Development in Substation Automation Systems

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***Abstract*--The rapid pace of technological development shows no sign of slowing. Technological development has had and is still having a big impact on Substation Automation Systems.**

Nowadays, with the move towards electrical utility deregulation throughout the world, it is imperative to exploit the latest trends. Utilities and industry must be able to provide an even more efficient and cost-effective service. They must ultimately optimise their assets and stay ahead of the competition.

This paper describes, by reflecting back on Substation Automation history, today's developments and how users could utilise them in their Substation Automation Systems. In addition a summary of the gained benefits is given and some references are shown.

1. INTRODUCTION

Since Siemens introduced the first digital/numerical and decentralised concept for Substation Automation Systems (SINAUT LSA) 20 years ago, some major achievements and trends have happened.

The first Substation Automation Systems (SASs) typically had a master-slave architecture in a star topology and used vendor-specific proprietary protocols within the Substation and to a Network Control Centre (NCC)/SCADA System.

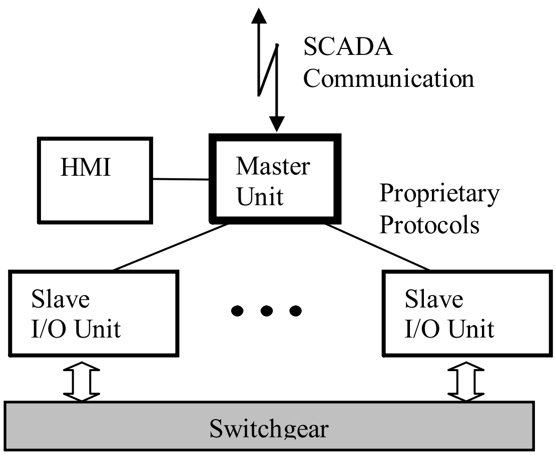

Figure 1: Typical Master-Slave Architecture of a 1st Generation Substation Automation System

Due to the non interoperability of communication & data modelling, substation integration was very complex and risky. Therefore the user was often bound to one vendor. The usage of protocol converters was quite often essential.

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Needless to say, in those days the interoperability of engineering data was not even a topic of discussion.

The master-slave architecture itself created some additional system immanent limitations:

- Station-wide automation functionality is located in the master
- Master represents a bottleneck
- Communication between master & slave is in polling mode only, i.e. not event driven
- No direct communication between two slaves

Hardware, communication equipment and the Human Machine Interface (HMI) were often from one vendor and thus development was constrained. This led to limitations in functionality, performance and participation in new developments.

The switchgear interlocking was mainly done by a separate independent system, which was hardwired in parallel to the I/O units.

The configuration of a SAS was done offline using a PC/Workstation and then either programmed onto EPROMS or later directly loaded onto the master or I/0 units.

These first substation automation solutions focused on getting operational data, e.g. voltage, current and the status of switching devices to a NCC. Displaying these data provided a snapshot of the current functional and operational status of the system, thus helping to easily run the substation, but they didn't offer a complete overview of the system.

In short, the first important milestone towards substation automation had been achieved. The use of microprocessor-based decentralised systems did, however, leave lots of room for improvement.

The rapid dissemination of IT and communication in today's world and the users' demand for a secure and sound investment have driven substation automation towards more standardisation, interoperability, reliability and superior performance. How did we meet these new requirements and address the existing and on-going trends and developments?

2. TRENDS & DEVELOPMENTS IN SAS

2.1. USE OF STANDARDISED COMMUNICATION

Before the new IEC 61850 standard entered the SAS world, Ethernet was already present. For example, Ethernet was used as the communication platform between HMI and the master unit. Why was Ethernet the right approach?

- Ethernet is part of the Internet Protocol Suite and is a packet switched network
- Ethernet is today's world standard for LAN office communication
- Ethernet supports multi protocols & services over one physical medium
- Redundancy such as redundant fibre optic loops is available
- Industrial communication is also trending towards Ethernet

The use of Ethernet in our substation automation environment provides standardised high speed communication. A wide variety of proven equipment and experienced engineers are available. At the end of the day, Ethernet enables us to merge industrial, power and office communication together.

