THE EMERGING COMMUNICATION ARCHITECTURE IN ELECTRICAL ENERGY SUPPLY AND ITS IMPLICATIONS

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Introduction

In the course of liberalisation of the electrical energy market, the pressure on the utilities to reduce their investment and maintenance costs is increasing. In order to lower these expenses and to be able to offer a more efficient supply with electrical energy, the utilities are increasingly using modern communication techniques. Control mechanisms that have been realized with a huge amount of hardware so far are more and more replaced by software-based solutions. Major points of concern in the near future are the standardisation of communication interfaces and protocols, as well as the implementation of autonomously acting entities performing vitally important actions like controlling protective systems.

Content

In this paper three major aspects of the present development of communication standards in the field of electrical energy supply are discussed. The first part of the paper focuses the nature of the emerging communication that will integrate wide areas of a utilities communication needs. In the second part some advanced integration issues, related to the further extension of the communication standards to new processes and views are briefly discussed. The final part gives an outlook on certain question related to the implementation of real-time operating systems.

Communication in electrical power supply

The controlling and monitoring of electrical systems has in general two perspectives. The first perspective is the process related one, concerned with the primary equipment and the processes necessary to provide customers with the needed electrical energy. In this scope real time data and real time control are of great importance. The main aim here is to provide the industry with standards in the sense of transmitting, representing and addressing the data. Currently there are many initiatives to standardize the representation of typical processes, like substation control, wind turbine control or the control of distributed energy resources (DER).[1]

The second perspective is a top down view on the electrical system. This perspective is concerned with topological information and tries to provide the needed information to monitor the electrical system as a whole.

For both perspectives it is possible to define a set of information needed for the operation of the particular part electrical system and additional information, not crucial for operation, but necessary for monitoring and maintenance purposes.

Future development will focus on integrating these two perspectives and provide an integrated communication system throughout the utility in order to provide the different divisions of a utility directly with the information needed.

Status quo

One standard widely used today is the protocol family of IEC 60870. The IEC 60870 family was developed by the IEC Technical Committee 57 to bring a communication standard to the field of electrical energy supply. It was meant to enable equipment from different vendors to cooperate with a minimum of integration effort. By the time of development the predominant architecture of programming languages was the so called functional orientation or 2nd Generation programming languages. Therefore IEC 60870 was also oriented on serial data structures. Thus IEC 60870 is a so called “signal-oriented” protocol. Within one node there are specific addresses for each signal, containing the actual information. As this address is a binary code, there is no possibility to figure out from the address what kind of information the specific field represents. This brings the necessity to map these addresses to their “meaning” while interpreting the data. This task is complex and cost-intensive and increases the risk of human errors.

Members of the protocol family are:

- IEC 60870-5-101 [2]
  “Transmission protocols – Companion standard for basic telecontrol tasks”
- IEC 60870-5-102 [3]
  “Companion standard for the transmission of integrated totals in electric power systems”
- IEC 60870-5-103 [4]
  “Companion standard for the informative interface of protection systems”
- IEC 60870-5-104 [5]
  “Network access for IEC 60870-5-101 using standard transport profiles”

IEC 60870 was meant to cover all aspects of communication within a substation, between substation and control centre and control centres between each other. Therefore IEC 60870 also includes standards for the physical and session layer of the Open System Interconnection Reference Model (OSI Reference Model). It includes definitions of bit sequence telegrams formats and defines obligatory data integrity standards. But this brings with it tough restrictions for the choice of the communication channel.

IEC 60870 was developed as a standard primarily for serial communication on dedicated communication channels and not for the use in packet switched networks. But with the enormous spread of IP-based networks and network equipment the necessity to adapt to this network technology to benefit from its development and the lower component prices increased. IEC 60870-5-104 was an intent to encapsulate IEC 60870-5-101 communication into IP networks to take advantage of the routing capabilities and to overcome the physical layer restriction.

