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New Challenges in Electric Substation Telecommunication and IT Networks

M. G. Castello Branco*, C. Esteve Rothenberg and N. Mincov
CPqD
Brazil

SUMMARY

This paper presents some views on the technical and operational convergence of electric substations telecommunication and IT networks. This convergence is becoming a reality very fast due to technological and multi-vendor industrial evolutions and the resulting new business opportunities to the utilities. This work aims at showing that network convergence is a technology trend that can be implemented today in high power electric plants meeting the high expectations on quality, resiliency, scalability and simplified network management. Similar to what the telecommunication sector experienced during the last decade, we foresee a potential network convergence trend in electric substation communication infrastructures leading to a new set of challenges and applications that will shape future operational and corporate communication processes. This paper outlines best practices towards a converged infrastructure enabled through the advances in network an IT technologies considering secure and reliable communications between interoperable network elements in substation automation, operation and communication processes.

KEYWORDS

IP Network Convergence – Telecommunication – Operation – Automation.

(*)castello@cpqd.com.br

1. INTRODUCTION

Historically, electric substations telecommunication and IT networks have been developed separately and treated as differentiated services or business units that were not expected or designed to integrate with each other. However, convergence is one of the key trends of the telecommunications industry today and has shown to bring financial and business benefits from the integration of networks and applications achieving an improved productivity.

Communications network convergence promises lowering the total cost of network ownership by reducing the operational expenses (OPEX) associated with equipment maintenance, network administration and data transport fees. Furthermore, a converged network enhances the productivity and communications capabilities of an utility infrastructure capable of scaling as new business applications are required. For example, the ability to expand and adapt to a new multi-vendor environment in the field of intelligent electronic substation components for automation and control processes.

The main technology drivers for convergence in the electric sector communication networks are the ubiquitous development of the Internet Protocol (IP), the performance advances in Ethernet technologies for industrial communications [1] and the massive adoption of the IEC 61850 [2] communication standard. Consequently, utilities are augmenting their communication infrastructure with high-speed networking technologies opening a new series of challenges and applications in their communication processes.

Up today, network capabilities were not mature enough to perform the convergence process cost-effectively. In this context, this works aims at showing that network convergence is a viable technology trend that can be implemented today in high power electric plants, meeting expectations with regards to quality, resiliency, scalability and a simplified network management. A cost-controlled roll out of the converged infrastructure is a key point for the success of the utilities enhanced business model.

The focus of this paper is not the well-known and accepted benefits [3][4][5] of IEC 61850 [2]for substation automation. Taking up the adoption of Ethernet technology for electric automation communication, the contribution of this work is to present aspects to be considered in order to make network convergence a beneficial reality for the utilities.

The remainder of this paper is as follows. Section 2 presents convergence in the context of electric power utility operational and corporate networks. Modern multimedia IP networks and their applications are shortly presented in Section 3. The main challenges of evolving electric plant networks are discussed in Section 4 and best practices for network evolution to a converged scenario are outlined in Section 5. Finally, Section 6 concludes the paper.

2. ELECTRIC PLANT TECHNOLOGY CONVERGENCE

As IP networks are becoming faster and flexible enough to accommodate a different set of applications with differentiated Quality of Service (QoS) (e.g. IEEE 802.1p), incorporate real-time characteristics (e.g. Real Time Ethernet [1]) and benefit from virtual network topologies (e.g. 802.1q VLAN), electric plant designers and manufacturers are inserting new elements and features that increase substation automation and control capabilities mainly through the local area network (LAN) or even over the wide area networks (WAN). For the substation plant, this new use of the LAN enhances the efficiency of traditional station and process buses. On the same way, the increasing number of new Intelligent Electronic Devices (IEDs) and associated logical functions (e.g. IEC 61850 [2]) progressively offer more flexibility for fully integrated substation designs and sophisticated management and control systems. Driven by the IEDs adoption, IP network elements currently used just for non critical communications are facing new challenges to provide performance and quality behaviors compatible with the requirements usually stated for the electric plant operation. These IP network elements, such as servers, switches and routers, have become the present focus of technological development and evolution in order to satisfy the most stringent requirements of operational plants.

