Information and Communications for Smart Grid

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***Abstract*—This paper intends to present an overview of information and communication technologies that exist. Some of them were already considered in some power system standards, for example in the IEC 61850 that defines IEEE802.3 as the communication of substation automation in substations. Smart grid is a concept that covers different knowledge integrated with electric power systems, with the purpose of making it smarter. Standardizations are needed, and efforts exist especially in North America and Europe with focus on information and communication technologies.**

***Index Terms*—Smart Grid, information and communications Technologies, protocols.**

I. INTRODUCTION

The concept Smart Grid is used to characterize the electric grid evolution, with full and seamless integration of automatisms all around the network, contemplating bulk generation, transmission, distribution and costumers loads. There are many questions from different viewpoints, many challenges, some initiatives around the world, and a need for a roadmap. A key point for this evolution is the standardization of interfaces between intelligent electronic devices (IED). Instead of what exists in terms of automatisms in the bulk generation, transmission and substations, in which due to large areas of influence justified the investments to help the system control, with international standardization efforts, the costs for smart grid development, implementation, operation and maintenance tends to decrease over time, if accepted and implemented in fact. There are a lot of activities paving the way for standardization on smart grid, with emphasis on International Electrotechnical Commission (IEC), National Institute for Standards and Technologies (NIST), International Organization for Standardization (ISO)/IEC Joint Technical Committee (JTC1), European Committee for Standardization (CEN), European Committee for Electrotechnical Standardization (CENELEC), European Telecommunications Standards Institute (ETSI), German Commission for Electrical, Electronic & Information Technologies (DKE), Institute of Electrical and Electronics Engineers (IEEE) and China State Grid.

There are eight areas identified with high priority for standardization: demand response and consumer energy efficiency, wide-area situational awareness, energy storage, electric transportation, advanced metering infrastructure, distribution grid management, cyber security and network communications. For these areas there are technologies to realize the objectives identified for Smart Grid, and a intelligent grid should be digital, has two-way communication, with distributed generation and special attention on wind energy conversion systems (WECS), solar photovoltaic (PV) systems and small-scale hydroelectric power generation, sensors throughout the grid, self-monitoring, self-healing, adaptative and islanding, remote check/test, pervasive control and many costumers choices.

The NIST defines a smart grid conceptual model with six domains that are: customer, markets, service provider, operations, bulk generation, transmission and distribution. The IEEE std 2030 [1], Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), End-Use Applications, and Loads defined smart grid as a "system of systems" and regardless of which smart grid application will be implemented, there are always the needs for information flow between the entities and so the needs for a trustful communication infrastructure. The Figure 1, presents an end-to-end smart grid communications model in which there are depicted smart grid power and telecommunications systems. Some of the clouds, that are used just to define a geographical influence, are common and known in the telecommunications area. The common definitions are Local Area Network (LAN), Metropolitan Area Network (MAN) and Wide Area Network (WAN), the wireless variants WLAN e WMAN and also Telecommunications Management Network (TMN). The

IEEE also defined new network concepts as Advanced Metering Infrastructure (AMI), Home Area Network (HAN), Industrial Area Network (IAN), Business Area Network (BAN), Neighborhood Area Network (NAN), Field Area Network (FAN) and Extended Area Network (EAN) to realize the applications that are already been implemented and others to be realized for the smart electric grid.

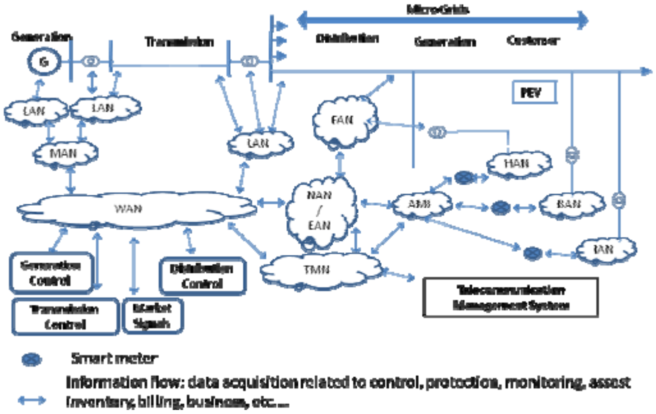

Fig. 1: End-to-end Smart Grid Communications Model

The objectives of this article is to identify and evaluate the functionality of the telecommunication technologies and their characteristics that can be used for the different network compositions illustrated in the Figure 1. This is a step for a future work that intends to simulate a complex telecommunication network for a "system of systems", and development to help the decisions if one technology is better than another, or more suitable for some electric grid features based on traffic characteristics that will be considered in future simulations.

