# A Survey of Protection, Automation and Control Systems in the Portuguese Distribution Substations

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## Abstract

In terms of cost reduction and productivity improvement, the protection, automation and control systems of Portuguese Distribution Substations have experienced major developments during the last three decades. Those changes aimed to increase the quality of service, financial performance, flexibility, reliability and more capacity to monitor and control all the primary equipments of a substation. The trend of the Substation Automation System (SAS) is established using multifunctional Intelligent Electronic Devices (IEDs) and advanced communication technologies to provide a more effective locally and remotely substation monitoring and control.

The key objectives for designing substation architecture are interoperability between IEDs and long term stability. So that, the International Electrotechnical Commission (IEC) has developed and released standards for substation automation (i.e. IEC 61850 standards). These standards define the substation Ethernet Local Area Network (LAN), plant and equipment models and support communication services.

This work presents a survey of the past and present trends in protection systems, automation and control systems in Portuguese Distribution Substations.

## 1 Introduction

Control and automation of power system substation has undergone dramatic changes since the introduction of powerful micro-processing and digital communication in substations. Smart, multi-functional and communicative relays called as IEDs (Intelligent Electronic Devices) have replaced traditional panels with dedicated stand-alone relays, meters, control switches and mechanical status indicators. Automation of control and management of a power system substation is becoming more popular and in the scenario of high pressure to improve the efficiency and productivity of the power system, substation automation is proving to be a cost-effective solution.

The replacement of protection, automation and control systems at the Portuguese Distribution Substation due to the existing substation control and protection devices reaching the end of their asset design life, present the opportunity to develop a new substation design solution. Thus, in order to ensure interoperability, free configuration and long term stability among IEDs, the IEC developed a common standard for substation communication IEC61850[1]. Important products with verified compliance to these standards are becoming more readily available. So that, protection relays become more powerful, being integrate with more functions, they have the potential to play an important role in implementing automation and control in substations.

The IEC 61850 standards define a consistent methodology for interconnecting IEDs in substation using LAN based technologies[2]. As the Portuguese Network Operator seeks for interoperability of products from different suppliers, easy expansion of existing systems and future-proof protocols and data structures which could be applied across a wide range of interconnection technologies, it is a great opportunity to start implementing these protocols in their power substation.

This paper presents a brief background to the protection, automation and control of the Portuguese distribution Substation as well as describes the approach adopted in implementing the project solution and summarise the issues faced and keys benefits. Section 2 shows the evolutions of protection systems in the Portuguese Distribution Systems from stand-alone relays, meters, control switches, mechanical status indicators to the actual multi-functions IEDs. Section 3 shows the equipments architecture that constitutes the protection, automation and control systems at the Portuguese Distribution Substations.

The emphasis of the physical topology characterization, technology applied, flux of information, security and reliability of the communication network is also showed in Section 3. A possible approach in implementing the project solution of Protection, Automation and Control Systems of the distribution substations is also presented.

## 2 Protection, Automation and Control Systems in Distribution Substations: Process of Change and Development

The strategy adopted in Portuguese distribution substations along the last three decades was focused in efficiency improvement, through operational costs reduction, Quality of Service (QoS) improvement and implementation of Substation Automation Systems (SAS) with strong support of information and communication technologies. In the 80's the main challenge was to reduce the operational costs with the substation telecontrol application. The telecontrol technology allowed the substation being control from a remote location without the requirement of any operators' presence at the substation , through the installation of Remote Terminal Units (RTU) [3].

Between the eighties and nineties, it was introduced the first automation systems in the Portuguese distribution substations. The main targets were to ensure the operations costs reduction and improvement of the QoS with the introduction of RTU with automation facilities. Thus, the number of persons that was still required to control the substation locally could be transferred to the remote centres. In these centres, specialized people could remotely control several substations [3].

In beginning of year 2000 it was introduced a new step in the SAS evolution. Then, the main challenges were standardizing the substations project and thus to reduction the maintenance and engineering costs. In order to achieve QoS required, another initiative took place. This initiative was the distributed automation project inside the substation which consisted in the protection and control integration and in the adoption of simplified wiring schemes. With the IEC 61850 standards, published between 2003 and 2005, new paradigm for communication network and systems in distribution substations was defined. Thereby, the substations projects were therefore reviewed between 2006 and 2007 with the aim of standardize the communication systems [3].

