HOW POWER GRID VIRTUALIZATION HELPS INDUSTRY MODERNIZATION AT LOW COST

Paper No.PCIC Energy EUR24_18

Bruno ANDRÉ
Schneider Electric
100 Avenue de la Gare Sud de France,
34970 Lattes
France

Yann-Eric BOUFFARD-VERCELLI
Schneider Electric
100 Avenue de la Gare Sud de France,
34970 Lattes
France

ABSTRACT :

Connecting and deploying new Protection, Control, Automation and Measurement systems for HV & LV industrial electrical grid has long been a laborious and time-consuming process. It requires a multitude of procedures to ensure safety and compliance with industry standards and utility grid codes. Now, taking benefits of advanced communication capabilities, leveraging advanced virtualization and remote connectivity technologies, new solution of Industrial site electricity management reduces the need for physical visits and significantly reduces installation time and costs.

The paper presents the technical key concerns of implementing Virtualization for LV & HV Electric grid. It also shows how industry will reduce OPEX and CAPEX strongly. The benefits of virtualization in Flexibility, Efficiency, Availability and Asset Management are described with the various alternatives to adapt LV & HV Electric grid virtualization to the various Industry site size. The integration of renewable sources (Solar, fuel cells, wind, ...) is also simplified by using virtualized solution compared to traditional or Digital ones

As conclusion, the paper describes the future of virtualization with the concept of Cloud approach.

KEYWORDS :

Substation Automation, Electrical Grid, Virtualization, Digitization, IEC61850, Centralized architecture, Merging Unit, Station Bus, Process Bus, IEEE 15-88, Hypervisor.

I° INTRODUCTION

The connection and deployment of new Protection, Control, Automation and Measurement (PCAM) systems in industrial HV and LV power network sites have followed over the past ten years a large number of technological, normative and safety developments to optimize the reliability and performance levels of industry standards.

The traditional approach to deploying PCAM systems in industrial networks is based on the physical location of primary equipment (circuit breaker, transformer, motors, ..) integrating IEDS (Protection, Control, Automation or Measurement), and connecting them together with hard-wiring and /or site communication networks. In addition, various control, and display elements(local HMI, Data archiving, EMS Gateway, ...) or engineering tools (Setting, configuration, parametrization software); All these are regularly tested per equipment and after per system or subsystem to ensure global HV & LV grid safety and, security. These operations are complex, expensive, and very consuming in terms of human resources and time. Moreover, this approach, due to its complexity and its IED-based architecture, does not allow for large-scale deployment of PCAM solutions and quickly, therefore, the modernization of industrial networks is not as responsive as expected.

Today, by taking advantage of the new capabilities of digital systems standards (IEC61850) and communicating solutions (Ethernet IEEE 802), Virtualization, becomes to be the new solution for industrial CPAM systems both simple and economical. These virtualization concepts applied for more than 10 years in Telecommunications systems and Datacenters make it possible to significantly reduce the number of physical elements (IEDs) source of failure and cost, limit the need for human interventions, downsize cybersecurity constraint impacts and limit maintenance times and installation costs.

Each basic function (Protection, Measurement, Control, Command, Local or Distributed Automation) is described as software blocks that can be hosted in open hardware and software environments at HV r LV substation level or at Site level : Typically, a hypervisor-based architecture that virtualizes physical server resources, such as CPU, memory, storage, and peripherals. This makes it possible to run several OS simultaneously on the same physical machine, without interfering with each other.

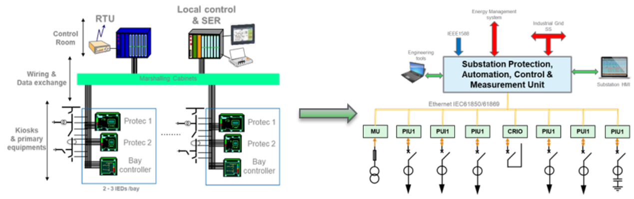

Fig 1: Evolution of traditional industrial grid systems towards Virtualized solutions

The basic concept of virtualization architectures of PCAM systems of HV and LV industrial networks is mainly based on 3 to 4 levels:

1. At the level of the various equipment and equipment of the electrical network (circuit breaker, transformer, motor, meters, ..) IEDs ensuring both the capture of logical and analog information (position, state, measurements, ..) and also actuators (all-or-nothing control, dimmer, ..). These IEDs are connected by cabling or networks dedicated to primary equipment.
2. One or more communication networks typically Ethernet TCP / IP responding or not on Optical Fiber or non-wired solution. The data is generally for virtualized electrical applications , compliant with IEC 61850.
3. A substation system (typically for each HV substation) or at LV voltage level or sub-level grouping, which through virtual machines (VMs) performs the various functions of Protection, Control-Command, Automation and Measurement of concerned parts of the industrial grid. These equipments can be secured by various redundancy methodologies (cold, warm or hot).
4. A central system (Blade type server for example) installed centrally and managing all virtual sub-systems data :archiving, transmission to the EMS and all remaining HV & LV industrial grid PCAM functions. This central system can be secured by various redundancy methodologies (cold, warm or hot).

Note : Level 3 and 4 can be merge in a unique data-server depending on industrial site size, function complexities and customer requirements.

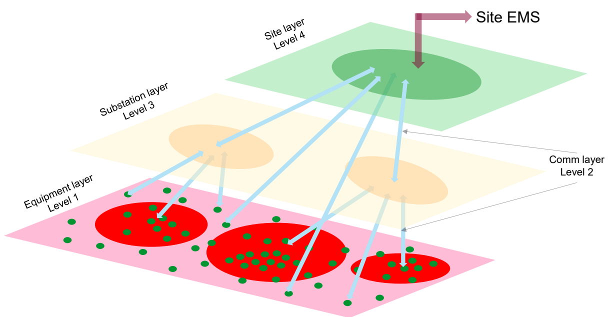

Figure 2: Virtualized system architecture

In addition, engineering tools and cyber-security elements are applied at all levels to ensure the capability of the virtualized system to Protect, Control and Manage the HV & LV industrial electrical grid.

II° SENSORS AND DATA ACQUISITION

The lower level of the Substation virtualization is to add new elements to transform the different measurement currents and voltage issued from the traditional CT & VT or from the Low Power Instrument transformers into digital data via Merging Unit as defined in IEC 61869.

The same way, logic inputs (status & position) and outputs (control & command) will be digitalized and distributed over the local substation and grid communication network for central computing use and other HV & LV substation and equipments over the grid.

Practical applications of such interfacings of the electric process are under review in various IEEE and CiGRE IEC WGs with real products coming on field:

- Merging Unit (MU) IED converting analog signals (protection and measurement Conventional Transformer or Low Power Instrument Transformer) into sampled values (IEC61869),
- Control & Remote IOs unit (CRIO) converts control and status information for primary equipment (SW, CB, Transformer, ...) to Process Bus GOOSE based mainly,
- Process Interface Unit (PIU) combines a MU and a CRIO unit into a single equipment. PIU can publish over IEC61850 analog values and equipment status and accept control commands for primary equipment operation.

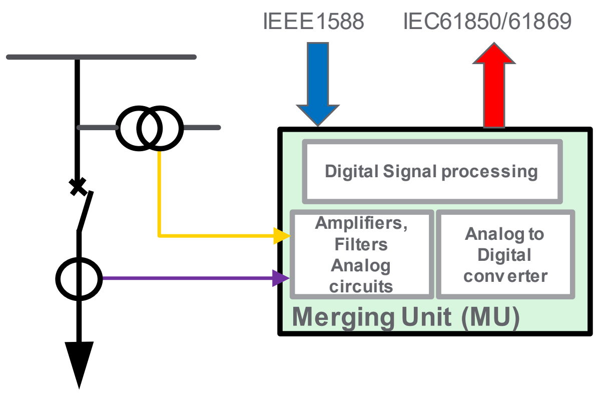

Figure 3: Merging Unit typical architecture

Based on study done in IEEE PES/PSRC H45 WG, two physical models of PIU are considered for real application in HV & LV substations and grids:

- PUI1 (Class 1 PIU) combining analog and logic bay equipment interface as per IEC 61850-9-2, IEC 61869-9/13,
- PIU 2 (Class 2 PIU) is a PUI1 with additional safety protection function (I>, Dir I>, U>) able to run in a stand-alone mode in case of communication failure.

