THE STANDARD IEC 61850 - A SIMPLE BUT COMPREHENSIVE SOLUTION FOR TODAYS POWER SYSTEM REQUIREMENTS

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Abstract – Most power systems today are operated at the capacity limit. The power flow has to be guaranteed by using the data flow between all the components of the power system management system consisting of all electronics acquiring data, making decisions, issuing commands, making simulations and archiving, etc. The main goal is to secure the supply and quality of power. Therefore, actual data have to be exchanged including its semantics that all users of this information understand its meaning. This is especially necessary in emergency cases. The source and the sink of all process data is the substation with its automation system. Therefore, the standard IEC 61850 for communication in substations is the key for a lot of solutions for the power system since it standardizes not only the communication but also provides an object oriented data model applicable to the complete power system. It is shown that all requirements are fulfilled by this standard. Also the substation configuration description language of the standard is applicable to the system wide configuration. It supports the optimal utilization, operation and maintenance of the power system.

Keywords: IEC 61850, power systems, power system management, substation automation, communication standards, protocols, IEC 60870, interoperability, engineering tools, liberalized markets, real-time, utility, object model, communication services, Ethernet, IED

1 INTRODUCTION

In the past the only way to ensure the supply of electricity was to build a very stable meshed grid that could survive mostly any critical situation. Of course those networks where over-dimensioned. The same grid today transports a multiple in electrical power but is unfortunately frequently loaded near his capacity limit. In this situation the Network isn't anymore secure enough all the time and automatically. It means that before and during the actual operation sophisticated simulations (State Estimation, Security analyses, Load flow calculations, Optimal power flow, etc.) and corresponding counter measures are continuously necessary to guarantee security of supply and prevent incidents or blackouts. Therefore, to optimize the performances of a system, it is necessary to collect in advance as well as in real time very accurate information about the planed and actual status of the system and make it available for processing at different levels. It means to optimize locally at station level as well at remote levels for a part ore the whole network.

The production of electrical energy is moving from a centralized generation in big hydro or thermal power plants to multiple decentralized productions in smaller gas turbines respectively wind and solar power plants. In the same time, because of the liberalization, customers may choose their supplier in energy and competition forces the suppliers to offer a wide range of different products and packages not only to the local market, but also to market players in other regions. Busy energy exchanges drive heavily the fluctuation of the energy flows. Very accurate and actual information from a very high number of places at all voltage levels independent of the dedicated collecting and communication technologies is needed. The complex power flow is stabilized by a more complex data flow, which is also the basis for the information flow needed by business systems (Figure 1).

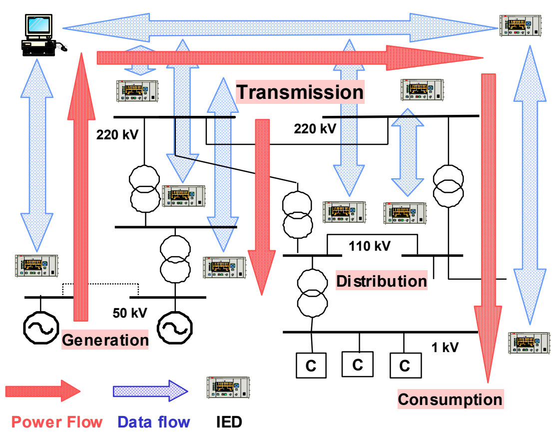

Figure 1 - Power system: Power flow and Data Flow

2 BASIC FEATURES OF THE POWER SYSTEMS AND ITS CONTROL

To select and evaluate the appropriate measures stabilizing the power system based on information some of its basic features have to be summarized. The interconnected power systems at least in industrialized areas are very large covering continents like Europe or North America. The grid contains ten thousands of nodes with thousands points of generation and millions of power consumers. Therefore, it is a very large distributed system. The impedance of the lines and cables controls the power flow. The active impedance control by FACTS is only at the beginning. Since today power storage is possible only to a very small extent, production and consumption have to be in balance. Basically, it is a three-phase system running with 50 or 60 Hz complemented by some HVDC links or backbones. Heavy discussion about the blackouts happened show that the complexity is not yet understood completely [1], [2].