### 2.1 Protection Relays lifecycle

The protection relays are crucial equipment at the substation. The incorrect application and operation of protection relays can have catastrophic effects to the costumers and equipment [4]. The relay technology has considerably changed since the electromechanical relays first appeared. Electromechanical relays have been replaced successively by static, digital and numerical relays. Each change bringing with it, size reduction and functionality improvements.

At the same time, reliability levels have been maintained or even improved and availability significantly increased due to techniques not available with older relay types.

This represents a great achievement for all those involved in relay design and manufacture. However, most of the EU countries still have a great percentage of electromagnetic relays in use. It is therefore recognized the need to manage the obsolescence protection relays.

Following [4], considering the evolution of protective relays, it is possible to establish and associate a specific phase to nowadays relay technology. Relay lifecycle could be divided in five distinct phases:

- Active - for Numerical relays (service entrance 1994-2009);
- Legacy, for Digital relays (service entrance 1984-1994);
- Pending obsolescence and obsolete, for static relays. (service entrance 1972-1984);
- Extinct, for Electromechanical relays (service entrance <1972);

During active stage, repairs and spare parts are readily available as so firmware updates, since the product is in current manufacture. At legacy stage, protective relays can still be provided as new, although, software and hardware upgrades are no longer available from the manufacture. When a protective relay reaches pending obsolescence, is very important to undertake an obsolescence survey, which usually takes the form of a protection audit in order to evaluate the technical and operation conditions of the equipment. At this point it is usual to recommend a protective relay system planning, assuring the future of the protection system. It is also worthwhile to keep training program workshops for technicians, making them able to operate the latest technology concerning protective relays.

Figure 1 shows the actual panorama of the existent technology concerning protection relay devices on the Portuguese HV/MV distribution substations. Making a brief analysis is well noticed that a big part of protective relays are on their useful lifecycle, as they are digital or numerical (74,68%).Pending obsolescence or even obsolete needing a protection audit are 7,38% of the total relays. Finally only 7,84% of the total relays are on Extinct Stage needing short notice replacement as they are on their terminal lifecycle and have more probability to fail .

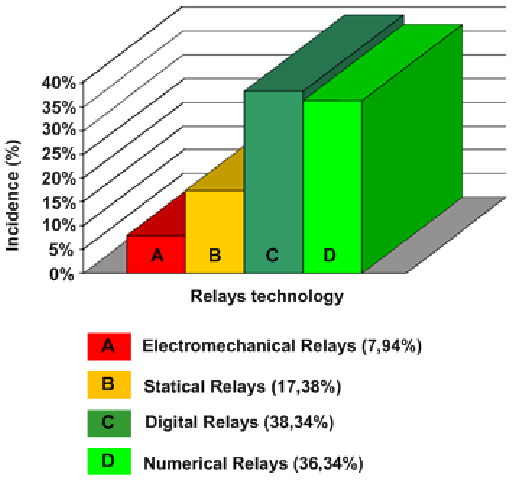


Figure 1 – Incidence of protection relays technology at the Portuguese distribution substation.

## 2.2 System Architecture

Protection, Automation and Control Systems are organized on a three levels model. Each of these levels has specific equipments and functions as shown in Figure 2. The first level (i.e. Level 0) is the process level. This level consists in the High Voltage (HV) and Medium Voltage (MV) primary equipments of the substation. The second level (i.e. Level 1) is the bay unit level. Typically, IEDs are the equipments installed at this level. The third level (i.e. Level 2) is the central unit level. In this level is the central processing unit that supervises and control the entire substation [5].

The bay units are responsible for the process automation, control and protection functions. These units are constituted by five modules: input module, processing module, output module, communication module and human machine interface module. In addition, each bay unit which belongs to Substation Automation System must have a set of protection functions able to ensure the surveillance of the electric system, fault detection and isolation. The main goal is guarantee high availability and QoS with a safe exploration of substation. The central processing unit must be based on equipment like industrial computer with technical features that ensures a good performance in harsh environments. This unit should have a monitor, a keyboard and a mouse to favour the interaction with substation operators [5].