II. THE IEEE 2030 SMART GRID INTEROPERABILITY REFERENCE MODEL (SGIRM)

The IEEE 2030 SGIRM is a conceptual representation of the smart grid architecture from three perspectives: power systems, communications and information technology. The goal of each perspective architecture is to address interoperability among them, and each perspective contains unique aspects addressed from its individual architectural-specific technology purposes. As the focus in this paper is to describe information and communications technologies, the power system perspective will not be covered in details, and is mentioned to justify the sources of data.

The emphasis of the communications technology perspective is connectivity among systems, devices, and applications, and this perspective includes communication networks, media, performance, and protocols. The communication technology interoperability architectural perspective (CT-IAP) should be constantly validated and refined by utilities and other stakeholders. This procedure is to make sure the communication technology attends all relevant aspects of the smart grid communications framework and technologies, specially physical needs of electric power protection.

Any large smart grid communications system will be made up of a number of different communication technologies and sub-networks for monitoring and control of all power system. The communications requirements will vary widely depending on each intended applications, and [1] defined a smart grid evaluation criteria (SGEC). The SGEC is used to categorize in tiers, communication cases with respect to protocols and technologies that can be used. The SGEC was used to define the requirements of architecture and is a basis for future certification and testing of smart grid components and subsystems. In Table I there are examples of applications, related tiers and standard references for implementations in smart grids.

The SGEC makes use of three aspects to make a quantitative and/or qualitative evaluation of the requirements for a particular application. These aspects are level of assurance, minimum latency, and impact on operations, that are classified as tiers. The technology chosen must meet the requirements defined under each tier class:

- Tier 1 (critical) ==> high level of assurance, covering operation data, control, and safe operation of the power system, including potential for loss of life and damage to assets.
- Tier 2 (important) ==> medium level of assurance, pertinent to operating data that can cause potential damage to assets and no risk to personnel.
- Tier 3 (informative) ==> low level of assurance for data not necessarily important for operations with no damage and risk to assets and personnel respectively.

Another evaluation criterium is level of assurance, that refers to the certainty that a service can be provided and meet the quantitative and qualitative use of communications links. In all cases, the impact on operations needs to be assured to guarantee the expected operation for that tier class.

A crucial and important point is the security categorization of links, that drives the requirements for a trustful communication, including resiliency, reliability, and fault tolerance. The IEEE std 2030 uses NISTIR 7628 for security categorization, that defines security-related logical interface categories, and their security objectives based on similar security properties such as confidentiality, integrity, and availability.

The European community, [2] Final report of the CEN/CENELEC/ETSI Joint Working Group on Standards for Smart Grids, defines examples of standards available for data communication interfaces between the subsystems (domains), that are presented in the following sub-clauses.

A. *WAN interface to Operations Subsystem*

IEC 60870-5 and IEC 60870-6 standards are the mainly used interface. IEC 60870-6 standard is for application in Wide Area Networks (Control Centre to Control Centre), and the IEC 60870-5 was designed for telecontrol (substations to RTUs - Remote Terminal Units) and operates over TCP/IP networks. In favor of IEC 61850, IEC 60870-5 has not been selected by NIST and IEC to be one of the core standards of the future smart grid

For the AMI interface to Home Automation, the interface should provide accurate information on consumption in order to increase customer awareness, enabling interactions with the user‘s environment. This interface also covers the connection of a Local or Neighborhood Network Access Point with a home automation or display functionality in the premises. Based on the same interoperability model, options may be provided for communication over standardized protocol on several media, or connection on IP LAN, or serial communication.