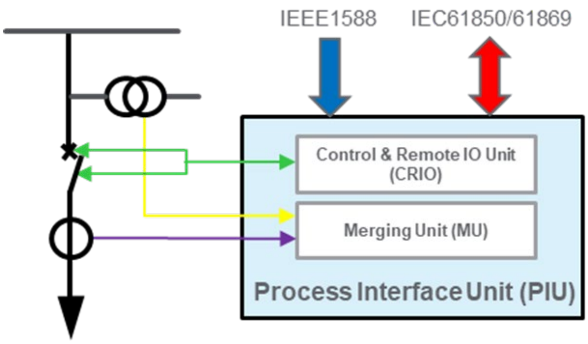

Figure 4: PIU typical architecture

All these new elements use Ethernet Fiber 1, 10 or 25 Gb/s with Standardized redundancy methods (Parallel Redundancy (PRP) and High-Availability Seamless

III° LOCAL COMMUNICATION AND DATA EXCHANGES

Data communication between the various elements of the HV & LV electrical grid are mainly based on Ethernet IEEE 802 optical fiber (1Gbps or upper) with, if needed for specific part the use of RJ45 100Mbps.In complement, the use of wifi IEEE 802.11 could be consider in line with the cyber-security rule to transfer data from LV mobile equipments or to access data from a non-permanent position (typically a local maintenance HMI)

IEC 62439-3 Standard is used in compliance with IEC61850 to define Ethernet network redundancy :

- IEC 62439-3 Clause 4 Parallel Redundancy Protocol (PRP), a device is connected to two independent ethernet networks,

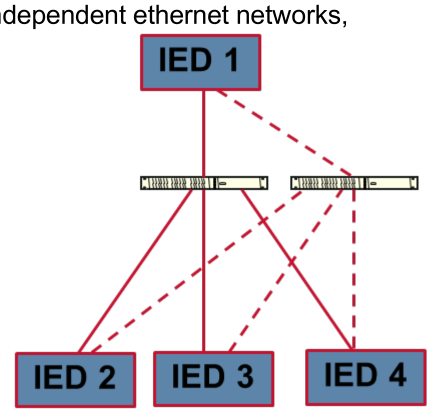

Figure 5: PRP redundancy

- IEC 62439-3 Clause 5 High-Availability Seamless Redundancy (HSR), all devices are connected over a ring topology, without switches.

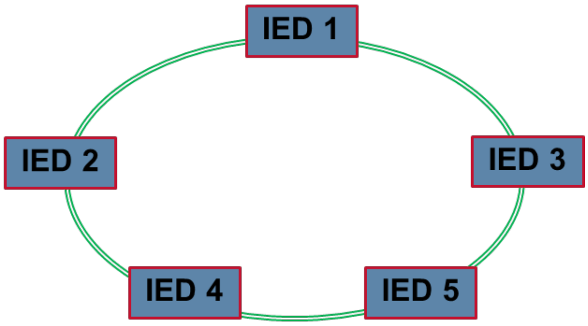

Figure 6: HSR redundancy

Both redundancy network methods provide “zero recovery time” without packet loss.

In complement, IEDs not requiring redundancy have only one port connected in a “single attached node” (SAN).

IV° SUBSTATION CENTRAL PCAM SUB-SYSTEM

A central potentially redundant data server acting as a substation central PCAM sub-system is connected to the different PIUs, MU & CRIOs of the substation via IEC61850 Ethernet fiber interfaces. It will support as functions :

- Multiple functional bricks as define by IEC61850 and running all primary equipment, voltage level and substation functions (Protection, Automation, Control & Measurements) in a coherent and consistent manner based on data received from the PIUs, MUs and CRIOs
- Local Data storage and Archiving on a dedicated unit (optional)
- Display on a local Human Machine Interface (optional)
- Interfaces to the outside of the substation with two main directions:
  - the upper-level grid PCAM central system,
  - Surrounding substations (HV & LV) for distributed protection and automation functions

Software applications can be integrated quickly, access real-time measurements, communicate with other devices and data platforms locally or remotely (including in the cloud) and generate control actions for HV and LV network elements. Interfaces to other industrial applications following dedicated protocols and data transfer are provided as well as the integration of hybrid or external data (weather station, energy prices, etc.) by dedicated software bricks, while legacy systems from previous generations (DNP3, OPC, MODBUS, ..) are also supported (dedicated ports).