No big surprise that the recently adopted world-wide standard IEC 61850 for substation communication uses Ethernet for layers one and two. The main drivers for developing IEC 61850 were to achieve interoperability of protection and control devices/systems from different vendors and to enable much more than just communication.

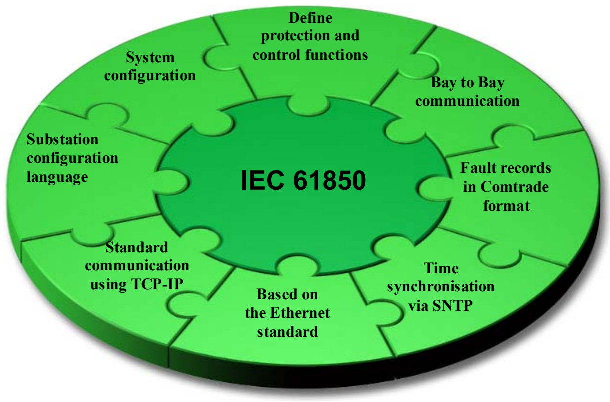

Figure 2: IEC 61850 Overview

These goals were met by considering the three fundamental parts [1] of communication within a SAS namely:

- Data models of the applications
- Services for transferring these data
- Real communication protocols.

The data models and the services rarely change in the course of time. The real protocols for implementing the communication can in theory be anything and can change. IEC 61850 standardises the data models, the generic services for transferring the data and specifies the following real protocols:

- Manufacturing Message Specification (MMS)
- TCP/IP
- Ethernet

These real protocols may be replaced by new ones so that the standard keeps pace with communication technology.

2.2. BENEFITING FROM WEB TECHNOLOGY

The rapid dissemination and indisputable acceptance of the World Wide Web (WWW) made us question the possibility of using web-based services and solutions in our SAS business.

We could for instance use web browser based configuration and diagnostics tools to remotely and cost-effectively access the substation. Another option could be to use a web server based HMI to monitor the substation and incorporate added value, e.g. by using webcams [2].

We simply use standard communication protocols for the SAS together with the standards from the IT-world, i.e. WWW-Services based on the Hyper Text Transport Protocol (HTTP). Figure 3 shows an overview of a SAS network, which comprises traditional telecontrol communication between a NCC and several substations, together with client/server technology using the Intra- and Internet.

Each substation communicates using two independent protocols via the station router. These two protocols are namely the traditional telecontrol protocol DNP over TCP/IP or IEC 60870-5-104 for communication between the substation and the NCC and the modern HTTP-based communication for communication between the substation and the web clients. It is possible to run these two protocols in parallel without loss in communication performance, due to the design of TCP/IP based communication, which allows different applications or services to operate over the same network.

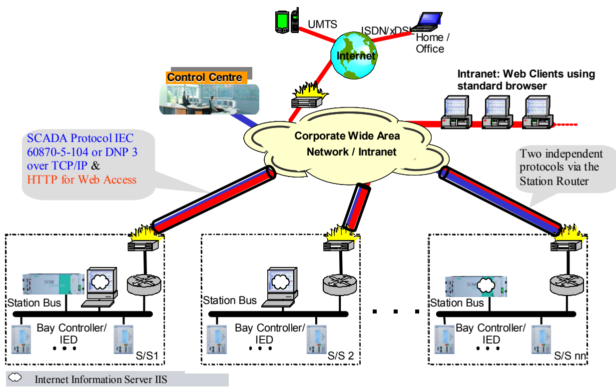

Figure 3: Web-Based Solution Overview

In large substations or estates with more than one substation it might be of interest to visualise a substation using web-based solutions.

To do this, so-called thin clients and terminal services can be used within the substation. For example, Windows 2003 terminal services can be installed on the substation's web server, along with the required applications and software.