TABLE I

EXAMPLES OF SMART GRID APPLICATION TIER CLASSIFICATIONS

Application	References	Tier
Revenue metering information model	ANSI C12.19/MC1219, IEEE Std 1377™	1,2
Building automation	BACnet® ANSI/ASHRAE 135-2008, ISO 16484-5	2
Substation and feeder device automation	DNP3/IEEE Std 1815™	2
Inter-control center communications	IEC 60870-6/TASE.2	1
Substation automation and protection	IEC 61850	1
Application level EMS interfaces	IEC 61968 [B6], IEC 61970 [B7]	1
Information security for power system control Operations	IEC 62351 Parts 1–8	1
PMU communications	IEEE Std C37.118™	1
Physical and electrical interconnections between utility and DER	IEEE Std 1547™	1
Security for IEDs	IEEE Std 1686™-2007	1
Cyber security compliance for the bulk power system	NERC CIP 002-009	1
Home and Building Electronic System (HBES)	ISO/IEC 14543-3	1
Price responsive and direct load control	Open Automated Demand Response (OpenADR)	2
HAN device communication, measurement, and Control	OpenHAN, IEEE 1451™ series, IEEE Std 1901™	2,3
HAN information model	ZigBee® Smart Energy Profile® (SEP)	2,3

B. *WAN interface to Distribution Automation*

The Common Information Model CIM (IEC 61970 and IEC 61968) which also cover distribution management models and automation are well accepted around the world. It consists of several sub-standards, which deal with the automation of distribution systems with special regard to the exchange of grid topology data, GIS (Geographical Information System), billing based data and asset management.

Since the IEC 61968 and IEC 61970 suites cover several domains of the smart grid landscape, such as Distribution, Transmission, Generation and Metering, they are included in the cross domain. The CIM layer builds an upper layer providing data model and system interfaces for secondary IT in terms of distribution management. Downstream, the IEC 61850 family focuses on the communication within the distribution equipment within substations.

In the field of distribution automation, the IEC 61850 communication standard offers functionality for the distribution automation domain. WAN interface to Substation Automation IEC 60870-5 and IEC 61850 have been the most prominent and growing standards in this technical area. IEC 61850 is mainly used for configuration and communication within substation and between substation equipment whereas IEC 60870-5 focuses on the communication between Energy Management System (EMS) and substation.

C. *WAN interface to Distributed Energy Resources*

The most prominent standard in this scope is from the IEC. It is derived from the substation communications standards IEC 61850 and is being standardized as IEC 61850-7-420: Communication networks and systems for power utility automation. Currently the Edition 1 has become the fastest growing standard for communications with distributed energy resources like Combined Heat and Power (CHP), Photovoltaic (PV), fuel cells and BUGS (Back-Up Generating Systems).

D. *WAN interface to AMI subsystem & Head-End*

This interface is used to connect the meter, a Local Network Access Point, or a Neighborhood Network Access Point to a Central Data Collection system. Typical interface platforms for these interfaces are PSTN networks, public G2 (GPRS) and G3 (UMTS) networks, DSL or broadband TV communication lines, power line communications (PLC), either in narrowband or broadband. LAN/WAN interface to Generation Resources External access can be provided at different levels: generation devices, generation operation controllers and generation management applications. These access points can be supported over LAN or WAN.

III. IEEE 2030 SGIRM INFORMATION TECHNOLOGY (IT-IAP)

The IEEE 2030 SGIRM IT-IAP views the Smart Grid from the perspective of the IT applications and associated data flows used to operate and manage the power system with the main goal of allowing interoperability of independently developed systems. The objective is not to define new information exchange architecture, but to work with the current best practices and technologies identifying and filling the gaps for information exchange between the seven domains as necessary. Some of the gaps may be non-functional rather than functional. Functional requirements describe the functions that the software has to execute, sometimes known as capabilities. Non-functional requirements are the ones that act to constrain the solution, sometimes defined as constraints or quality requirements.

Utilities operating a Smart Grid may have petabytes of operational data, both real-time and archival, static and dynamic. There is a wealth of information generated by field crews, and from root cause analyses of past system failures. AMI becoming a fine-grained distribution sensor network feeding communication aggregation systems. Both devices, the ones which provide data and others collecting data require architectures to enhance, support, and provide context for real-time data coming in from new IEDs and other smart grid devices. Considering renewable energy sources, management of the machines, including weather forecasting and grid stability, it become another data source. With renewable energy sources, such as wind-driven systems, micro-scale weather forecasting can provide valuable information for optimized grid operation.

A well-defined data model not only makes exchanges of data and legacy program adjustments easier, but it can also help the applicability of security and performance requirements. For instance, the IEC Technical Committee 57 (IEC TC 57) Common Information Model (CIM) (IEC 61970) enables the interoperability of information exchanges through the use of standardized object models that provide semantic, contextual, and syntactical views of the information elements used within a smart grid infrastructure.