IEC 61850 defines the next generation of standardized high-speed substation communications for control and protection processes. With its object–oriented data model and formal description language the communication standard IEC 61850 offers high potentials in terms of re-usability, data interoperability and seamless engineering. IEC 61850 communication services provide multiple methods for information exchange. These services include reporting and logging of events, control of switches and functions, polling of data-model information, real-time peer-to-peer communication (eg. GOOSE messages), sampled value exchange, and file transfer for disturbance recordings.

The new communication profiles may take advantage of the improvements of Ethernet networks features of transmission bandwidth and network span. Today, the Ethernet profile of IEC requires: 100 Mbit/s bandwidth, flexibility to adapt for underlying transport technology changes, priority-based QoS traffic differentiation and synchronization capabilities.

Due to the convergence trends and the Ethernet evolution, the communication infrastructure architecture for an electric power utility is expected to change from the present separated networks paradigm illustrated in Fig. 1 to the converged approach illustrated in Fig. 2.

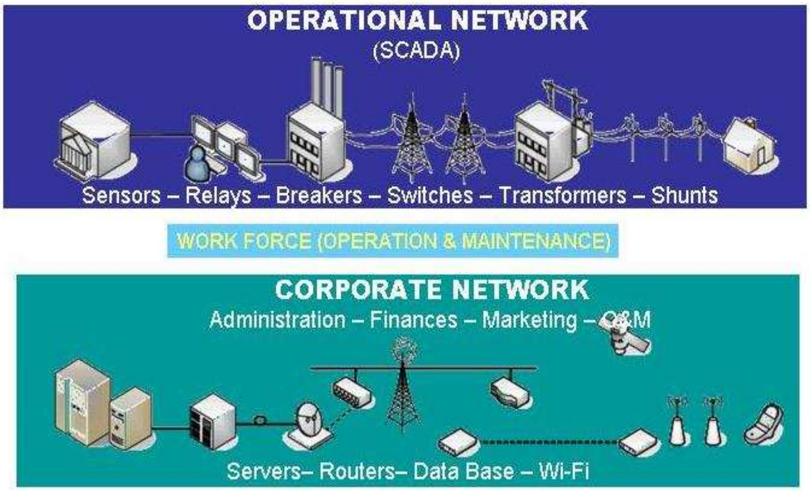

Figure 1 – Present separated network architecture in the electric power utility plants

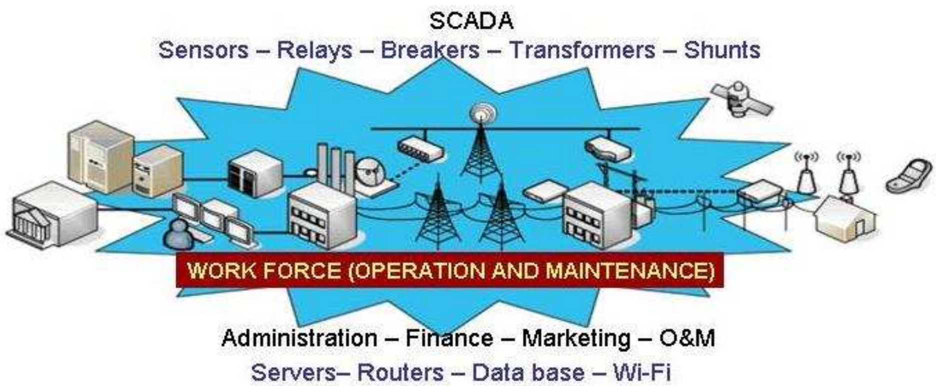

Figure 2 – Future converged network architecture for electric power utility plants

A converged network provides the following benefits:

- **Improved connectivity** so that devices can be assigned specific tasks (e.g. peer-to-peer communication between IEDs); the number of devices required is less which makes installation, and deployment easier tasks as well as network management because of the uniform setup in which the system resources operate;
- **Single platform** on which interoperable devices can be run in innovative ways. The openness of the communication standard helps in fostering interoperability and improving network efficiency.
- **Business cost savings** by having an uniform environment which requires fewer components in the network. Smoother maintenance and management result from this and in turn lead to improved processes. Affordable deployment results from the elimination of multiple networks operating in parallel and manageability improves. In a converged environment, fewer platforms need to be tested and gateways between networks are eliminated;
- **Flexibility** in terms of molding utilities communication patterns to its management practices. This is a dynamic process that can be continually improved with collaboration from inter-substation communications and across different utilities and partners resulting in the right information securely delivered to the right person at the right time which leads to improved decision making [6]. The on-going and cascading failures occurred during the 2003 blackouts after initial power equipment failures have been traced back to problems in providing the right information to the right place within the right time [7];
- **Data availability** where and when needed. Data should be able to go from all substation devices to any sink. As pointed out in [8], some data may be needed in multiple locations, such as control centers (and their backups), regional security coordinators, neighboring control centers, ancillary service partners, or even in other substations in support of special protection schemes. In [6], one utility has investigated the use of both operational and non-operational data across all of its entities;
- **Differentiation**. Convergence opens new communication paradigms, easies the introduction of new services, increases employee productivity and mobility, augmenting thus differentiation and competition because of faster information relay.

3. MODERN MULTIMEDIA IP NETWORKS

This section presents some of the most recent features of IP multimedia networks that are increasingly occupying modern communication infrastructures in both corporate and residential environments. These types of networks are already being implemented in the electric power utility as presented in [9].

Figure 3 illustrates a Voice over IP (VoIP) scenario in a hybrid wired and wireless network environment. In this example, the Session Initiation Protocol (SIP) servers allow the VoIP users access authentication and control. Fixed Mobile Convergence (FMC) has a solid place in the enterprises. Users with Dual-Mode Phones (e.g. supporting GSM and Wi-Fi) can roam between the public mobile network and the enterprise Wi-Fi network with seamless roaming and call handoff. Field workers can attach to wireless access points installed at the electric utilities and get real time information from the management systems or directly from the process bus elements interfaces.

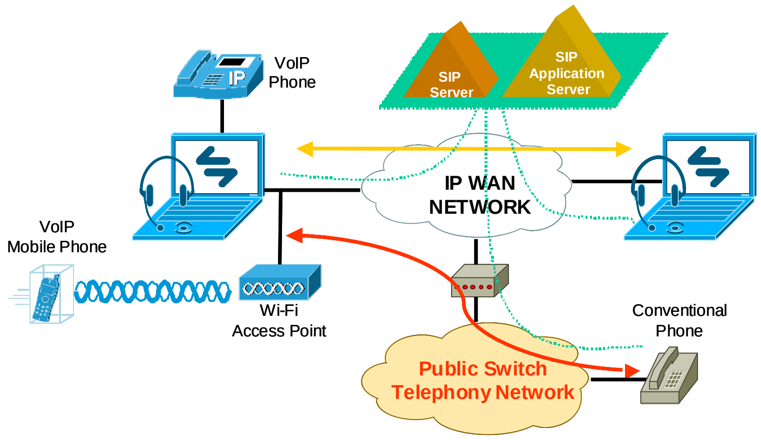

Figure 3 – Modern telephony network example integrating VoIP and conventional terminals

Figure 4 illustrates a video network scenario including Video over IP which is a further example of convergence over modern IP multimedia networks.