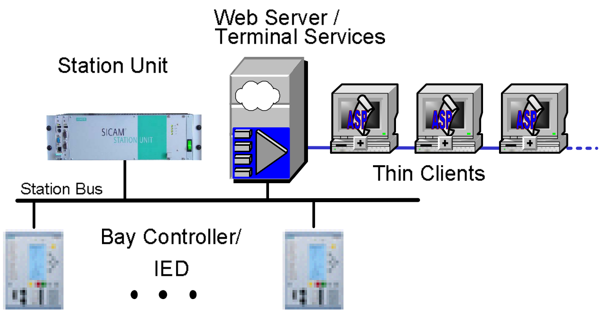

Figure 4: Thin-Client Technology Using Terminal Services

Each thin client opens its own session on the web server and operates like a terminal. Only keyboard signals, mouse signals and display contents are transmitted between the thin client and the web server, therefore reducing the system administration effort. Various operating platforms, e.g. UNIX, Linux, Mac, can run on the thin clients. Figure 4 shows an example of thin client technology using terminal services. Please note that the master unit is referred to as the station unit in today's SASs.

2.3. MAKING CONFIGURATION EASY & EFFICIENT

As described in my introduction, the first and so-called embedded systems based on proprietary hardware needed an offline tool running normally on a PC/Windows platform to configure and download data onto the system.

The engineering process comprised the system configuration (data mapping, automatic logic, etc.), compilation into a binary code and downloading onto the master unit. After which a restart was required to check the results. This was very time consuming and mainly done offline.

Another problem arose concerning the life cycle time of the SAS and innovation cycle of the IT world. The SAS life cycle is estimated at 15-20 years, but availability and support of the associated hard and software is much less. In other words, after 5-10 years it is very difficult to get a suitable set of compatible hard and software to configure an existing SAS. Substation retrofits and extensions are particularly affected.

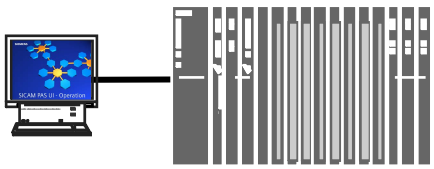

Figure 5: Typical Configuration/Download Process of an Older Generation Master Unit Using a PC

How did we combat this problem? Answer, we started to use standardised components such as specially designed industrial components with a life time of 15 years (hard and software). So now the station unit has both the runtime components and the necessary configuration tools already on board. This means no compilation and loading onto the runtime system is necessary. Changes can be made online which helps to accelerate the engineering process and a workable platform is available to maintain and configure the system for the entire life cycle.

Figure 6: Configuration and Operation Tools are Running on the Station Unit

2.4. MOVE TO DISTRIBUTED INTELLIGENCE

Compared to the classical master/slave systems used in the past, the intelligence has now been moved closer to the process by introducing distributed functionality. Today's bay and protection units have enhanced functionality, i.e. the SAS is based on distributed intelligence. This approach is fully supported by IEC 61850 and the so-called GOOSE (Generic Object Oriented Substation Event) mechanism. The GOOSE mechanism refers to the bay to bay or peer to peer communication between IEDs. The peer to peer communication can now be used for time critical automatic functions like load shedding, fast network restoration, reverse interlocking, etc. Needless to say, bay related and station-wide interlocking can be easily implemented using GOOSE.

Distributed intelligence eliminates system limitations associated with typical master/slave architectures, such as bottlenecks in the master unit. Functional redundancy, i.e. the HMI and station unit (data concentrator) are independent from each other, thus improving system availability.

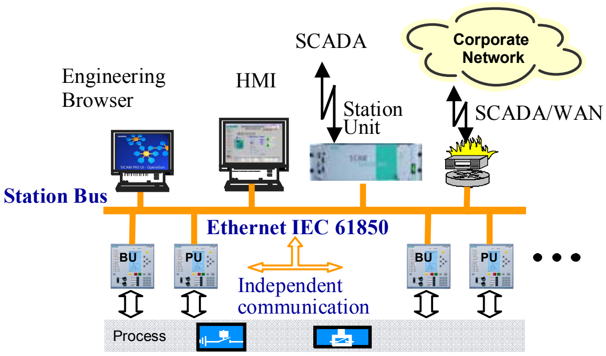

Figure 7: Client/Server Architecture Providing Distributed Intelligence

Although IEDs using new protocols such as IEC 61850 and DNP over TCP/IP could, provided that bandwidth is available, talk directly to a SCADA system; a station unit acting as an intermediate data concentrator is still useful and necessary, since most SCADA servers do not have enough CPU capacity to process frequent communication exchanges with every IED [4]. The station unit acts as a protocol translator and provides the SCADA with a single point of entry. The amount of data communicated to the SCADA is reduced and the system and controls are better secured.

