Cloud IEC 61850

Architecture and Integration of Electrical Automation Systems

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Abstract — **The idea of using Virtualization and Cloud as the underlying infrastructure of electrical automation systems has been presented in literature but not properly evaluated. In this paper, a Physical to Virtual solution, or simply P2V approach, for a specific application case of a substation automatic voltage control (SAVC) is proposed in a simulated environment. Along with some fundamental IEC 61850 concepts, the paper presents the physical versus virtual mapping idea and the system requirements. From the logical design that describes the problem from the domain engineering perspective, the derived architecture design and main components are presented, followed by some implementation details and results obtained so far. The initial findings are that the solution can be closer to the logical design, and from the functional perspective, the virtualization approach of the IEC 61850 standard is possible. Performance issues, considering mainly metrics and measurements, are some of the challenges to be studied and assessed.**

Keywords — virtualization; Cloud; P2V; vIED; PAC; SAVC

I. Introduction

Computing and network technologies have evolved tremendously in the last decades. In particular, Protection, Automation and Control (PAC) systems have evolved from hard wired designs to network interconnected devices. This kind of system has rigid requirements [1]. It is a challenge to design a system that fulfills them and at the same time achieve a compromise between interoperability and flexibility in the face of the innumerous available technologies, solutions, and suppliers.

In this regard the IEC 61850 "Communication networks and systems for power utility automation" standard [1][2] comes into play. By standardizing a common way for engineers to design a whole PAC system, from pieces of functions to devices and their interrelationships and interfaces, the standard may allow customers to push both industry and vendors to fulfill their specific needs and requirements in the most interoperable and flexible way.

Virtualization and Cloud technologies, in turn, have brought a new paradigm shift yet to be explored. One step beyond would be to implement PAC IEC 61850 systems on the Cloud. The idea of using Virtualization and Cloud as the underlying infrastructure of electrical automation systems was first presented in the "Cloud IEC 61850" paper [3].

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The goal of this paper is to start assessing the potential of this paradigm shift in practice. In a simulated environment, the paper presents the derived solution proposed to the so called P2V approach, or Physical to Virtual, for a specific application case: substation automatic voltage control (SAVC).

Along with some fundamental IEC 61850 concepts, the paper presents the physical versus virtual mapping idea and the system requirements. From the logical design that describes the problem from the domain engineering perspective, the derived architecture design and main components are presented, followed by some implementation details and results obtained so far.

The main achievement and contribution obtained up to now is a Cloud design and implementation functional reference of a simulated IEC 61850 environment that can be improved and used to deploy and evaluate other electrical automation systems and applications.

II. Problem Description

The IEC 61850 PAC systems are created using Physical Devices (PDs), Logical Devices (LDs) and Logical Nodes (LNs). The PDs are, in fact, the Intelligent Electronic Devices (IEDs), specific hardware devices with different characteristics manufactured by many suppliers.

The proposal of this paper can be viewed in a simplified roughly way as to replace the PDs, the IEDs, by a Cloud computing infrastructure (that also could be provided by different suppliers with different characteristics). This approach could allow a complete application and hardware decoupling, so that application designers could focus and concentrate their effort in what really matters: the PAC system functions [1]. Other advantages of this approach can be viewed in [3].

The shift from traditional to virtualized is based on the idea of virtual machine software, basically divided in two groups:

- Process (application) virtual machine software, as the well-known Java Virtual Machine (JVM) that enables the execution of Java applications in different Operating Systems (OS) and computer architectures; and

- System (hardware) virtual machine software, which includes Virtual Machines (VMs) like VMware that enables the execution of different OS on the same physical machine.

The logical design based on the IEC 61850 standard could be directly mapped as virtual machines providing the services of the designed functions. The designed interfaces (note that this interface differs from ACSI – Abstract Communication Service Interface – defined in the IEC 61850 standard [2]) are naturally provided by the Cloud network infrastructure, or simply "Cloud IEC 61850" [3]. There are a lot of technical difficulties. It is up to us to decide if and when it is worth to break this new technological frontier.

