Substation Automation Systems

Design and Implementation

Evelio Padilla

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Preface

A number of technological changes have occurred in the substation environment over the last 30 years. Surge arresters built with metal oxide discs, circuit breakers isolated with SF6 gas, numerical protective relays and other novel products that appeared early in the 1980s, were quickly adopted without significant impact on substation design. A few years after, however, the incursion of digital technology caused a "jerk" in the field of substation secondary systems. While young system engineers with a limited knowledge in substation-related concepts have become engaged in development of the engineering process Substation Automation Systems (SASs) from the side of device manufacturers, experienced utilities personnel had to (and in some cases still need to) face up to many disconcerting and complex scenarios characterized by an unusual lexicon and a lot of abstract resources that are now being applied to define and implement control and monitoring functionalities in their substations.

This book intends to help both professional groups accomplish their responsibilities by giving them guidelines with respect to the scope and functions of SASs based on current technology, including requirements from Standard IEC 61850, as well useful details for dealing with various stages needed for SAS project development.

The material is organized into 19 chapters; Chapter 1 providing a brief review on how SAS has recently evolved, Chapter 2 outlines the purpose of the SAS as an essential part of the substation, in Chapter 3 the effects of Standard IEC 61850 on different stages of SAS projects are presented, Chapter 4 illustrates constructive and functional features of equipment that make up the primary power circuit, Chapter 5 introduces the characteristics of Intelligent Electronic Devices (IEDs) used for control and monitoring and describe briefly certain phenomenon able to affect in detrimental way the physical/functional integrity of such devices, Chapter 6 provides an overview of how the features and functions of devices installed into the main control house are used for controlling and monitoring the substation as a whole, Chapter 7 contains different SAS functionalities including switching commands and constraints like interlocking and blocking conditions, Chapter 8 shows the set of signals coming from different substation components that need to be managed by the SAS, Chapter 9 suggests how the SAS ought to be engineered, Chapter 10 covers the theory and practical principles that support a typical implementation needed for the substation control and monitoring from a remote master station, Chapter 11 describes a lot of items that may characterize the SAS structure including options for the network topology further to quality requirements and cyber-security considerations, Chapter 12 contains recommendations regarding the tests to carry out on SAS components, Chapter 13 may serve as a baseline for programming and checking results of Factory Acceptance Tests (FATs) performed on representative SAS segments, Chapter 14 covers site testing scope and strategies, Chapter 15 proposes scope and sequence of training programs addressed to utilities personnel, Chapter 16 outlines how to deal with SAS projects, Chapter 17 offers a number of tips useful to help in getting timely acceptable SAS components and functionalities, Chapter 18 summarizes resources to be used and methodology to be followed for the engineering process according to Standard IEC 61850, and finally, Chapter 19 forecasts where control and monitoring technologies may go in the future.

In summary, the book intends to serve the practical needs of different participants in SAS projects with respect to technical matter and also from the management perspective.

Evelio Padilla

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Evelio Padilla

List of Abbreviations

AC	Alternating voltage system
A/D	Analog/digital
APT	Auxiliary power transformer
AV	Analog value
BB	Busbar
BC	Bay controller
BC-AS	Bay controller for auxiliary system
BF	Breaker failure
BI	Binary input
BIL	Basic impulse level
BO	Binary output
BPD	Bushing potential device
CB	Circuit breaker
CIGRE	International Council on Large Electric Systems (Conseil International des Grands Réseaux Électriques)
CPU	Central processing unit
CT	Current transformer
DB	Database
DC	Direct voltage system
DG	Diesel generator
DI	Disconnector
DR	Disturbance recorder
DNP	Distributed network protocol
EMC	Electromagnetic compatibility
EMI	Electromagnetic interference
ES	Earthing switch
GOOSE	Generic object oriented substation event
GPS	Global positioning system
HMI	Human machine interface

