1999.
- [3] N. Kusano, *New Trends in Protection Relays & Substation Automation Systems in Japan*, IEEE/PES T&D Asia Pacific Conference, Japan, 2002
- [4] IEC 61850 "Communication Networks and Systems in Substations" 2002-2005 ([www.iec.ch](http://www.iec.ch))
- [5] Lars Andersson, Christoph Brunner, Fred Engler, *Substation Automation based on IEC 61850 with new process-close Technologies*, IEEE Bologna Power Tech Conference, Italy, June, 2003.
- [6] Klaus-Peter Brand, *The Standard IEC 61850 as Prerequisite for Intelligent Applications in Substations*, IEEE/PES General Meeting, USA, 2004
- [7] Masayuki Kosakada, Hiroshi Watanabe, Tokuo Ito, Yoshito Sameda, Yuji Minami, Minoru Saito, Shiro Maruyama, *Integrated substation systems – harmonizing primary equipment with control and protection systems –*, IEEE/PES T&D Asia Pacific, Japan, 2002.
- [8] M. Saitoh, T. Kimura, Y. Minami, N. Yamanaka, S. Maruyama, T. Nakajima, M. Kosakada, *Electronic Instrument Transformers for Integrated Substation Systems*, IEEE/PES T&D Asia Pacific, Japan, 2002.
- [9] Y. Minami, et al, *Substation architecture with protective relays using digital instrument transformers and digital interface technology*, IEEE/DPS, 2004
- [10] Klaus-Peter Brand, Martin Ostertag, Wolfgang Wimmer, *Safety related, distributed functions in substations and the standard IEC 61850*, IEEE Bologna Power Tech Conference, Italy, June, 2003.
- [11] Bogdan Kasztenny, James Whatley, Eric A. Udren, John Burger, Dale Finney, Mark Adamiak, *Unanswered Questions about IEC 61850, What needs to happen to realize the vision?*, 32nd Annual Western Protective Relay Conference, USA, Oct., 2005.
- [12] Lars Andersson, Klaus-Peter Brand, Christoph Brunner, Wolfgang Wimmer, *Reliability investigations for SA communication architectures based on IEC 61850*, IEEE PowerTech, Russia, 2005.
- [13] Martin L. Shooman, *Reliability of Computer Systems and Networks – Fault Tolerance, Analysis, and Design* -, John Wiley & Sons, 2002.
- [14] Jan Pukite, Paul Pukite, *Modeling for Reliability Analysis - Markov Modeling Reliability, Maintainability, Safety, and Supportability Analyses of Complex Computer Systems*, IEEE Press, 1988.