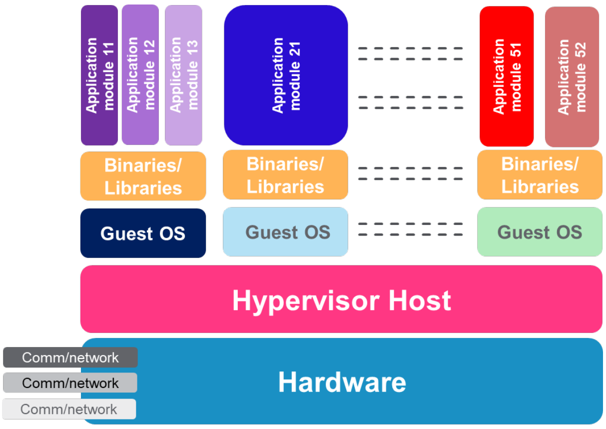

Fig 7 : Virtualization server hardware and software architecture

V° GRID PCAM CENTRAL SYSTEM

A central Substation central PCAM system with redundant data server acting as grid central PCAM sub-system is connected to the different substation PCAM sub-stations via IEC61850 redundant Ethernet to perform grid and distributed protection, automation, and control functions at HV & LV levels. It will support as main features :

- Grid functions (Protection, Automation, Control & Measurements) in a coherent and consistent manner based on data received from the different PCAM substation systems or for specific mainly LV equipments directly from PUIs, MUs and CRIOs
- Global Grid Data storage and Archiving on a dedicated unit (optional)
- Industrial grid Human Machine Interface (optional)
- Interfaces to the Site Energy management application,
- Interfaces to Utility for Grid codes management.

Nota : Depending of the industrial site size and complexity, the central PCAM can support the entire grid and substation over a single data server instead of having one per substation.

VI° ENGINEERING TOOLS

PCAM solutions for industrial electrical HV & LV grid are configured based on IEC61850 concepts. The use of IEC61850 System Configuration Language (SCL) combine with the standardized data and function modeling (IEC61850-7) allows application engineering to be fully independent from the physical implementation and an easy migration from a traditional architecture to a full virtualized concept.

Applying IEC61850 concept, each standard bay (LV feeder, HV/LV transformer, HV busbar, ...) is associated a series of logical devices representing the various PCAM functions housed in a virtual IED.

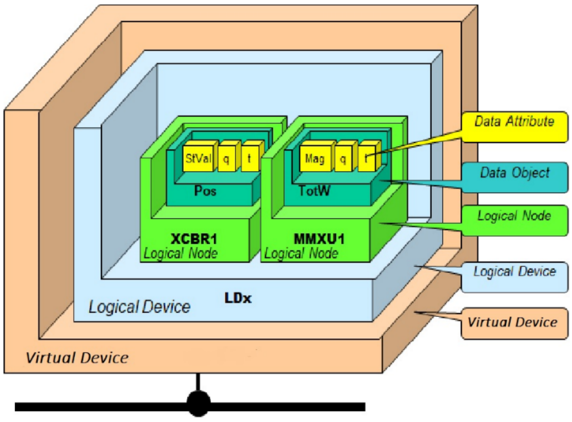

Fig 8 : Virtual IED functional architecture

IEC61850 engineering are built mainly around three layers/tools:

- The System Specification Tool (SST) for the specifications of process signal, automation data exchange, communication and electric network topology. SST allows to associate IEC 61850 Logical Nodes to Industrial Power system resources :
- The System Configuration Tool (SCT) integrate SST data and will generate application functions, communication network topology & characteristics.
- The IED Configuration Tool (ICT): in Digitization process, the ICT create the functional capabilities of a virtual IED including parameters.

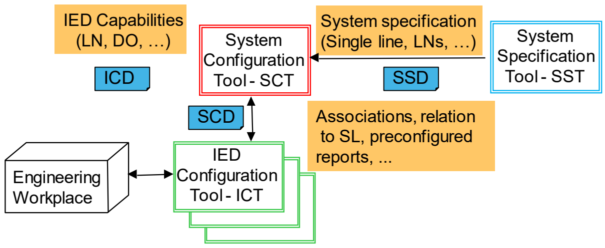

Fig 9 : IEC61850 configuration tools

Virtualization takes fully benefits of IEC61850 ed2 concepts and elements and provide all potentials to the designer and the user for a better and more efficient HV & LV electrical grid architecture and use.

VII° CYBER-SECURITY

Cyber security management rules are applied to maintain application availability as a priority and then device integrity and data confidentially. Cybersecurity acts at 2 levels:

Network and Device. All are regulated by dedicated standards and regulations.