Another effort, the series IEC 61968 enables inter-application information exchanges among distributed software application systems supporting the management of utility electrical distribution networks. These series are based on the use of the CIM definitions, normative message structures, parameters and informative recommendations along with examples.

Data consistency and de-duplication can be major issues in complex enterprises, where uncoordinated development of systems have resulted in independent data naming constraints; however, the equipment to which they refer is fairly constant. A device can have different names or identifications depending on the application intended to access it.

Once data is sensed, securely communicated, modeled, and analyzed, the results need to be applied for business optimization. This means that new smart grid data gets integrated with existing applications and metadata locked in legacy systems is made available to provide meaningful context However, issues of common data formats, data integrity, and name services must be considered.

AMI storage consolidation addresses the concern that the volume of data coming into the utility will be increasing exponentially. As more meter data can be read, some kind of data analytics must be employed to properly understand and derive knowledge from it all, like patterns of customer usage or delivered voltage. This requires a robust hardware architecture to manage, back up, and feed the data into the analytics engines.

Power grid information security and protection requirements have aspects of both control (operation) systems as well as enterprise IT (business) systems. Both systems require information security services for combating malicious attacks or providing protection against errors. Confidentiality, integrity, and availability are the order of priority for a business IT system. However, availability, integrity, and confidentiality are often the prioritization order for control and protection systems. Increasingly, utilities have to deal with data privacy issues as well as traditional defensive security.

IV. SIMULATION STRATEGY

The International Electrotechnical Commission IEC is the leading international body for electrotechnical standardization, and in 2008 created a strategy group to guide and coordinate the Smart Grid standardization in IEC. This group developed a framework which includes protocols and model standards to achieve interoperability of Smart Grid devices and systems [3]. The base of the IEC framework is the seamless integrated architecture that is presented in Figure 2. Its scope is the convergence of data models, services and protocols for efficient and future-proof system integration for all applications.

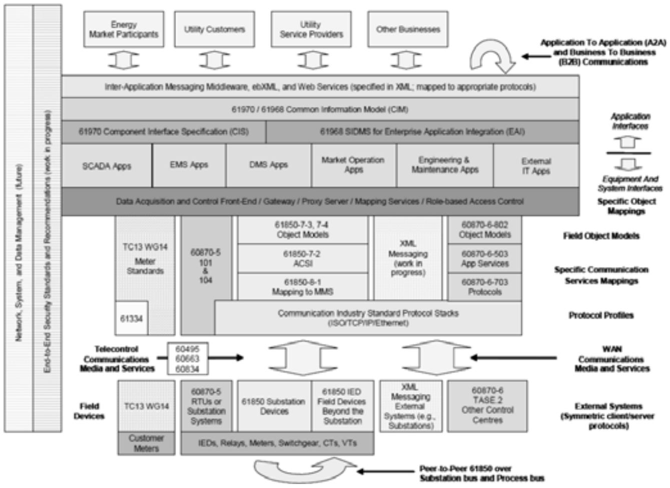

Fig. 2 IEC Seamless Integration Reference Architecture

The simulation strategy to be used in future works is a collection of communication technologies interconnected to allow communication between the different networks as presented in Fig1. The intention is to use the network simulator - NS2, a well proven and acknowledged in computer field as a trust software.

From [1], the Table 2 presents a data classification reference. For a particular communication technology, the parameter presented can be easily satisfied, but in some circumstances it may be not. For example, in a occurrence of a blackout, if there is no scheduling, all the devices can try simultaneously inform the absence of power to a control center, and then the network performance decreases over all. One example related to it that is common in public networks, is related to special holidays, as new year´s eve, when many subscribers tries to make a call and most of them receive a busy signal from the network. The intention of simulations is to define some common traffic cases, and suddenly impose an abnormal situation to check the network performance and compare with the parameters from Table 2.

A. Protocol Stack

Interoperability in ICT has generally been improved by use of a functionally layered protocol in accordance with the International Organization for Standardization (ISO) Open Systems Interconnect (OSI) reference model. The idea behind this reference model is that the functions are placed into seven layers, and the layers are connected with service interfaces. The layered structure simplifies the replacement of one communication technology with an alternative one without affecting the remaining technologies.