All the information is collected from the sensors in the nodes of the electrical power systems and all commands issued by operators or automatics are performed via the actuators there. Therefore, substation automation systems with there data processing and communication facilities are the main key to the solution of the power system requirements (Figure 2).

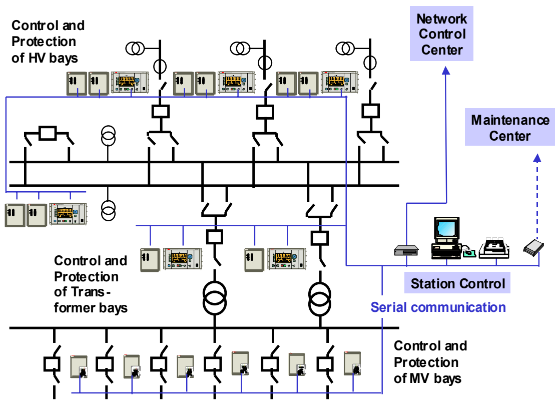

Figure 2 – The single line of a Substation with the allocated Substation Automation System (example)

3 REQUIREMENTS FOR THE DATA EXCHANGE IN POWER SYSTEMS

3.1 Interoperability

Because of the high number of substations in the power system, the complete power system is controlled, protected and monitored by a very high number of microprocessor-based devices called IEDs (intelligent electronic devices) which constitute together with the centralized computers of the network control centers the overall power management system. All this equipment is provided by many suppliers, has different functionalities and consists of different technology generations. The key requirement for such a distributed system is an *exchange of consistent data easily understood* by all relevant system participants.

This mutual understanding of all IEDs involved in the data exchange process is called *interoperability*. It is defined as the ability of two or more intelligent electronic devices from the same vendor, or different vendors, to exchange information and use that information for correct co-operation (definition according to IEC 61850 [3], part 5). Interoperability is the basic requirement for power system communications. It is often limited by the high variety of devices and technologies. This limitation may create big problems for managing a reliable power supply.

3.2 One information system for all users

The same information about an element in the power system is needed for different functions and at different locations. If all the different users install their own information systems and, therefore, collect the same information several times, there is a very high risk that the data are not consistent at any time, especially important in emergency situations. Not only for technical and organizational reasons but also from the economical point of view, there has to be one consistent information system acquiring all the information from the process and providing it to all the interested users at the right place in the right time. Redundancy for increased availability of data has to be designed very carefully to avoid the risk of conflicting information from the beginning.

3.3 Data maintenance only once

Utilities have not only to handle process data but also asset and business data. For consistency and efficiency the whole data maintenance in today's utilities must be simplified and standardized. There should be only one place where the data are maintained. This refers especially to the input of configuration data about the network. The maintenance procedure has to guarantee that all the users have always the actual configuration, asset and business information as needed.

3.4 Common data model

To achieve the same semantic meaning for all the information to all users, a single data model with standardized objects for the complete power system, i.e. from substations with any kind of RTUs and Substation Automation Systems up to the Network Control and Energy Management Centers at any control level is required. The data model should be oriented at the objects of the power system.

3.5 A common system for an acceptable maintenance

Acceptable maintenance and guaranteed high availability including short repair-times if necessary are also a very important goals for today's overall power management system. It means that there should be not too many dedicated systems and technologies at the same place (bay, substation, control center). If there are only secondary systems installed, which are based on a common standard, the necessary know-how can be acquired and maintained by a small number of experts using limited documentations and instructions.

4 REQUIREMENTS FOR THE DATA EXCHANGE IN SUBSTATIONS

4.1 Functional and technical requirements

Despite the increasing number of substation automation systems [4], these systems have been left for a long time as communication islands with proprietary protocols. But being part of the overall power system management system and exposed to the economic pressure in liberalized power markets, interoperable communication within substations is requested, especially because of the large assembly of IEDs in decentralized substation automation systems.