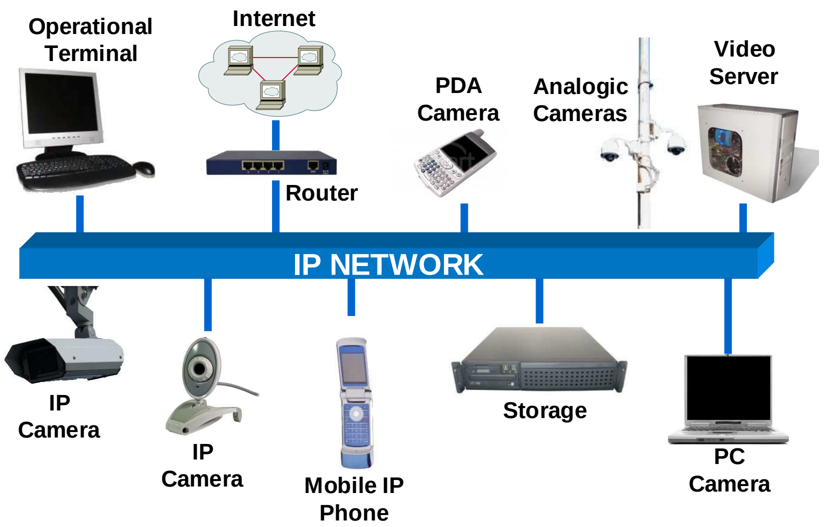

Figure 4 – Video over IP network scenario

Enterprises increasingly use IP to converge and transform their communication networks adding capabilities that greatly enhance their ability to reduce costs and increase functionality. At the same time, the way employees communicate is evolving and now incorporates a wide range of video and voice communications like desk phones in the office, mobile phones in their pockets, and IP phone services like GoogleTalk, X-Lite or Skype on their laptops. Moreover, they use voicemail, E-mail, text messaging (SMS), as well as presence-enabled instant messaging and community based communications. They access Web content and private intranet information from multiple end-points through different access technologies within an enterprise, at home, or remotely. Typically, an application server (AS) handles the advanced enterprise communications services such as call forwarding, voicemail, as well as the integration with the enterprise IT infrastructure.
Another significant indication of the “All over IP” worldwide avalanche is the IP Multimedia Subsystem (IMS) architecture which is being adopted by telecommunication service providers in order to adequate their networks to the most flexible structure for IP multimedia applications and services. Figure 5 illustrates the IMS architecture that allows applications to work across mobile and IP networks by deploying the mechanisms of the global mobile network in the IP network.

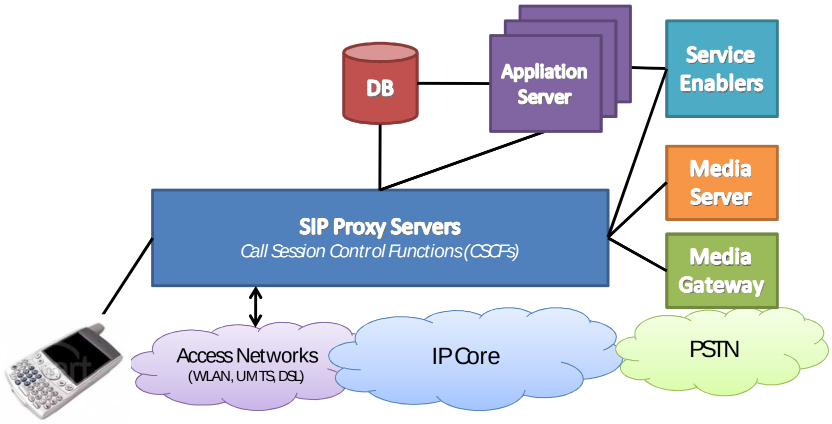

Figure 5 – Basic architecture of the IP Multimedia Subsystem (IMS)

IMS promises richer communication services (e.g. push-to-talk, location-based services, find me - follow me) and FMC solutions for enterprises. However, such applications already exist in enterprise environments (IP PBXs and application servers). IMS scenarios in the enterprise have begun to appear with increasing frequency, nevertheless the place for IMS in the enterprise is still uncertain [10]. With these regards, the ECMA International (formerly called the European Computer Manufacturers Association) has done some work on enterprise communications in next-generation corporate networks (NGCN) [11].

4. MAIN CHALLENGES FOR ELECTRIC PLANT IP NETWORKS

Based on the points raised in sections 2 and 3, the main challenges for the electric plant IP networks can be synthesized as the following:

- To achieve the best model of a converged corporate and operational network based on an optimized architecture of logical nodes and associated set of functions for each part of the utility plant;
- To clearly define the requirements for each function to be implemented in the new converged network so that the data flow and network capacity can be optimized;
- To specify the requirements for the core and intermediate network elements in order to properly deal with the functional requirements;
- To specify the edge elements (such as IEDs and user terminals) of the converged network so that their associated logical nodes can be adequately implemented according to the network functions requirements;
- To verify the adequate interoperability between the edge elements in order to assure the reliability and time requirements for data exchange over the entire network and associated corporate and operational functions.