It is important to mention that the interfaces with the process are still needed. In the proposed solution this role is done by the so called Process Interface Units (PIUs), introduced in [3]. They are physical devices that could replace the Merging Units (MUs) and the Input-Output Units (IOUs) of the IEC 61850 standard [2]. Basically the PIU can be seen as a remote terminal unit with capabilities of a programmable logical controller. In the IEC 61850 context, it is a process level IED.

A. IEC 61850 Main Concepts

The main objective of the IEC 61850 standard is to standardize two important aspects to simplify the specification, design and implementation of PAC systems [1][4]:

- Common object and data model for the system logical design; and
- Service model and communication mechanism among IED's.

The data model is depicted in Fig. 1 (note that in the LN there are "Data Classes" and "Data").

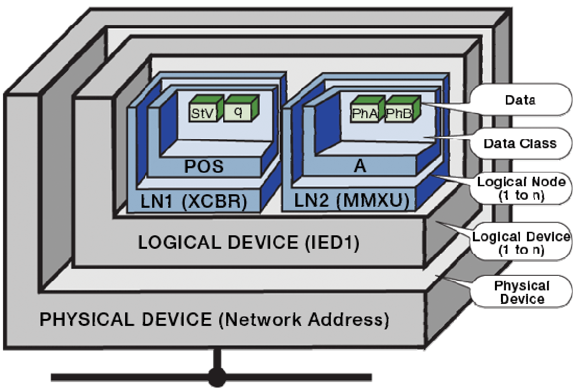

Fig. 1. IEC 61850 Data Model [5]

The main domain concepts are [2]:

- ***PD***: the Physical Device is the specialized hardware for the IEC 61850 implementation. The generic term used for this kind of hardware is IED;
- ***LN***: the Logical Node is an abstract model that represents a basic function, for instance: circuit breakers, current transformers and specific protection and automation functions; and
- ***LD***: the Logical Device is basically a container of related LNs.

The standard also defines core messages for fast data exchange [6]:

- ***GOOSE***: Generic Object Oriented Substation Events;
- ***GSSE***: Generic Substation Status Event; and
- ***SMV***: Sampled Measured Value.

The communication model can be represented by Fig. 2, adapted from [6].

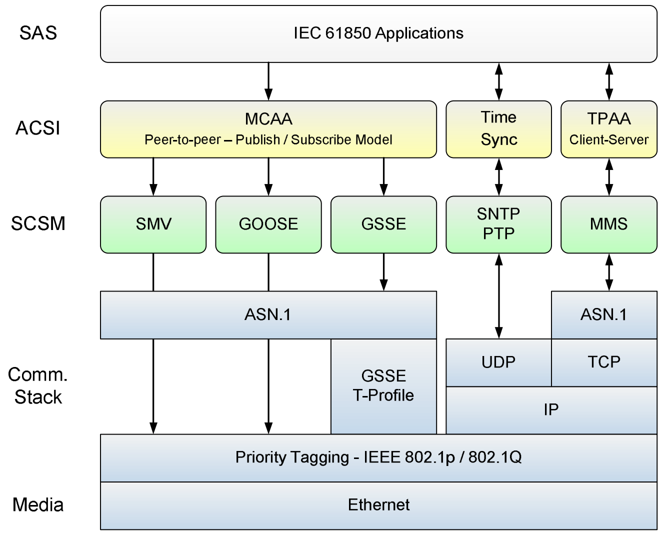

Fig. 2. IEC 61850 Communication Profiles

SAS stands for "Substation Automation System". It is a term used by the standard to represent IEC 61850 applications at the substation. Nowadays, PAC is a broader and better term to represent any IEC 61850 application, henceforth used to represent any solution of any automation subsystem of an electric power system, including SAS.

The Abstract Communication Service Interface (ACSI), defined in part IEC 61850-7-2 [2], provides the communication service Application Programming Interface (API). There are three types:

- ***Client-Server***: represented by the Two Party Application Association (TPAA);
- ***Peer-to-peer***: represented by the Multicast Application Association (MCAA); and
- ***Time and Time Synchronization***: corresponding services.