TABLE II
DATA CLASSIFICATOIN REFERENCE

Data Characteristic	Classification/Value range			
Data use category	To be determined by the user of the table based on the intended use of the data /(i.e., control data, protection data, and/or monitoring data)			
Reach	Meters(feet)		Kilometers(miles)	
Information transfer time	<3 ms	Between 3 ms and 10 s	Between 10 s and minutes	hours
Data occurrence interval	milliseconds	second	minutes	hours
Method of broadcast	Unicast	Multicast	Broadcast	All
Priority	Low	Medium		High
Latency	Low-low (<3ms)	Low (<16ms)	Medium (<160 ms)	High (≥160 ms)
Synchronicity	Yes		No	
Information reliability	Informative	Important		Critical
Availability (information reliability)	Low (limited impact)	Medium (serious impact)		High (severe or catastrophic impact)
Level of assurance	Low	Medium		High
HEMP, IEMI	Hardened, yes		Hardened, no	
Data volume	bytes	kilobytes	megabytes	gigabytes
Security	Low (Limited impact)	Medium (serious impact)		High (severe or catastrophic impact)
Confidentiality	Low (Limited impact)	Medium (serious impact)		High (severe or catastrophic impact)
Integrity	Low (Limited impact)	Medium (serious impact)		High (severe or catastrophic impact)
Availability (security)	Low (Limited impact)	Medium (serious impact)		High (severe or catastrophic impact)

The bottom of the stack, the layer 1 or physical layer, provides mechanical, electrical, functional and procedural means to establish, maintain, and release physical connections between data link entities. It can be wire-line, wireless and optical. For wire-line, the intention is to use Unshielded Twisted Pair (UTP) for Ethernet, PSTN or DSL, cable TV and also PLC technologies. In wireless communications the focus will be on wifi, WiMax and zigbee, but as redundancy it can use PLMN as GPRS and UMTS for data communications. For optical only Ethernet will be considered, as defined in IEC 61850.

The layer 2, or data link layer has the purpose of providing the functional and procedural means to establish, maintain and release data links between entities. In the past, there were many choices (ATM, FR, V24, etc) but nowadays for wire-line and optical the Ethernet, specially because of its costs x benefits is the best choice for LANs and will be implemented in the simulations. For wireless, it will be considered wifi and ZigBee for WLANS and WiMax for WMAN and maybe also point-to-point communications technologies.

The layer 3 or network layer provides functional and procedural means to exchange network service data units between two transport entities over a network connection. It provides transport entities with independence from routing and switching considerations and after protocols evolutions, nowadays there is one choice, the IP, or Internet Protocol. In its Version 4, there are some limitations and the most important is the addressing space. There is no routable addresses available, and there is a need for Classless Inter-Domain Routing (CIDR) and Dynamic Host Configuration Protocol (DHCP) to be implemented inside the network, or intranet to operate properly. It works well for some applications, but limits others. The newer version, the IPV6 has some improvements and the most known one is the increased addressing capabilities, but other capabilities exist, such as mobility, security and smaller overhead than the older version, increasing the performance of routers.

The transport layer provides a universal transport service in association with underlying services provided by lower layers. It is required to optimize the use of available communications services to provide the performance required for each connection between session entities. The most common protocols are TCP and UDP. UDP is unreliable and used for connectionless applications. TCP is byte-streamed, providing a single stream of data and guarantees delivering in byte-sequence order. It is particularly sensitive to delays caused by network errors like loss of bytes, messages or sequence violation. When using IP for telephone services (PSTN or PLMN), if a single TCP stream carries the ISUP signaling for many connections, the loss of a message relevant to only one resource will result in delay to all messages. Another gap of this protocol is its vulnerability for DoS attack and difficult support for multi-homing.

Sigtran is a working group of the IETF, formed in 1999, and tasked with defining an architecture for the transport of real-time signaling data over IP networks. It comprises layers or a suit of protocols to adapt the SS7 to be transported by IP networks, instead of the circuit switched used by the principles of telephony. This protocol suite works below a new transport layer, the Stream Control Transmission Protocol (SCTP). The application for Sigtran is Voice over IP (VoIP) and nowadays more accurately, Media over IP (MoIP). 'Media' applies to any real-time traffic: voice, music, video, and so forth and so the opportunity to consider smart grid applications.