2.5. DEVELOPMENT OF ENHANCED & COMPREHENSIVE SECURITY

Open & standard TCP/IP based communication requires enhanced security, i.e. the transport must be secured using, for example, IPSec, VPN, Wireless with WPA, in order to ensure privacy of data, voice and video streams.

Threat defence is implemented to defend the edge, protect the interior and guard the endpoints. Detection and prevention against external attacks can be managed by integrated network firewalls and intrusion detection systems (IDS). Protection against internal attacks is a typical task of integrated network security such as network behaviour analysis (NBA), policy implementation, etc. host protection against infection is normally implemented by desktop firewalls and antivirus software.

Trust and identify based networking using AAA (authentication, authorisation and accounting) can be implemented to control who or what has access to which resources.

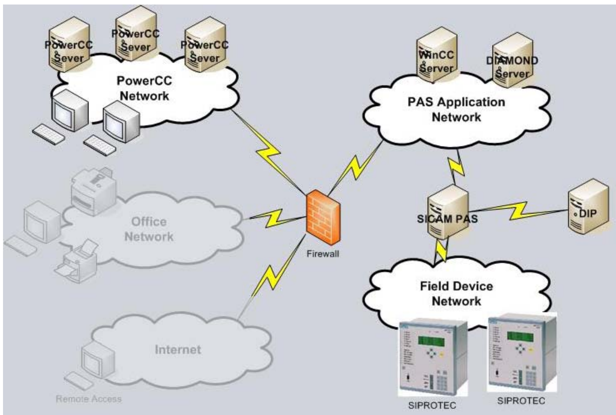

Figure 8: Typical Architecture of an Energy Automation Network

2.6. AIM TO MANAGE NON-OPERATIONAL DATA

A further challenge arises from the use of new SASs and intelligent high-voltage substations with integrated monitoring, which is leading to another irreversible trend – the increase in the amount of available data, which must be skilfully managed. These kinds of SASs contain a considerable number of IEDs which are capable of locally storing measured values, fault records and signals, to better support status monitoring of the substation equipment.

We also have the non-operational data like gas pressure, gas dissolving, transformer temperature, lightning, weather conditions and protection relay settings. This data mainly remains untapped.

Also older generation IEDs still using legacy protocols do not have separate independent ports allowing different users to retrieve both operational and non-operational data. Thus each type of user, e.g. a user responsible for maintenance, has to connect the IEDs to retrieve the required data.

As we discussed (or learnt) IEC 61850 uses Ethernet and TCP/IP which provides one common high speed data highway to transmit all kind of data simultaneously without impeding each other. So IEC 61850 solves the problem of data transmission, data model and interoperability, but still there is a gap between data generation and data understanding.

The future challenge will be to develop and improve data analysis techniques and methodology to extract the maximum benefit for the user. These so-called "Expert Systems" will be able to generate and support, for example, customised reports, condition based maintenance for transformer/circuit breaker and provide predictable future health and performance of the power system, i.e. optimise asset management.

3. USER BENEFITS

The main focus of all innovation and development has to be the generation of real user benefits. It is too easy to assess user benefit by only considering the investment cost and not comparing the life cycle costs. The added value of a modern SAS should be quantified. According to a study done by Helsinki Energy in Norway [3] the comparison of life cycle costs of conventional and numerical secondary systems showed that a fully numerical system saves 25% compared to a conventional one.

The following benefits attempt to emphasise the advantages of a new and fully numerical SAS using IEC 61850.

The IEC 61850 represents the first world-wide standard for all interoperable needs in a SAS environment. This standard gives the user the freedom of choice when selecting equipment from different vendors and allows the user to easily integrate the chosen equipment.