In modern Energy Transmission Systems the protocol family of IEC 60870 is widely in use. From the control of secondary reserve power plants to the communication between two Intelligent Electronic Devices (IED) within one substation it is one of the most important standard. Figure 1 illustrates the field of applications of some protocol member standards.

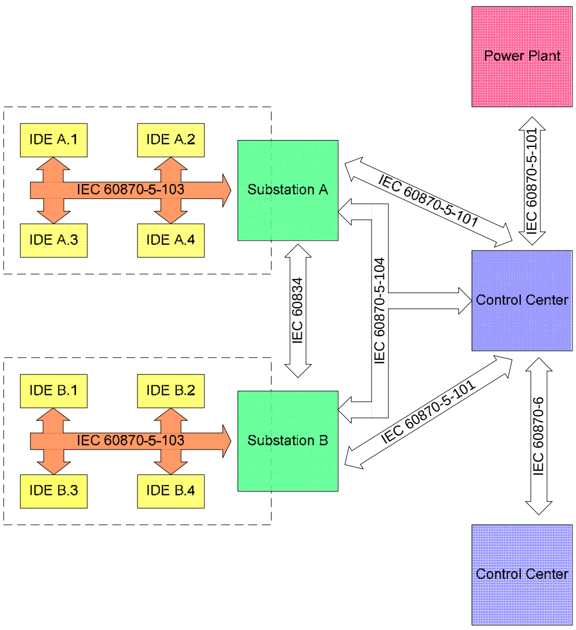

***Figure 1: IEC 60870 and its application**.*

Although most of these protocols are part of the IEC 60870 protocol family communication is not directly possible between two devices using different standards (e.g. a Control Centre workstation and an IDE in the substation). In such communications there is always the necessity to use a gateway to couple both worlds. In the case of a substation for instance there has to be an IEC 60870-5-103 to -101 or 104 Gateway in order to connect the substation to a control centre. A big disadvantage is that if the IDE and the workstation of the above mentioned example would have implemented a function not supported by the gateway a use of this function would be impossible.

The IEC 60870 standard does not only restrict the domain in which data exchange is directly possible, but also which data can be exchanged and how it could be exchanged. These are strong restrictions to the design of utility communications and in many cases impede the different divisions to get the information they need with a minimum of effort.

To overcome restrictions like the lack of direct communication and to include a system for easing the configuration and deployment of equipment from different vendors the development of IEC 61850 was started.

IEC 61850

IEC 61850 is initially designed to integrate all the devices within a substation. It is intended to provide interoperability between devices of different manufacturers and vendors, as well as being capable to be adapted to new communication technologies and technical requirements. To be able to take advantage of mainstream communication technologies IEC 61850 does not define a concrete communication stack. Presently IEC 61850 includes a standard on how to map the communication on to TCP/IP and Manufacturing Message Specification (MMS) [6]. IEC 61850 strictly divides the process of communication and control into three main aspects.

The first aspect is the structure of the data representation. This is on how information is stored and structured and how data is related to each other. It is also about naming conventions and a prerequisite to integrate equipment from different vendors. In the following to data representation will be referred to as "data model".

The second aspect deals with accessing the data model. Equipment from different manufacturers has to use a common syntax and semantics in order to be able to "understand" each other. In IEC 61850 this is not about how to address another device or open a communication channel to it. At this level of the standard it is just about standardizing orders and reactions to orders in an abstract manner [7].

The third aspect is the transmission of data. It deals with mapping the communication onto a concrete communications infrastructure. This communication layer is independent from the two upper layers. This makes it possible to adapt to a new communication technology without having to change the data model or the standard to access these data models.

In contrast to IEC 60870 IEC 61850 did not integrate these three aspects into one standard, but defined sharp interfaces between these three layers of the communication (cf. Fig. 2).

IEC 61850-7-3 and -4 [8][9]
: Defines the data model for substations

IEC 61850-7-2 [7]
: Defines the syntax and semantic of the exchange of data.