Regarding the long lifetime of substations and the fast increasing power of communication technology this interoperability has to be assured by a modern, long-lasting communication standard supporting all functions and any configuration in substations. Open access to data has to be provided not only for operation but also for emergency situations and for post-mortem analysis. More intelligence to cope with the high information flow has to be supported. Special requirements are coming from the strong real-time behavior of many functions and the harsh environment in substations.

Because of the dedicated position of the substation within the power system, the acquisition of data in the substation is directly done at the source. Therefore, any data model for substation automation systems has to be the basis for the complete power system information. But being part of the overall power system management the communication standard in substations should support the idea of "seamless" communication" in power systems, i.e. from breaker IED up to the network control center. The very practical requirement is to get rid of protocol conversions and to have a consistent semantic meaning of the data traveling through the communication system.

4.2 Additional user requirements

Besides the functional and technical requirements the users in utilities claim for more. Most utility engineers are no communication specialists. They need information on application level in a very convenient way with unambiguous meaning for design, operation and maintenance of the system.

Everyday engineering objects out of the domain substation are requested instead of abstract number schemes. Engineering has to be possible by tools on the user level and has to be comprehensive at least for the substation domain.

The user likes to have the choice to select the equipment with best functionality needed and highest benefits provided. The selected equipment has to fit into the substation automation system using a common communication standard.

All users, which need some information from the substation, should be able to subscribe exactly this information via the substation communication system and receive it with full semantics.

5 SOLUTIONS

5.1 Protocol converters

Very expensive solutions for interoperability are protocol converters, often called gateways, converting all the seven ISO/OSI layers of all the dedicated protocols used elsewhere in the system. The conversion of single signals may be easy; the interpretation of the complete context needs a lot of dedicated efforts since there are no object-oriented data models behind. The much cheaper, more reliable and comprehensive solution is the use of communication standards if there are any.

Nevertheless, there is also a need for sophisticated protocol converters left. In case of refurbishment of a complete substation or a part of it (e.g. one voltage level) a protocol converter guarantees the interconnection between the old and new part transient or permanent as needed. With such a solution it is possible to build a new part with the state of the art technology and interconnect it to the existing one with a reasonable lifetime left.

5.2 First standards for utility communications

According to the early introduction of computers to NCC, the communication between NCC and RTUs was standardized first by the IEC 60870-5 protocol family [5]. This very common protocol was intended for slow point-to-point or multi-drop links with dominant master-slave behavior. The very basic semantics of the single signals was given by a number scheme. The IEC 60870-6 family (ELCOM and TASE2 or ICCP) was developed for fast inter-center communication networks between NCCs [6]. To overcome some limits and to improve the implementation to be more user-friendly, the development of a new standard IEC 61850 was started. A detailed comparison is beyond this paper but the features of IEC 61850 will be discussed in what follows.

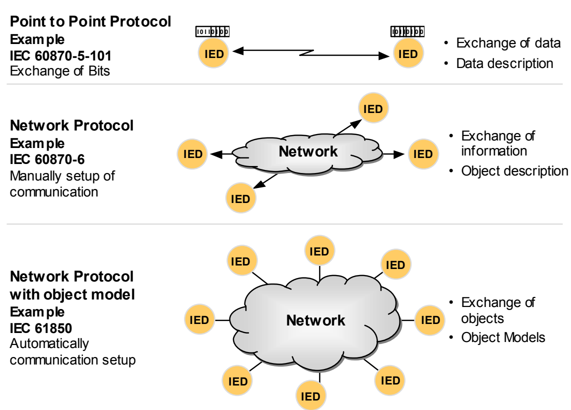

Figure 3 - Legacy protocols and IEC 61850

6 THE SIMPLE AND COMPREHENSIVE ANSWER OF IEC 61850

6.1 Communication standard for substation automation

The new global standard IEC 61850 "Communication Networks and Systems in Substations" [3] fulfills all requirements stated above. It is now issued completely and being introduced into the first products and systems. This standard is globally accepted and intended to be the only standard for communication in substations. It supports all communication tasks from the intelligent process interface up to the station control level.