On the other hand, the Specific Communication Service Mapping (SCSM), defined in parts 8-1 (MMS-TCP/IP-Ethernet), 8-2, 9-1 (Peer-to-peer) and 9-2 (SMV) of the IEC

61850 standard [2], performs the mapping of the available services (ACSI) to specific messages.

B. Physical Mapping versus Virtual Mapping

The transition proposed is from a conventional IEC 61850 system to a Cloud IEC 61850. Basically the PD of Fig. 1 is replaced by a “Virtual Machine” on the Cloud.

Instead of doing the traditional mapping of the IEC 61850 logical design and functions to specific hardware machines (IEDs) and logical interfaces to interconnections provided by the underlying network infrastructure, now the physical machines and its resources are abstracted by the Cloud. The idea is depicted in Fig. 3 and Fig. 4.

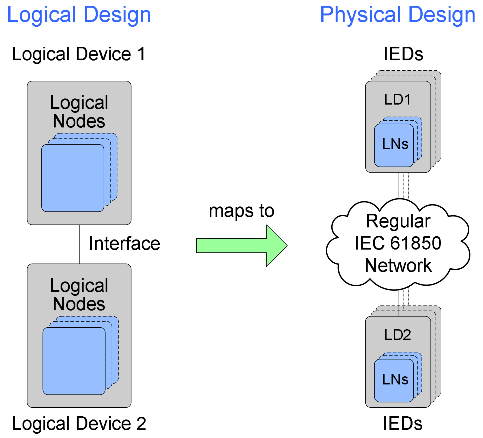

Fig. 3. Logical-Physical Mapping

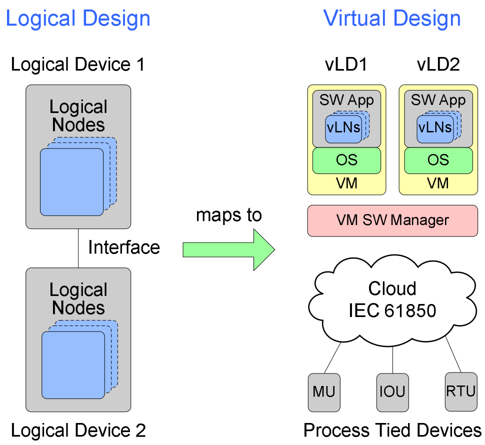

Fig. 4. Logical-Virtual Mapping

In that way, all hardware infrastructure acts as a unique hardware unit, leaving to the virtual abstraction layer and software architectures the responsibility to manage and control every aspect of the application execution, communication and resource allocation.

C. Requirements

The basic requirement of the solution is that it must deal with different types of architecture for automation of substations and power plants. Besides, there are a lot of specific requirements. The main requirements are listed below.

The solution must be compliant with the IEC 61850 standard, maintaining the same semantic structure and services. The basic requirements for this are:

- Use IED (PD), LD, LN (in this case vIED, vLD and vLN, respectively [3]);
- Apply ACSI (Abstract Communication Service Interface);
- Apply SCSM (Specific Communication Service Mapping);
- Support Client-Server and Peer-to-Peer services;
- Use the same data allocation in the LNs LLN0 and LPHD;
- Use the stack protocols of the IEC 61850 standard;
- Goose, GSSE and MMS messages, for interlocks, trips, supervision and commands;
- SMV messages, for measure and protection;
- Substation Configuration Language (SCL), for the system configuration through the standardized files ICD, SSD, SCD, CID, etc.;
- Support for time synchronization trough SNTP; and
- The PIUs must work as single IEDs.

The Cloud must support:

- Real-time applications;
- Activities for configuration and development;
- Managing of the complete infrastructure;
- Free specification of VMs characteristics; and
- Free allocation of VMs in the hardware.

The Cloud resource needs have to be defined: memory consumption, storage, processor power, network bandwidth, etc. This detailed information can be obtained from the PAC system specification. It is directly related to the resource needs for each LD (indirectly for the LNs contained in the LD). Each LD has a computational cost that will influence the required Cloud infrastructure. The required resources can be evaluated using tabulation. For a small example, TABLE I. can be used for this purpose.