The interconnection between level 0 and level 1 is made with power cables. In the other hand, the connection between level 1 and level 2 is made through a local communication network. This communication network is mostly supported by optical fiber cables and it should ensure a baud rate (transmission speed) suitable to the Protection, Automation and Control System functions execution and within the time requirements [5].

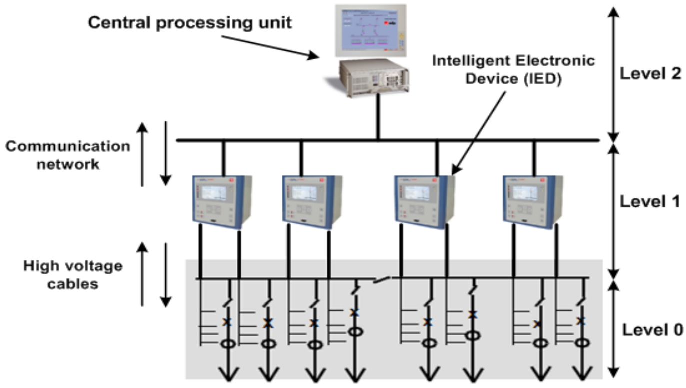


Figure 2 - Protection, Automation and Control Systems structured in a three level model.

# 3. Protection, Command and Control System Communication Network

## 3.1 Legacy substation communication networks

Until the year 2006, in the most cases the communication network architecture was not equal between different distribution substations. Typically, in distributed SAS the network architecture depends on the manufacturer equipment, their own communication protocols and their own specific network topologies. The main suppliers of Protection, Automation and Control System equipments for these solutions were ABB and EFACEC where each of these manufacturers used, typically, propriety communication protocols. So, the integration among equipments from different manufacturers appeared to be a hard task with additional economical costs. These expenditures resulted from the need of install communication protocols converters and independent communication network to connect IEDs that belongs to the same manufacturer. ABB used Lonworks as communication protocol. EFACEC implemented two networks within its architecture (i.e. Lonworks and SPA-Bus) [6,7]

## 3.2 Actual substation communication network

The IEC 61850 standards brought a new paradigm for the distribution substations taking into account the communication system. This standard defines Ethernet and TCP/IP like the protocols to be used in the substation communication system. Thereby, IEC 61850 defined two communication buses to ensure the connection between all the equipments which belongs to the substation automation system (SAS). So, the application of IEC 61850 within the Portuguese distribution substation has a great impact in the architecture and operation mode of communication system. One of the major advantages was the standardization of communication network architecture between distinct substations.

The actual substation communication system has two main changes comparatively to the legacy communication systems: the introduction of Ethernet switches and the usage of standard protocols to communicate with remote control centre. The connection between Ethernet switches presents a ring topology while the connection between IEDs and Ethernet switches track a star topology. In Figure 3, optical fiber connections are represented by two lines. This physical connection allows the full-duplex communication mode which enables the transmission and data reception to occur at the same time between two equipments. So that, in the actual substation communication system, the baud rate can reach 100 Mbit per second.

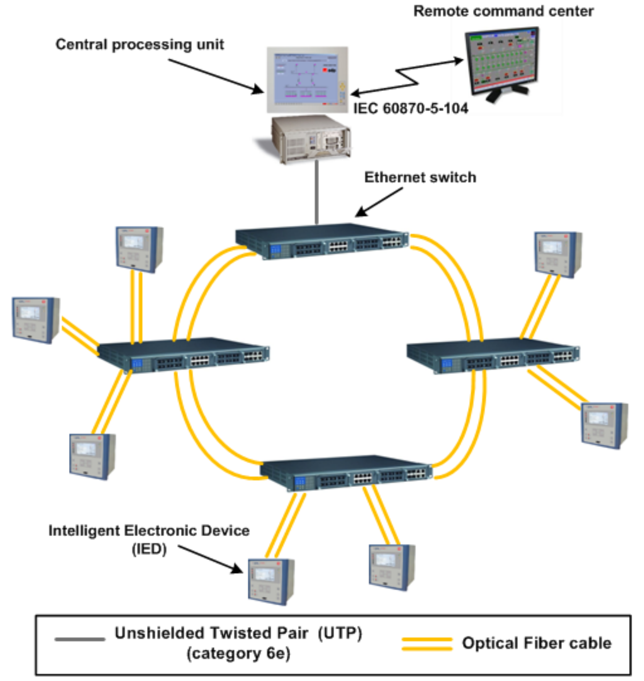


Figure 3 – Actual communication network architecture installed in the Portuguese distribution substations.