Because of the role of the substation in the power system and the role of substation automation as process interface for the power system management, an important impact of IEC 61850 on the overall system is expected.

6.2 The object model

IEC 61850 defines a domain specific object model with objects well known to the substation engineer (Figure 4). The object model is based on the data provided (sensors) and needed (actuators) in the substation, i.e. near the switchgear and the instrument transformers. Therefore, the object-oriented data model with all its semantics reflects the view of the power system engineer. The semantic meaning is not coded in a complex number schemes but provided in a hierarchical set of objects (Logical Nodes), data and attributes identified by mnemonic alphanumeric terms. There are strict rules for extensions, which are only allowed if data cannot be modeled by the existing standardized means. Nearly all extensions have to be identified by a name space reference.

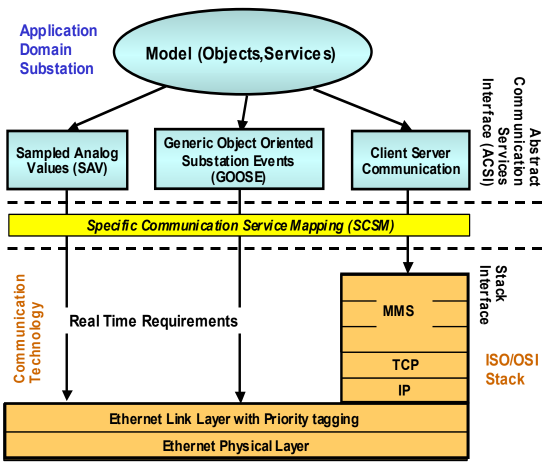

Figure 4 - Approach of IEC 61850: Split of data model and communication (7 layer ISO/OSI stack simplified, especially for MMS layers)

Also the operators in the network control centers and the energy management programs like to operate with high-level semantic information. Therefore, about the same time when the data model of IEC 61850 was developed for the substation level, the Common Information Model (CIM) was developed in the context of the standard IEC 61970 [7] for the energy management level. Since the substation automation system has to handle much more details compared to the remote NCC, the model of IEC 61850 is much more elaborated than CIM but both describe the same reality, i.e. objects of the power system. Therefore, the CIM has to be in some sense a condensed set of the model in the substation. In the meantime the compatibility of both models developed in parallel has been proven.

The services to access the data objects in a standardized way are close to the functional needs of the users. An example is the command service “select-before-operate”.

6.3 State-of-the art communication technology

The domain specific data model with its services is mapped by standardized mapping rules to a communication stack composed of MMS, TCP/IP and Ethernet and, therefore, selected from the mainstream communication technology. The domain specific model guarantees the long-term stability of the standard and the application based on it. The use of the state-of-the art communication technology allows following the advances in communication technology and if necessary upgrading to a higher performance (Figure 4).

6.4 Functionality and hidden technology

On problem mentioned for the overall power management system is its constitution out of devices of different technologies. The domain specific model provides standardized data based on common functions to be performed in the substation. Since the data and their exchange is standardized on functional level, the technology of the implementation is hidden and of no relevance for the user. Therefore, not only different providers but also different technologies are compatible on the basis of the standardized data exchanged. Especially, the switchgear technology and the physical principles of instrument transformers (magnetic, capacitive, optical) are hidden behind the process interface. That is an additional benefit for the users and allows specifying *requirements* instead of *solutions*.

6.5 Complex for the developer but simple for the user

Like in modern office tools, the complexity of the implementation of IEC 61850 is shifted completely to the development engineers both of products and tools. The user gets a very simple but powerful standard to solve his communication problems in substations and beyond without going to cumbersome codes or down to bits and bytes.