TABLE I. TABULATION OF LDS AND AMOUNT OF LNS

Logical Device	Logical Node Sets					
	Protection Functions		Automation Functions		Control Functions	
	PDIF	…	ATCC	…	CILO	…
LD1						
⋮						
LDn						
Total:						

The requirements for the P2V approach implementation are:

- Keep the IED concept but now as a virtual one, i.e., vIED [3];
- Support the communication model (Fig. 2) at least from the ACSI and SCSM up to the presentation layer (ASN.1) to keep the standard data exchange mechanism;
- Basic engineering software with model based on the IEC 61850 standard;
- Development in C/C++ and Linux as Guest-OS;
- Simulated PIUs (at least in the beginning of the project);
- Simplify low level data communication scheme using UDP and sockets;
- Provide a simple Human Machine Interface (HMI) enough to visualize and check data, change parameters and set control data; and
- Use basic simulation algorithms enough to simulate a meaningful dynamic of the system.

III. Case Study

In order to test the solution and also to serve as a guideline to further improvements, it was created a case study. It is a system for the voltage control of a busbar through regulating transformers equipped with On Load Tap Changers (OLTCs) [7]. The case study is based on an existing real system of the Right Margin Substation (SEMD) at Itaipu Binacional.

The power system is composed by six regulating transformers with identical nominal electromechanical characteristics. Up to five of them can be operated in parallel. The control system should automatically raise or lower the taps to change the transformer relations to regulate the voltage of a 220 kV busbar, according to some rules.

Firstly the case was described by a functional technical specification. Then, a specification of the logical design according to IEC 61850 was developed. The implementation of the application on the Cloud is based on those documents (texts, diagrams, figures, etc.).

This case study will represent the reference or benchmark for the initial development of the Framework IEC 61850 as well as the reference standard documentation for other future specified subsystems.