### 3.3 Switched Ethernet

When a new IED is installed in the substation, datasets are generated and consequently the amount of data traffic rises in the communication system. So that, is important to assure that the Protection, Automation and Control Systems performance is not affected when a new IED is introduced.

The switched Ethernet technology brings some important features like data throughput improvement and traffic isolation. Moreover, Ethernet switches provide a private collision domain for each of its ports once there is no direct connection between each of its communication ports. What about data routing, when a message arrived to a switch port, it is analyzed and moved only to the destination port [8].

### 3.4 Station bus and process bus

IEC 61850 defines two communication buses to the substation communication system: the station bus and the process bus [9]. Actually, only the station bus is being implemented in the Portuguese distribution substations. The station bus provides primary communications between the IEDs. This station bus supports also the remote access which provides a wide variety of substation information and assures the connection with some equipment within the substation like HMI (Human Machine Interface) and central processing unit [9]. The process bus (which is not yet implemented in Portuguese substation) provides a connection between the substation primary equipments and IEDs through a communication network. The Merging Units (MU) collects data from Optical/Electronic Voltage and Current sensors and other kind of Input/Output (I/O) information. Then, all this information is grouped into datasets and published through the communication network and IEDs subscribe it. Typically, MUs are physically located in the substation yard [9].

### 3.5 Communication with remote control centre

The communication between substation and remote control centre uses IEC 60870-5 standards [10,11]. Legacy communication systems use IEC 60870-5-101 which is based on serial links. Actually, is in process the migration to IEC 60870-5-104. This standard allows communication between remote centre and substation be done over public networks like Internet and it covers the transmission over Internet Protocol (IP). A major advantage is that IEC60870-5-104 is based on IEC60870-5-101 and therefore the existing communication lines used by legacy communication systems to ensure the connection between substation and remote centre using IEC 60870-5-101 protocol can be re-used in the migration to IEC 60870-5-104 [11].

There is a trend in Portuguese distribution substation to use communications over Internet Protocol (IP) to communicate with outside of these installations, particularly with the remote centre. To establish this connection, it is considered two main physical transmission mediums: wired and wireless communications. Wired communication uses the optical fiber while wireless communications uses public GPRS (General Packet Radio Service) [11].

### 3.6 System Application and Services

Protection, Automation and Control Systems have a set of applications and services among which are Supervision, Control and Data Acquisition (SCADA) system, Tele-metering, Tele-engineering, equipments supervision and Tele-protection. However there are other services which uses communications facilities like video surveillance, telephone, technical support by video call and monitoring of quality of technical service played by substation.

Table I summarize the technical characterization of communication services associated to the applications and services in the Portuguese Substations.

| Communication service | Minimum communication speed (baud rate) | Service availability |
|---|---|---|
| SCADA | 2 MB | Permanent |
| Tele-metering | 9600 kbps | On demand |

| | | |
|---|---|---|
| Tele-engineering | 512 kbps | On demand |
| Equipments supervision | 256 kbps | On demand |
| Tele-protection | 64 kbps | On demand |
| Quality of technical service monitoring | 512 kbps | On demand |
| Video surveillance | 2 MB | Permanent |
| Telephone | - | On demand |
| Technical support through video call | 2 MB | On demand |

MB = Mega Bytes
Kbps = kilo bits per second

Table I: technical characterization of communication services [5]

## 4. Summary

During the last decades, Protection, Automation and Control Systems of Portuguese distribution substations have undergone a great process of change due to the development of the communication network and protocols and IEDs. The IEC 61850 standards brought a new paradigm into the project and implementation of substation communication networks. These standards brought interoperability, free configuration and hopefully long term stability to the design of Portuguese distribution substation. There is still ways to continue improving quality of service by reducing costs. The Distribution Network Operators need to continue seeking quality of service, financial performance, flexibility, reliability and more capacity to monitor and control all the primary equipments of a substation

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