HV	High voltage
HW	Hardware
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IED	Intelligent electronic device
IT	Information technology
I/O	Input/output
LAN	Local area network
LCD	Local control display
LV	Low voltage
MCB	Mini circuit breaker
MMS	Manufacturing message specification
MTTF	Mean time to failure
MU	Merging unit
MV	Medium voltage
MVA	Mega-volt ampere
NCC	Network control center
OLTC	On-load tap changer
OPGW	Optical grounding wire
PB	Process bus
PC	Personal computer
PCG	Protocol converter gateway
PR	Protective relay
PT	Power transformer
RTU	Remote terminal unit
SAS	Substation automation system
SB	Station bus
SC	Station controller
SCL	Substation configuration description language
SF6	Sulfur hexafluoride
SLD	Single line diagram
SOE	Sequence of events
SV	Sampled values
SVC	Static var compensator
VT	Voltage transformer

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Historical Evolution of Substation Automation Systems (SASs)

The key goal in the operation of electrical power systems is to maintain the energy balance between generation and demand in an economic manner. This often requires changes in system configuration to keep voltage and frequency parameters at acceptable pre-specified ranges; furthermore, configuration changes are needed for maintenance work at utility installations or for clearing faults due to short-circuit currents. Typical changes in system configurations include connection and disconnection of generators, power transformers, transmission lines, shunt reactors and static reactive power compensators. Therefore, such changes in system configuration are made through control facilities available in both generation stations and substations located along transmission and distribution systems (see a view of a substation in Figure 1.1).

Until a few decades ago, the control of electric substations was based on systems consisting of discrete electronic or electromechanical elements, where several functions were carried out separately by specific subsystems. Although those arrangements were reliable because the failure of a subsystem does not affect the performance of the rest of control facilities, it was also quite expensive, as they require a large investment in wiring, cubicles and civil engineering work. Back then, stations were controlled through a large mimic control board located in the main control house, as shown in Figure 1.2.

Sometimes, primary arrangements of substations were placed outside control cubicles lodged in dedicated relay rooms (Figure 1.3).

One of the most emblematic components of that age was the flag relay shown in Figure 1.4, which was the main way to display alarms for the attention of the substation operator.

In terms of civil engineering work, some substations were provided with large concrete channels where several kilometers of copper cables were run, as shown in Figure 1.5.

When microprocessor based substation control systems were originally developed, they were conceived as RTU-centric architecture, and later a distributed LAN architecture became the predominant technology. In more recent years, when control systems and other secondary systems began to incorporate new communication technologies and Intelligent Electronic

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Figure 1.1 View of a 765 kV electric substation. Source: © Corpoelec. Reproduced with permission of Corpoelec

Figure 1.2 Old mimic control board. Source: © Corpoelec. Reproduced with permission of Corpoelec

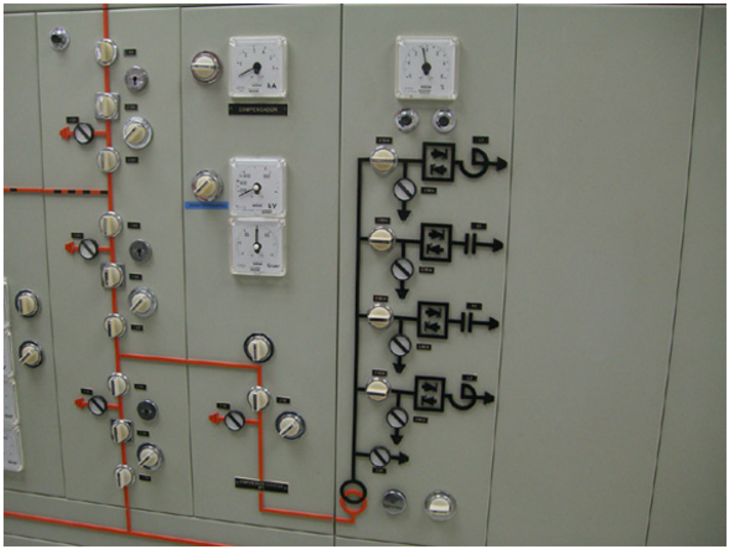

Figure 1.3 Substation primary arrangement shown outside control cubicles. Source: © Corpoelec. Reproduced with permission of Corpoelec