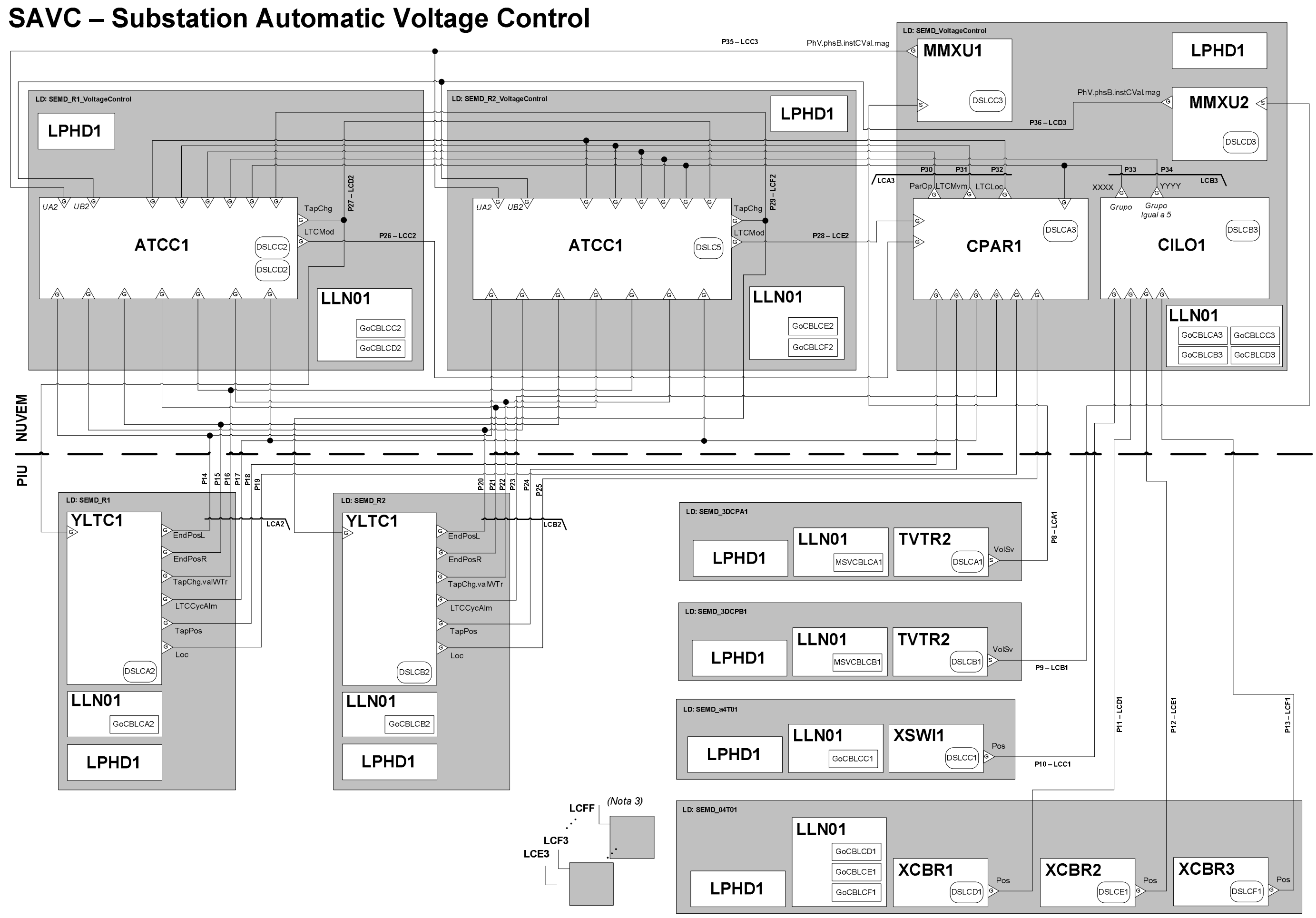

Fig. 5. IEC 61850 Logical Design

It is important to point out that the main LNs used in the case are defined in the IEC 61850 standard: YLTC (tap changer) and ATCC (automatic tap changer controller). Besides, all other needed LNs (high voltage equipment and measurement devices) are in the standard.

The basic intelligence behind the SAVC application can be seen as a simple control algorithm, with well-defined inputs and outputs.

IV. Methodology / Approach

The main focus here is to build a simulated environment, based on virtualization and Cloud technologies, capable of deploying a functional IEC 61850 system, i.e., the case study described above.

Performance, although crucial, is going to be studied and considered in future works.

Following the P2V approach, the idea is to keep as much as possible the same traditional physical application implementation of IEC 61850 systems in the virtual infrastructure, so that the whole IEC 61850 application could be migrated directly to a Virtual Machine, ideally. In this regard, as first presented [3], the physical IED becomes a "virtual IED", or vIED, since the hardware is now replaced by a VM; and similarly the data model, LD and LN, become vLD and vLN, respectively.

A. Logical Design

The starting point is to have a comprehensive specification. For IEC 61850 systems the logical design is a good way to describe the problem from the domain engineering perspective, as shown in Fig. 5, a preliminary version of the SAVC case study.

B. Architecture Design

The resulting virtual mapping of the logical design to the P2V approach is the Cloud IEC 61850 architecture depicted in Fig. 6.

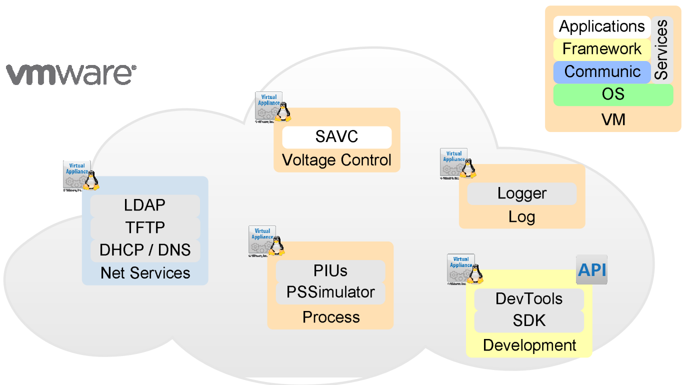

Fig. 6. Cloud IEC 61850 Architecture: P2V Approach

Thanks to the hardware abstraction, namely, the virtualization, the mapping tends to be closer to the logical design, which is highly desirable.