IEC 61850-8-1 [6]
: Defines the mapping of communication onto TCP/IP and MMS

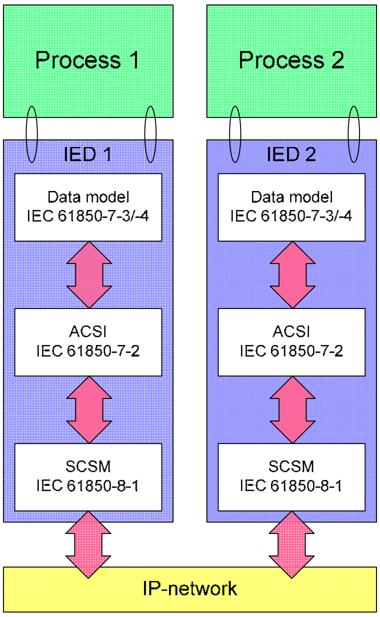

***Figure 2: IEC 60870 and its application*.**

Each of these components of the standard can be replaced without influence on the others. E.g. for the mapping onto a new communication technology a standard replacing IEC 61850-8-1 could be defined without the necessity to change the other two layers. The same is true for the data structure and the data exchange methods. Currently under development are extending standards to standardize the data model for other processes like Power Quality Monitoring, Control and Monitoring of Hydroelectric power plants and for the control and monitoring of DER in general [1][10].

All of these data models have a common structure enabling them to be mapped onto other layers of the communication standards within IEC 61850.

IEC 61850 was developed under the influence of 3rd generation programming languages. The so called object oriented (OO) programming Languages use a data storage structure where data and functions are organized in Classes and Instances of classes, called Objects. Classes are blueprints for Objects, defining their interface to the outside world and their inner data structure. These Classes are organized in a heritage tree structure, in which the offspring of a parent class inherits functions and data structures from the parent class. In this manner Classes can be specialized to their specific behaviour while leaving common function implementations to the parent class. This eases the standardization of common functionality without the loss of specialization. Equipment of different vendors can implement common basic functionalities and at the same time additional features only provided by a particular vendor.

The possibility to form tree structures of instances also simplifies the representation of nested configurations. A whole substation can, in the first place, be addressed as a single node within a tree structure of components.

Class

A class defines the characteristics of the representation for a real or abstract thing, including attributes and properties. This is needed by an object to store its state in order to represent the real or abstract element it was instantiated for. Additionally a class contains definitions for methods. Methods represent the ability of a Logical or Physical Node to perform a certain operation.

Object

Objects are instantiated from a certain class. By instantiating an Object a new set of attributes defined in the particular class is generated, so that the new object represents one single real or abstract counterpart.

Method

Methods encode the ability of an Object to perform certain actions. They are are called members of that class. From a programmers point of view it is possible to give an object orders by calling one of its methods.

Message

Messages are used to invoke a remote object's method and to pass data to it.

Inheritance

Class definitions can be ordered hierarchically. More general characteristics can be defined in a parent class whose offspring inherit these characteristics and methods.

Encapsulation

Object-oriented programming languages usually realize a low-level security mechanism in order to impede the manipulation of data or the invocation of methods by parts of the running program that are not supposed to do this. Often members (attributes, methods, etc.) are named to be either private, or protected or public.

Data representation in IEC 61850

Corresponding to the structure of Object Orientation the data structure of IEC 61850 bases on the representation of physical devices, called Physical Nodes (PN) as Logical Nodes (LN) within the communication system. A logical node represents the physical device as a logical device that can be accessed by other software components. The before mentioned data models are standards for the structure of this Logical Nodes and therefore defined a classes.