Figure 1.4 Flag relay. Source: © Corpoelec. Reproduced with permission of Corpoelec

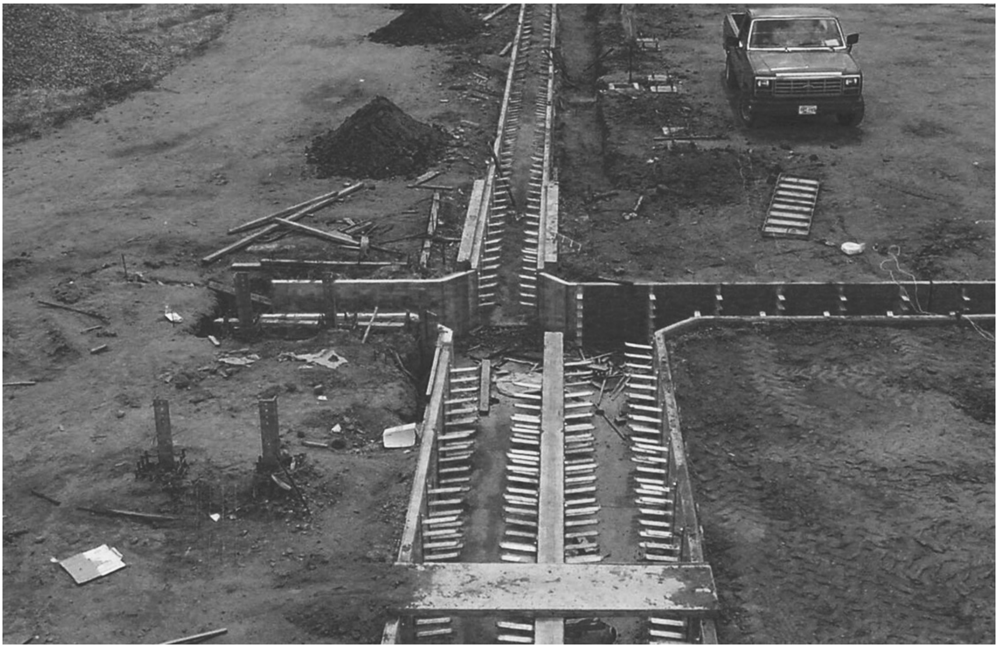

Figure 1.5 Old cabling channels. Source: © Corpoelec. Reproduced with permission of Corpoelec

Devices (IEDs), the complete set of secondary facilities and functionalities was referred to as "Substation Automation Systems" (SASs).

1.1 Emerging Communication Technologies

Development of communication technologies represents an important step allowing SASs to be more and more versatile and increase functionality. The most influential new technologies applied in substations are described in the following sections.

1.1.1 Serial Communication

Serial communication is the process of sending data one bit at a time, over a single communication line. In contrast, parallel communication requires at least as many lines as there are bits in a word being transmitted. This kind of communication was widely used at the beginning of the digital technology incursion in substations; in particular for relay to relay connections through a RS-232 interface. In recent years, instead of serial communication, Ethernet connectivity is gaining a place.

1.1.2 Local Area Network

As a group of computers/devices connected together locally to communicate with one another and share resources, this solution was early dedicated to office environments and later introduced to industrial applications, including substations. The use of LANs in a substation is increasing, in particular the Ethernet LAN specified in Standard IEEE 802.3.