IEC 61850 running on an Ethernet based station bus reduces the wiring and commissioning time by providing one common platform for all communication within the substation.

Engineering expenses play an important role in the SAS life cycle costs. The IEC 61850 with its standardised substation configuration language reduces the engineering effort. This is becoming more and more relevant when implementing complex functions using IEDs from different vendors, i.e. doing substation integration.

In our SAS environment we consider a life time of approximately 15-20 years, i.e. the innovation cycle is much lower than in the IT world. In other words we need systems that provide a sound investment. Therefore the IEC 61850 separates the application and data model from the real communication network (today 100Mbit/s Ethernet). This means further and new innovation of communication networks can be easily adapted.

SAS web-based solutions allow us to benefit from the available Intra- and Internet networks and provide us with a very economic world-wide platform. We can offer user friendly and convenient remote access from any location, minimise costly substation visit and site supervision. Moreover vendors are able to give their customers remote diagnostic and hotline support. This results in a much faster and more effective service, especially if the customer and vendor specialists are located in different continents.

The new architecture using distributed intelligence clearly improves the reliability and performance of the entire SAS. Using the GOOSE peer to peer communication, the parallel wiring and engineering costs can be reduced. In addition, trouble shooting and further extension over the life time is much easier.

4. IEC 61850 References

According to the Frost & Sullivan Global Developments in Substation Automation 2006 Technical Insights Paper [4] Siemens holds a record for commissioning the world's first SAS based on IEC 61850 in Winznauschachen Switzerland early November 2004, only 6 months after the IEC 61850 was released. Another quite impressive project using IEC 61850 is Garzweiler Substation, owned by RWE Power (German power generation company).

In January 2006 Siemens announced its hundredth project running on IEC 61850 – Nanqiao Substation owned by the East China Power Grid Company.

A short overview of each application is given below [1], [5].

4.1. Winznauschachen Switzerland

The Swiss distribution network operator AVAG, a company of the Atel Group, requested a 16kV substation to be fitted with an IEC 61850 automation system. Figure 9 shows the corresponding automation system. The order was placed in April 2004 and the automation system has been in service since November 2004.

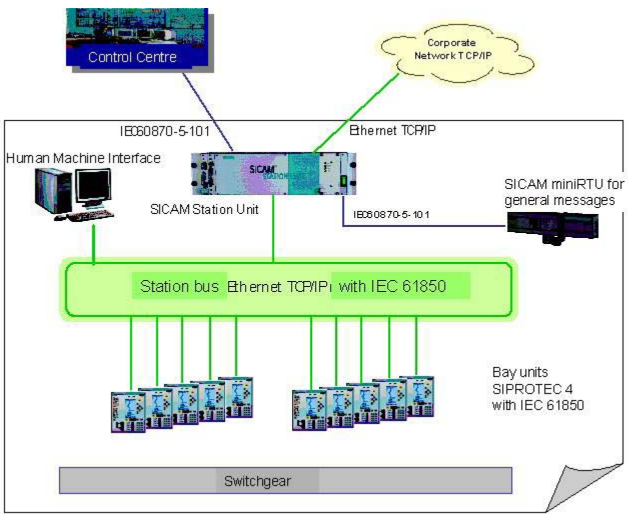

Figure 9: Atel Winznauschachen's Automation System

It is a non redundant system for a 16kV substation. The number of IEC 61850 devices is 9 and a small RTU is used to collect and transmit general alarms via IEC 60870-5-101 to the station unit. The link to the SCADA system was also done using IEC 60870-5-101.

4.2. Garzweiler Germany

The German power generating company RWE Power has equipped the Garzweiler substation with equipment compliant with IEC 61850. Three substations with 110kV, 25kV and 6kV respectively, supply electricity to an open cast mine which serves four power stations. Figure 10 shows the corresponding automation system. The order was placed in summer 2003 and the substation automation system has been in service since April 2005.