Figure 6, extracted from IEC-61850, points out to a converged architecture that includes human / human, human / device and device / device communication interfaces over the same communication network. The first two interfaces (human / human and human / device) represent the telecommunication and IT networks respectively. The IT network, depending on the performance requirements, can also be used for management and control processes. The last one (device / device) represents the automation process. There is no indication in this figure that two overlaid networks are necessary for corporate and operational communication in the substation. A single adequately dimensioned and equipped redundant network seems to be sufficient for both uses.

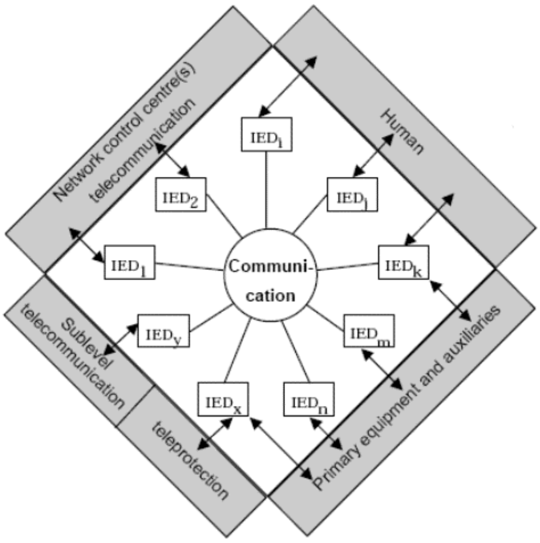

Figure 6 – IEC-61850 substation network primary architecture (extracted from [2])

5. NETWORK EVOLUTION TO A CONVERGED SCENARIO

The investment and operational costs are the major concerns when performing any type of network evolution plan. In that way, a cost-controlled roll out of the converged infrastructure has to be considered. In the "All over IP" scenario, the most feasible and practical way to achieve the best transition is to implement convergent network solutions. This means to choose network elements and architectures that are able to aggregate the highest flexibility to the increasing multimedia applications. At the same time, it is necessary to implement traffic classification and prioritization, and security policies in order to provide the required dynamic properties to the IP network. For this purpose, network elements need to be adjustable with the traffic flow and user's profiles, even for human or devices "users". The definition and enforcement of these policies at the network elements are the key factors to achieve QoS sensitive high data rate exchange over fixed, nomadic and mobile accesses in a standards based communication scenario. Another success factor is to provide the new required technical skills for the human task forces (operation and maintenance) and a customized process mapping of electrical corporations.

Due to the inherent complexity of network evolution, utilities have to rethink the way they conduct their own business when it comes to business partnerships and vendor relationships towards the so-called IP transformation [12]. Convergence increases the pressure to seek outside help for all aspects of secure end-to-end network integration, including network design and engineering, installation and implementation, system integration, network and operations management, disaster and fault recovery, project management, service delivery and other services.

Working together with a network integrator is recommended as a trusted and experienced allied that understands the company needs, its communication processes and the underlying networks. One of the main tasks is to assist the adoption and implementation of the required network transformation. This includes leveraging a comprehensive methodology with a full range of end-to-end network lifecycle capabilities. As a consequence, utilities are able to maximize their revenue opportunities in a cost-controlled manner. By defining a proven set of benchmarked processes, a network integrator can manage organizational changes and deliver both the required network and IT expertise for a successful network transformation that supports the evolved business models and processes.

Some examples of converging network performance indicators include delivery time, number of end nodes, basic network topology, number of switches between end nodes, RTE (Real Time Ethernet) throughput, non-RTE bandwidth, synchronization accuracy and redundancy recovery.

6. CONCLUSION

This paper raised some aspects to be considered in the upcoming converged network scenarios for the corporate and operational processes in an electric power substation plant. Some practical examples of modern IP multimedia network architectures have been presented to illustrate the present trend in telecommunication and IT cases. Convergence is a beneficial but challenging process and spans over technical, operational, cultural and organizational aspects. A network transition plan is therefore critical for utilities in order to benefit from the convergence trend. With these regards, relevant network related suggestions have been brought including network integration, performance indicators and requirements.

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