6.6 Support of device and system engineering

To set up a complex system with all its data and functions in a comfortable way without inconsistencies, the communication standard IEC 61850 provides also an XML-based standardized Substation Configuration description Language (SCL). SCL allows also exchanging data between engineering tools and providing a lot of supporting since it describes not only the communication between functions and IEDs but also the topology of both the single line diagram and the allocation of the substation automation system with all related functions and IEDs to it. The description power of SCL goes no beyond the first approaches and supports the configuration of all devices in the substation from intelligent sensors up to control and protection IEDs sequencers and, on station level, to protocol converters and single lines in the HMI. It should be stated that the machine-readable XML part is standardized but not the engineering tool with all the ergonomics for the user (right window vs. left window in Figure 5).

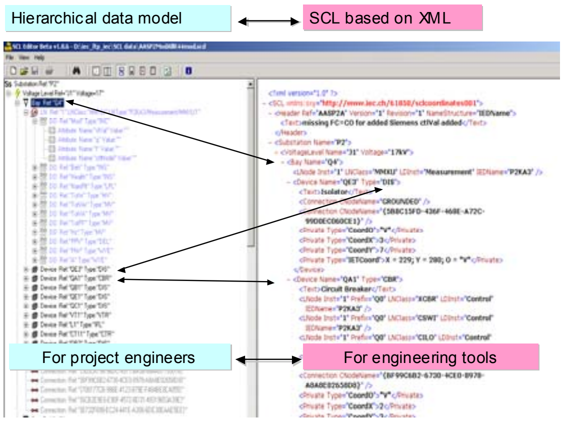

Figure 5 - Substation configuration description language (SCL)

6.7 System architecture

All functions and links in between the different equipment in the substation are implemented in IEDs. The mainstream communication basis for IEC 61850 is Ethernet. Therefore, a lot of architectures with interesting components like switches are possible. Functionality, availability and a lot of boundary conditions determined the resulting system architecture [8]. Specifying requirements only instead of devices allows for optimized solutions [9].

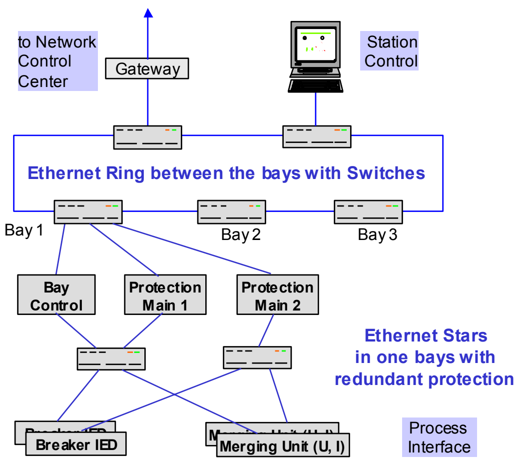

Figure 6 - System architecture (example) according to IEC 61850

6.8 Testing and commissioning

Because of the object oriented data model including semantics, standardized services and SCL, sophisticated tools for testing and commissioning are possible and more and more available. This allows easy but comprehensive device and system testing on all control levels. Most testing tools can easily be connected everywhere to the communication system. The testing can be performed stepwise from single devices independently of projects up to complete systems for projects.

6.9 Summary of functions and station parts supported

The standard 61850 supports all the functions, which are required within the substation but also for the complete power systems. Important ones are listed below.

6.9.1 Basic Functions

Control and supervision
Protection
Event recording
Alarming
Metering

6.9.2 Advanced functions

Configuration data handling
Automation sequences
Interlocking
Parameter handling
Data engineering
Calculated values

6.9.3 System functions

Power frequency control
Local/remote control
Simulations with on-line and off-line data

6.9.4 Station parts

Substation handling
Substation automation system handling
HMI
Auxiliary systems handling

7 INTEGRATION POTENTIAL OFFERED BY IEC 61850

7.1 Integration of primary and secondary equipment

IEC 61850 supports also the process near communication in a standardized way. By this and with the advent of EMI proof electronics it is easily possible to combine the primary und secondary equipment in one set-up if accepted. By this approach, power system, process near IEDs and the communication system for the whole information exchange could be integrated in one pre-configured and pre-tested set-up as needed for the refurbishment of components, fields or whole stations or for the extension by new parts. Every set-up or element has already integrated all its objects with all basic data ex works. Only simple electric connections with the power system and a fiber optic link with the substation automation system have to be established hardware-wise. After installing the electrical part, the necessary configuration data will be exchanged over the communication interface and all users get the information needed. A schematic example is given in the Figure 7.