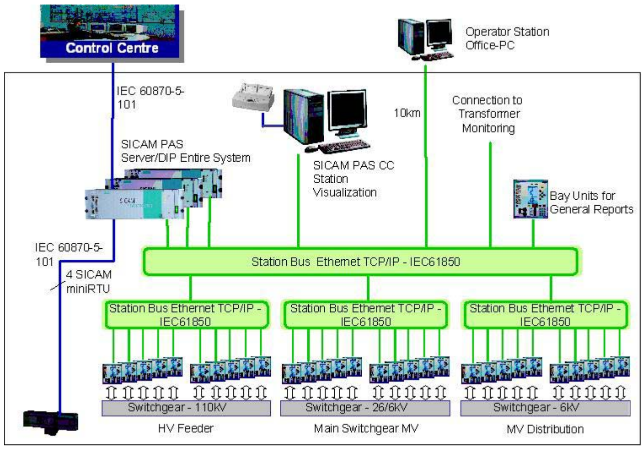

Figure 10: RWE Power Garzweiler's Automation System

The substations have a large number of IEC 61850 devices (134). The link to the SCADA system is similar to Winznauschachen, i.e. uses IEC 60870-5-101. A link to the office was installed to allow convenient remote access to the IEDs, HMI, and station unit at any time.

4.3. Nanqiao China

East China Power Grid Company's 500/220/35kV transformer substation Nanqiao plays a key role in supplying the city of Shanghai with electricity. This is due to its position at the end of a high-voltage direct current transmission (HVDC) route, where electricity is transported over 1000 km (600 miles) from Gezhouba in central China to Shanghai. This HVDC transmission system is the first of four large HVDC long-distance links that Siemens has built or is currently installing in China. For the modernisation of the Nanqiao substation, Siemens is deploying the Sicam PAS station automation system together with Siprotec-4 bay controllers using IEC 61850. The system has been energised since January 2006. Figure 11 shows the system overview.

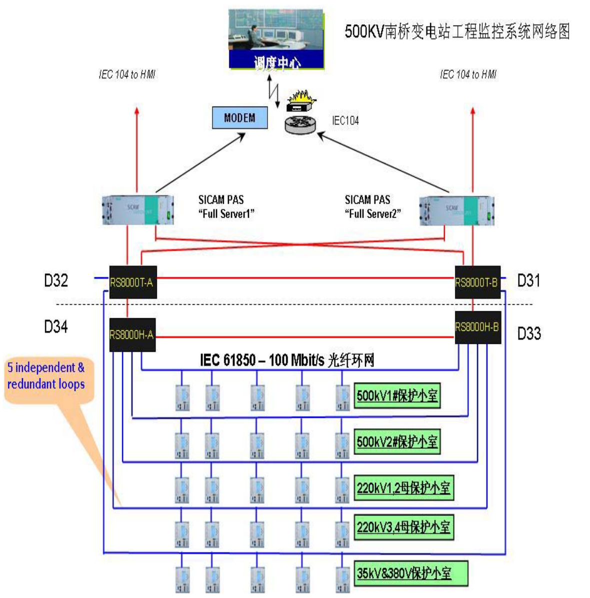

Figure 11: East China Power Grid Company Nanqiao's Automation System

Data communication between the devices is via several redundant 100-Mbit/s Ethernet fiber optic rings that comply with the IEC-61850 standard. The automation system is linked with an HMI system from a Chinese manufacturer via the telecontrol protocol IEC 60870-5-104.

It is a fully redundant system with 80 IEDs and two links to the SCADA system. One link uses IEC 60870-5-101 the other one IEC 60870-5-104.

5. Conclusion - Outlook

IEC 61850 will dramatically reduce the number of protocols in the SAS and will be further developed to talk up to the SCADA/NCC – creating a so-called seamless telecommunication architecture. Furthermore IEC 61850 will define the process bus with real time Ethernet, which will also have an impact on the SAS architecture.

The ability to integrate today's vastly installed IEDs that still use legacy protocols, i.e. support multiple protocols when doing substation integration, remains essential for the future.

The increasing availability of non-operational data using intelligent IEDs will allow us to develop better expert systems for optimising asset management. The use of new web-based applications and services will find its place in this field and provide utilities and industry with new business opportunities.

References

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