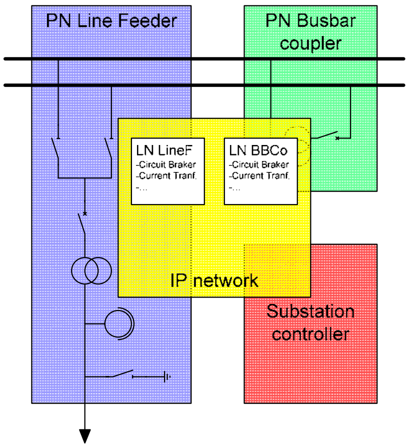

Figure 3: *Physical Nodes within a substation.*

Substation data model

As mentioned before IEC 61850 was primarily designed to standardize the communication within substations. In order to model the processes of a substation four major object classes were defined to meet the requirements of all used IED. The four major classes are:

- Power System Model Object (PSOM)
- Client-Server Object Model (CSOM)
- Generic Service Provider (GSP)
- Storage Subsystem

These four basic classes are integrated by the Common Application Services (CAS) which is the messaging specifications for substations.

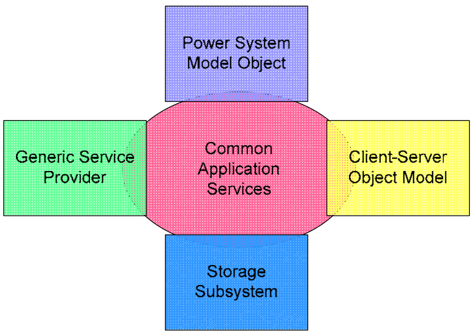

Figure 4: *Data Model of a substation.*

The basic components of IEC 61850-7-3 and -4 in details are:

PSOM

The Power System Model Object defines a data model for autonomous protection subsystems that can also be used for data acquisition.

CSOM

The Client-Server Object Model is designated for general communication issued inside a substation. This includes Peer-to-peer communication between two IDE, as well as general client-server relationships.

GSP

Effectively the Generic Service Provider can be seen as being the communication controller of the substation. It is in charge of managing the data exchange between devices of the substation as well as the communication with the outside world.

Storage Subsystem

The Storage Subsystem may be centralized within a substation, or as well distributed among several IDE, servers or storage systems inside the substation.

The ability of IDE to communicate in a peer-to-peer manner together with the storage subsystem being able to reside in more than one location brings with it the issue of critical tasks concurring on distributed resources. In this case the distributed resource is the data stored in the storage subsystem. This issue will be addressed later on.

Further requirements to IDE from IEC 61850

Self description services

In order to ease up the integration and configuration of IED IEC 61850 includes a standard that enables IED to inform communication partner about what parts of the data model they actually are using. Within IEC 61850 a file format called "Substation Configuration description language" (SCL) is defined as standard. SCL is a format based on the "Extensible Markup Language" (XML), a cross-vendor standard for storing nested data. Every IED has at least to provide a file containing its configuration so other IEC 61850 compatible devices can access this IED. More complex IED may also be able to receive their configuration through a SCL configuration file delivered through IEC 61850.

Data transfer services

In order to transmit the above mentioned SCL files as well as larger amounts of data whose transmission is not time-critical, IDE have to provide a basic file transfer service. IEC 61850 contains a definition of such a service, but may be complemented by services like FTP.

Priorities:

Priority is a Quality of Service (QoS) parameter negotiated at connection time between any two IDE. Four levels are defined in IEC 60850:

- Reserved: for network management
- High: highest level intended for short, critical control messages
- Normal: medium data level
- Low: for large, non-critical files

If just two levels are supported by the transport protocol the high priority should be exclusively reserved for the highest priority level of the original priority scheme.

Integrating other parts of the Electrical Energy system

Presently IEC 61850 focuses on substation control. But there are many approaches to integrate further aspects of electrical energy supply into IEC 61850. Due to the open communication standard this is mainly an issue to the definition of data models, reflecting the requirements in the certain field of technology. Present development intends to integrate the following aspects:

- Data model for monitoring and control of wind power plants (IEC 61400-25) [11]
- Data model of a power system from the control centres point of view (IEC 61970 CIM) [12]
- Data model for Distributed Energy Resources (DIN 61850-7-420) [10]

Control Centre data model

The data model for communication on substation control level is well defined within IEC 61850. When transmitting this information to a control centre the requested data has to be mapped into a data model suited for the use on Control Centre level. IEC 61970 defines such a data model, called "Common Information Model" (CIM) [12]. The integration of process related data representation to CIM and its more general perspective would need a gateway to map data between both standards. The locally available information relevant for the control centre has to be mapped into a CIM representation by the substation controller or some kind of gateway connected to the substation network and the control centre. In order to be able to represent the whole substation to the outside world, the gateway has to hold local copies of the relevant data generated by the IED. These local copies are subject to accessibility concerns addressed later on.