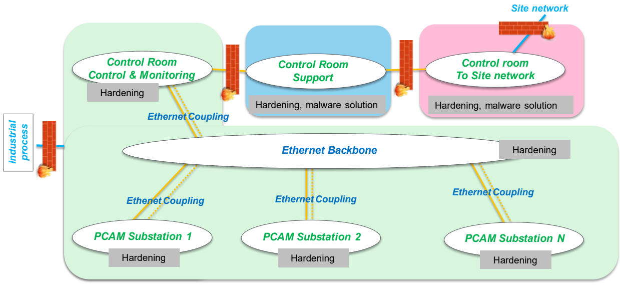

Fig 10 :HV & LV secured Virtualized integrated architecture.

The Cyber security design applied to Industrial Virtualized Electric grid must integrate the following items:

- In-depth Defense- concepts with firewall and Demilitarized Zone (DMZ)
- Role-based Access Management
- Authentication, security, and access management
- Remote communication Encryption
- Consistent patch management for all software and firmware components
- Intrusion detection systems

Use of NERC, NIST, IEC62351, ISO17065 rules and standards to analyze and prevent cyber threats is mandatory to protect industrial electrical grid from most of cyber threats of malicious intrusions.

VIII° HOW CAN VIRTUALIZATION HELP MANUFACTURERS

Virtualization enables manufacturers to optimize the construction, management, and evolution of their HV and LV power grids and equipment by increasing operational efficiency, security, and reliability, while reducing costs and simplifying management.

The main benefits of virtualization for industrial HV and LV power-grids are :

- **Efficiency:** All Protection, Control, Automation and Measurement applications virtualization over one or more servers makes it possible to significantly reduce all electronic equipment (IED, Communication, Server) and leads to substantial savings in material costs, maintenance and necessary space but also energy consumption and therefore the equipment concerned (charger, batteries, ..),.
- **Flexibility:** Virtualization makes it easier and faster to scale networks, substations and electrical equipment at a lower cost as needed, without having to physically add or remove servers or equipment by simply adding dedicated software application blocks.
- **Management:** Virtualized solutions for the protection, control, automation and measurement of industrial HV and LV substations and electrical networks facilitate the monitoring and management of equipment, communication networks, application blocks and software given the centralization of all operation and maintenance data improving the efficiency of maintenance and troubleshooting.
- **Security**: A virtualized architecture based on different separate and redundant virtual machines and each of its applications of Protection, Control, Automation and Measurement of all or part of the industrial HV and LV power networks significantly increases the level of security of the whole in case of failure or failure.
- **Reliability:** By reducing downtime in the event of software failure, modification or evolution, virtualization improves the overall reliability of industrial HV and LV power grids by reducing downtime and minimizing the impact of system failures. Migration to a physical standby server or to the cloud without downtime or data loss.
- **Testing** Applying the concept of "Virtual Twins" to each project help and secured the capability to change the software bricks and the setting changes, without impacting production systems.

IX° IMPACT ON ELECTRIC EQUIPMENTS AND SUBSTATIONS

Virtualization of PCAM system at HV and LV levels impacts directly the primary equipements (CB, SW, BB, Transformer, ….) by removing of various cubicles and cabinets previously housing elements now virtualized.

The main today visible impacts of Virtualization in the real projects commissioned world-wide since 2018 are :

- At HV Circuit Breaker level, the suppression of the LV cabinet traditionally hosting the various Protection relays, Measurement and Control IEDs and all associated wiring and power management reduce strongly the size of the HV CB. Some major suppliers take benefits of the limited size to pile CBs (2 CB cubicles with busbar in between) and thus save up to 40% of HV substation space. In addition, the direct material cost of the CB will be strongly reduced (10 to 35%)
- At substation level the number of wiring paths, auxiliary power and other interposing relays is strongly reduce or suppress with direct impact also on the civil work and the size of the various installations and buildings (-10% to 30%)

When combining the cost reduction of the primary equipments (CB, SW, etc..) with the substation civil work impact and associated element such as power supply, cabling and wiring, etc. .The project cost reduction for a virtualized HV & LV industrial project can reach 12 to 20% compare with already delivered similar projects.

X° VIRTUALIZATION, THE FUTURE OF HV AND LV POWER GRIDS

The next step toward HV & LV industrial Grid virtualization will be to migrate all functions and software from the local servers to the cloud; Today, this concept is well known and apply in some industrial domains such as Telecoms, etc..; But today, acceptance at HV & LV industrial grid is low mainly due to :

The starting application of virtualization to HV & LV electrical grid management. Less than 500 projects covering Utility, Building and Industry applications have been commissioned over the last 5 to 7 years and the systems architectures, engineering tools and IEDs are still under evolutions; A Return On Experience is needed before going further to the Cloud even some features could be independently migrated to an upper level (measurement and quality management e.g.).