The main components developed are shown in TABLE II.

TABLE II. Components Developed

Component	Description	IEC 61850 & 61970
Process Simulator	Simplified power system simulator (PSS) application that basically receives data from the PIUs, updates the electrical system topology, triggers a simple algorithm solution, returning the results back to the PIUs an to a local GUI. The electrical system was modeled according to the CIM [8].	Only CIM components. The harmonization [9][10][11] scheme was implemented to simplify data exchange between CIM and IEC 61850 data models.
PIU	The set of specific process IED applications were designed according to the IEC 61850 data model. For design simplification, the final application was fully integrated with the simulator, avoiding data exchange over the network communication. In practice, the PIU would get filed data directly from the process, so this simplification is not a IEC 61850 issue.	Main LNs: • YPTR • YLTC • TVTR • MMXU • XSWI • XCBR
SAVC	Case study application developed fully according to the IEC 61850 logical design model. The control algorithm was first developed and tested in Scilab and it is going to be implemented in C++ code.	Main LNs: • ATCC • CILO • IHMI

C. Technologies

The technologies applied were:

- For the main Cloud and Virtualization infrastructure, the VMware solution [12] was used, based on vCloud Director and vSphere, respectively;
- For the application software development, the C++ language and Qt 5.0 library were used;
- For software engineering, EAP (Enterpise Architect) was used;
- For version control, Git; and
- Linux, Ubuntu 12.0 flavor, was used as the Virtual Machine Guest-OS.

D. Communication

The main design simplifications were most notably made in the communication model:

- Use of UDP for every communication, instead of following the IEC 61850 TCP/IP stack (Fig. 2); and
- Use of Java Script Object Notation (JSON) in the presentation layer, instead of the ASN.1 standard.

The ACSI and messages (SCSM) were kept fully compliant to the standard.

E. *Unified Modelling Language - UML*

For the Commom Information Model (CIM – IEC 61970) [8] implementation in the simulator (PSS), a complete UML model was found in [13], version 15v33.

For the IEC 61850, unfortunately, there is not a UML model available to this date. One is expected to be released in the future, following the CIM standard example. Following the IEC 61850 standard documentation, it would be possible to derive a UML model. From [14][15], a survey led to a IEC 61850 UML model [16] available through a browser UML Case tool. This UML model dates back to 2009.

V. IMPLEMENTATION

The whole project is designed in Enterprise Architect software engineering tool, both UML and Use Cases, following the SCRUM framework for Agile project management and using Git version control.

The main achievements so far are most regarded to the static part, namely:

- IEC 61850 and IEC 61970 (CIM) libraries built from the C++ code generated from the UML models;
- PSSimulator application built upon a CIM model from the study case load flow case;
- PIUs IEC 61850 data model, integrated into the PSSimulator;
- SAVC IEC 61850 data model;
- Simplified communication scheme based on UDP and JSON; and
- Set of displays for the PSSimulator, PIUs and SAVC composing the system HMI.

The dynamic part is still under development:

- SAVC modeling and control algorithm; and
- IEC 61850 messages scheme (ACSI and SCSM).

VI. CONCLUSIONS

Cloud computing technologies open possibilities to implement industrial automation systems. The difficulties of transition to the new technology are compensated, in part, by the intrinsic advantages of the Cloud. However, to realize this kind of system, many studies, developments and tests are still needed. Whereas the industrial automation systems have migrated to computer systems implementations, the migration to the Cloud computing would be seen as another step of evolution.

The initial findings are that the solution can be closer to the logical design, and from the functional perspective, the virtualization approach of the IEC 61850 standard is possible. In other words, one of the main advantages of the approach proposed in this paper is the fact that it is possible to build the systems on the Cloud following a similar structure of the IEC 61850 standard with their data models, naming, configuration files, and so on, used in traditional implementations.

Thus, the solution proposed enables the virtualization approach of the IEC 61850 standard: physical to virtual, besides the virtualization in the context of the paper. Performance issues, considering mainly metrics and measurements, real-time issues, improvements in design, implementation optimizations, sizing specification, are some of the challenges yet to be studied and assessed.

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