1.2 Intelligent Electronic Devices (IEDs)

Generally, this refers to any device provided with one or several microprocessors able to receive/send data to or from another element. The most common IEDs used in substations are the following types:

1.2.1 Functional Relays

Digital relays (sometimes called computer relays, numerical relays or microprocessor-based relays) are devices that accept inputs and process them using logical algorithms to develop outputs addressed to make decisions resulting in trip commands or alarm signals. Early on, this kind of relay was designed to replace existing electromechanical or electronic protective relays and some years later they were also extended for use in control and monitoring functions.

1.2.2 Integrated Digital Units

Integrated digital units (also called multifunctional relays) have been developed for improving the efficiency of the substation secondary system decreasing the total cost of the asset by adding, in one element, several functions such as protection, control, monitoring and communication. This kind of device is widely used in particular for medium voltage substations where required availability is not a critical aspect.

1.3 Networking Media

The physical structure of LANs compresses cabling segments and connectivity devices allow computers and other IEDs connected to the LAN to share data and communicate. In the past, these elements were made up of copper wires and standardized communication ports and interfaces. Nowadays, these networking media are made with the following resources:

1.3.1 Fiber-Optic Cables

The use of optical technology eliminates the need for thousands of copper wires in a substation and replaces them with a few fiber-optic cables, making savings derived from installation and maintenance work while at the same time increasing worker safety and power system reliability. The main technical advantages in using fiber-optic cables in substations include high immunity to electrical interference and generous bandwidth. Today, the industry offers standardized fiber systems compatible with IEC 61850 devices oriented at reducing the chance of mistakes and minimizing costs in testing and commissioning activities.

1.3.2 Network Switches

These components are required to network multiple devices in a LAN. Their main function is to forward data from one device to another on the same network. They do it in an efficient manner since data can be directed from one device to another without affecting other devices on the same network. The most popular network switch used today in substations is the Ethernet switch, with different features or functions.

1.4 Communication Standards

Standards development is currently like “the motor” for SAS evolution. Initially, the Standard IEC 61850 had solved the important paradigm of vendor dependence that was blocking the advances in digital SAS installation for some years. Now, the Standard IEEE 803.2 allows an increase in networking facilities and functionalities. Both standards represent the state of art of SAS design and implementation as we know today, bringing clear rules for hardware design trends by manufacturers and more confidence in SAS users worldwide.

1.4.1 IEC Standard 61850 (Communication Networks and Systems for Power Utility Automation)

This Standard is a collection of publications intending to satisfy existing and emerging needs of the power transmission industry keeping interoperability as the main goal (allowing IEDs provided by different vendors to exchange data and work together in an acceptable manner). The Standard is based on continuous research and studies carried out by prestigious institutions such as UCA, CIGRE and IEEE, as well as the IEC itself. The scope of the standard currently is mainly addressed at the following:

- Technically define communication methods and specify their quality attributes.
- Provide guidelines for SAS project management and network engineering.
- Give recommendations for SAS testing and commissioning.
- Establish procedures for communication between substations.
- Define methods for communication between substations and remote control facilities.
- Provide guidelines for wide area control and monitoring.

The IEC still continues to develop several new areas. Utilities are waiting for them.

1.4.2 IEEE Standard 802.3 (Ethernet)

This standard defines the communication protocol called the “Carrier Sense Multiple Access Collision Detect” (CSMA/CD), which works under the broadcasting principle of carrying all delivered messages to all IEDs connected to a LAN. Currently, the standard maintains leadership on a LAN substation since such protocols were adopted by the IEC 61850 Standard as their communication platform. IEEE is very active in introducing innovations as the basis for network protocols, leaving behind a long history of proprietary protocols.

All these technological changes now provide the opportunity to have comfortable solutions for SAS design at reasonable cost and with reasonable levels of risk, in such a way that modern SAS are equipped with clean and sophisticated control cubicles lodged in appropriate control rooms (see Figure 1.6), and are operated from the main control house by means of ergonomic control desks such as that shown in Figure 1.7. This allows substation owners to get a high performance system characterized by excellent availability and reliability.