In today Digital application a main concern is Cyber-security, not only the simple virus and malicious worms but also the cyber-attacks , software evolutions, user rights managements , etc.…

The large-scale deployment of virtualization technologies in HV and L V electrical grid is still in conceptual phase. For manufacturers, this type of migration from real to virtual is well known both in telecom applications, data management (data-server) and since the beginning of the 2020s become a standard architecture in industrial processes. It is now necessary for hardware suppliers (protective relays, measuring devices, etc.) to convert their catalog into software applications and in the same time the various primary HV & LV device suppliers (Switch, Circuit-breaker, Transformer, etc..) to adapt their equipment to the new concepts and architectures of virtualization (LV cabinet, CT&VT sensors, cabling & communication paths, etc..) . If today Cyber-security allows to detect intrusion, malware, syslog management, etc.; the virtualized PCAM system will support continuous CS evolutions in action field blocking infected parts or devices (back-up use) and will ensure when PCAM system is in maintenance/functional evolution the secure restart.

All certification and qualification procedures in parallel must adapt, business methods will have to change (less sale of single-payment hardware and software products and more renewable rights of use and limited time software licenses) and also engineering and service approaches. Virtualization concepts will over the next years being deployed in electricity HV & LV utilities and for all large industries, transportation, and commercial buildings at all voltage levels HV & LV es to facilitate the integration of carbon-free sources and reduce energy impact on environment .

At the same time, international standards and standards bodies are starting to publish reference documents accelerating the creation of open, inter-operable and secured architectures and enabling the deployment of virtualization across HV and LV power grid applications.

XI° ACKNOWLEDGEMENTS

The authors gratefully thanks IEEE, IEC and CIGRE virtualization and digitization concepts teams and especially , Ratan Das, Alex Apostolov and Henri Grasset for their supports and advice for this paper.

REFERENCES

[1] C. Alvarez, J.I. Moreno, MC. Ruiz, G. Lopez, 2017, “Methodologies and Proposals to facilitate the integration of small and medium consumers in smart grids” CIRED conference, At1 Volume 1

[2] D. Samara-Rubio, G. McKenzie, R. Ariya, V. Ravindran “Virtual Protection Relay, a paradigm in power system protection” INTEL-KALKITECH 2021

[3] HE. Olovsson, SA Lejdeby “L’Evolution des postes électriques ” Revue ABB , 2008

[4] “Future Architectures of Electrical Substations” PCIC Europe 2020

[5] T. Yip, C; Brunner “Application of IEC61850 distribution network automation with distributed control”,.

[6] A. Apostolov, “Centralized Substation Protection, Automation & Control Systems”, PAC World Magazine 2019.

[7] IEC 61850 - Communication networks and systems for power utility automation” 2020

[8] IEC 61869-9:2016 Instrument transformers - Part 9: Digital interface for instrument transformers

[9] IEC 61869-13:2019 Instrument transformers - Part 13: Stand-Alone Merging Unit

[10] IEEE PES PSRC PC37.300 Guide for Centralized Protection and Control (CPC) Systems within a Substation

[11] A. Apostolov. Functional Testing of System Integrity Protection Schemes PAC World Magazine 2014

[12] IEC62351 2020: Power systems management and associated information exchange - Data and communications security

VITA

Yann-Eric Bouffard-Vercelli, Doctor in Automation & CAD of Montpellier University, joined Alstom, which became AREVA and in 2010 Schneider

Electric, where he is group expert for the IEC61850 Digital Control System.
yann-eric.bouffard-vercelli@se.com

Bruno André graduated from ESME (France) in 1985 and after 4 years in EDF/ National Dispatching, he joined PSC ENERTEC in 1990 which became GEC-ALSTHOM then ALSTOM and AREVA and in 2010 Schneider Electric. He oversaw new Substation Automation System IEC61850 based (PACiS) and is EHV & HV Grid expert leader by Schneider Electric Energy with special focus on Virtualization and Grid adaptation to new generation sources (Hydrogen) . He is member of CIGRE B5 committee, IEEE PSRC WG and CIRED and authored of many technical papers.
bruno.andre@se.com