A stage in the evolution of VoIP, was the definition of an architecture which would support integration between the PSTN and IP networks. This architecture would provide a signalling capability for call management as well as defined media paths through the IP network with reserved bandwidth for real-time media. Related to the requisites of power system protection, the experience that comes from the above mentioned implementation can be used to define a complex communication network that stands for the smart grid applications sharing the same communications media.

The session layer has the purpose of assisting in the support of interactions between cooperating presentation entities. It provides services of binding two presentation entities into a relationship and unbinding them. Another service provided is the control of data exchange, delimiting and synchronizing operations between two presentation entities. One example of protocol implementation is the Session Initialization Protocol (SIP), which was defined by 3GPP as a session protocol for UMTS.

The presentation layer has the purpose of providing a set of services, to be selected by the application layer, enabling interpretation of data exchanged. The services are for management of the entry exchange, display, and control of structured data. Specially for displaying of data, cryptographic can be implemented to protect the data against attacks.

The application layer is the interface with users, and in a power system environment, it can be the costumer in a marketing point of view, business applications, protection devices, costumers loads, electrical vehicles, bulk and distributed generation, etc. In a business perspective, all the internet applications can be used for advertisement, and maybe the biggest challenge is to change habits. In a communication perspective, the frequency and amount of data of each advertisement is the source of traffic that can be managed with low priority crossing at least part of smart grid communication infrastructure. In the operation and management (O&M) point of view, there are systems limited to the boundaries of a substation, transmission and generation environment, specially related to fault elimination functions that must be considered of high priority traffic and uses some intranet to guarantee the requirements of these applications. O&M functions and consequently data traffic, can be considered of medium priority, and related to devices configuration and supervision that can use intranet or internet, as in "home office". Also in O&M area, but pertinent to business in the AMI features, that maybe can send generation and transmission costs informative data at interval that are fast than the practices nowadays. It should be noted that it is not only the frequency, but also the possibility of integrating a variety of generations at the distribution level of voltage, that tends to have bidirectional energy flow, microgrids, etc, will increase drastically the traffic amount. Applications that can have access to weather forecasting, to predict the power generated by intermittent sources, to assist in decision to dispatch other sources that affect the costs of energy is another are other examples of not only one application, but a system that uses information from different systems, as defined by IEEE, a system of systems. As the application is the interface with the user, it should be constantly adapted to existing and future needs, and new solutions can emerge. Here, we have just presented some ideas.

After covering the seven layers of OSI reference model, considering some practical implementations of substation automation, AMI, and specially at management system a simple protocol stack that can be considered is presented in the fig. 3. It should be noted that most of the layers presented has more than one layer in it, making the presentation of all protocols and technologies in a unique stack impractical. In the fig 3, the ellipsoids represents the different applications presented above,

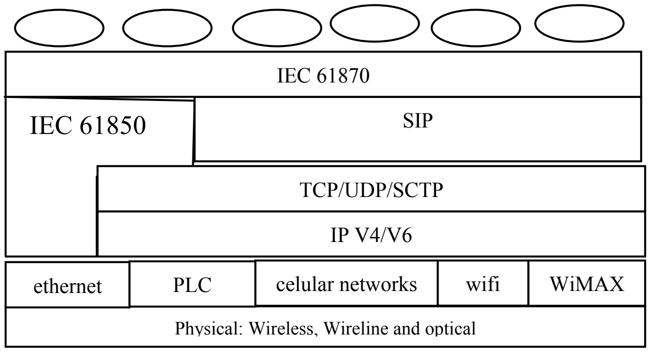

Fig3. Example of a protocol stach for smart grid

FINAL COMMENTS

The intention of this paper was not to reinvent the wheel, but to present a study of the tendencies in smart grid that must be considered in a communication infrastructure simulation. Smart Grid is not a new technology or system, but there is a big challenge involved in it. It is the integration of a variety communications and information technologies intending to make the electric power systems smarter. Historically, the electric knowledge grow to levels that were divided by the Academy. The electronics evolution by telecommunications and military needs in the early 1990's, in the end of nineteen century got into the homes, in the palm hands, in automobiles, and so on. Not only because of smart grid, because electronics, communication and information tech already is used in the electric networks, but with the tendencies to interact more intrinsically with the power system, making the loads and costumer closer to it. The computer and communication areas, managing data faster than ever will be the enabling tools for smart grid and one can conclude that the division of knowledge that starts with the electric science, should be integrated to the electric again.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

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