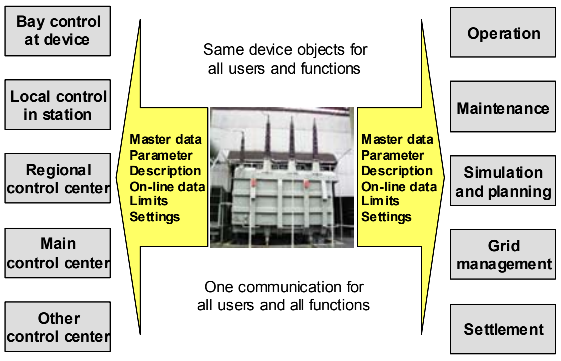

Figure 7 – Schematic view of integration of primary and secondary equipment in case of a transformer

7.2 Seamless communication in power systems

It was indicated in this and other papers that IEC 61850 is in favor also for applications outside the substation. This powerful trend is summarized here:

Besides using the state-of-the-art communication technology, IEC 61850 is providing all the standardized information (data with semantics) which is needed for the operation and management of the power system in a standardized way without getting stuck in the big variety of technologies, sources and sinks of information.

IEC 61850 is defining data and communication at the lowest possible level at the power system process. Therefore, it is the primary source of information for any other application elsewhere in the power management system.

Spreading out this approach also outside the substation opens up for a seamless communication in utility systems.

8 CONCLUSIONS

The paper has shown that the standard IEC 61850 is more than a communication standard. This standard is simple at users level and a comprehensive solution for today's requirements where the economical and secure utilization, operation and maintenance of the power system is guaranteed by the information flow between complex arrangements of IEDs at all levels.

Behind the simple and comprehensive solution there are a lot of details as seen form more than 1000 pages of the standard IEC 61850 in 14 parts [3] and from a lot of publications about topics of the standard, e.g. in the very comprehensive etz report [10].

In different countries there are already substation automation system based on IEC 61850 in operation or under construction. The first experience has shown that interoperable data exchange between the devices in the substation is reality.

The benefits of a seamless communication in the complete power system are feasible but have to be proven and exploited by future installations and applications.

Because of the high impact of this standard for the complete power system, the continuous maintenance of IEC 61850 is very important. This maintenance has already started in cooperation of experts both from the working groups of IEC TC57 and the UCA International Users Group [11].

REFERENCES

[1] P.Fairly, The unruly Power Grid, IEEE Spectrum, August 2004, p.16-21
[2] Blackout 'could have been prevented', Modern Power Systems, April 2004, p.3
[3] IEC 61850 Communication Networks and Systems in Substations, 14 parts, 2003-2005
[4] K.P.Brand, V.Lohmann, W.Wimmer, Substation Automation Handbook, ISBN 3-85759-951-5, 2003, www.uac.ch
[5] IEC 60870-5 Telecontrol equipment and Systems. Part 5: Transmission protocols
[6] IEC 60870-6 Telecontrol equipment and Systems. Part 6: Telecontrol protocols compatible with ISO standards and ITU-T recommendations
[7] IEC 61970-301 Energy management system application program interface (EMS-API) – Part 301 Common Information Model (CIM) Base
[8] K.P.Brand, C.Brunner, W.Wimmer, Design of IEC 61850 based Substation Automation Systems according to Customer Requirements, CIGRE Plenary Meeting, Paris, 2004, Paper B5-103
[9] K.P.Brand. M.Janssen, The Specification of IEC 61850 based Substation Automation Systems, Paper at DistribuTECH 2005, January 25-27, San Diego
[10] K.Schwarz et al., Offene Kommunikation nach IEC 61850 für die Schutz- und Stationsleittechnik (Open Communication according to IEC 61850 for protection and substation automation systems), etz-Report 34, 2004 (English edition with report number 35 in preparation)
[11] UCA International Users Group, www.ucainternational.org