Mapping between Data models

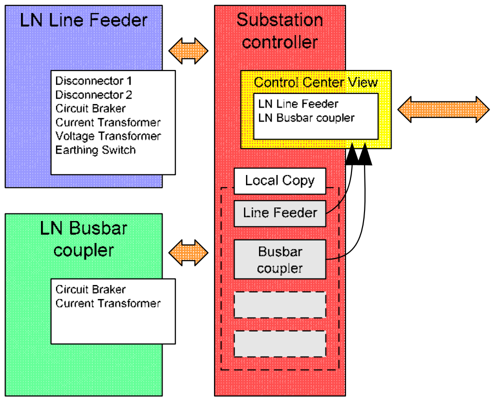

***Figure 5:** Mapping the substation data model to Control Centre data model.*

Real Time Operating Systems

A real time operating system is an operating system that is deterministic in terms of the execution time of tasks. Typically one or more tasks are created by external sensors or human interaction, on which the operating system has to react in a certain amount of time.

This is of grand importance in terms of safety and fault tolerance. Task may arrive whose timely execution is crucial for the survivability of a system. In case of this task not being executed before its deadline, it could damage or even destroy the system. These kinds of tasks are called essentially critical. Wide areas of tasks within the field of protection systems do include tasks of this kind. In case of an electrical network failure, a failed attempt to open a circuit breaker may be fatal and even result in its destruction.

In electrical utilities the technological trend leads to an increase of digital and autonomous systems that need to interact. In the situation of a substation consisting of several sensors, circuit breakers and autonomous security systems, a distributed real time operating system is needed to coordinate those entities in a way that meets the requirements.

The standard IEC 61850 does not include standards for implementation. The design of the operating system of the IED is up to the manufacturers' choice. But within the above described scenario of distributed critical tasks dependent on distributed data and concurrently accessing this data it is not possible to guarantee the timely execution of critical task, because it is not foreseeable if the allocation of the needed resources will be possible in time.

MELODY

To meet this kind of requirements a real time operating system, called "MELODY", has been developed at the School of Computer Science at the University of Dortmund. MELODY. One major part of MELODY is the extension of the standard task criticality based scheduling by the introduction of resource sensibility based scheduling.

The criticality is a measure of how much the survivability of a system depends on the execution of a certain task before a given deadline. Tasks may be characterized as being non-critical, critical or essentially critical. Tasks that are considered essentially critical affect the survivability of the system directly. MELODY incorporates a task scheduling scheme that supports increasing criticality of tasks, depending of how often a critical task failed to complete before its deadline. After a certain amount of deadlines not met, a critical task may become essentially critical. Essentially critical tasks that failed to complete before their deadline are not further scheduled [13].

By preferring essentially critical tasks over critical tasks and critical tasks over non-critical tasks for execution the scheduler's objective is to execute as many essentially critical tasks as possible. In the environment of i.e. a substation the occurrence of tasks is not predictable, thus completion before their deadline cannot be guaranteed. By utilizing the measure of criticality, the chances for a timely execution of crucial and thus essentially critical tasks improve drastically.

Another cause that can impede the execution of tasks before they reach their deadline is the allocation of resources. In the situation of a substation with data acquired and made accessible at different locations that are out of scope and influence of the task scheduler, a task may not be able to meet its deadline because it was not able to access the required data in time. In this context MELODY introduces a second measure for tasks, the sensibility [14].

The sensibility is a measure of how much a certain task really requires the latest information about a process. By approaching the deadline of an essentially critical task and the task not being able to receive the latest information about a process due to concurrent access on the needed resource, it may be useful to use a local copy of that data, even if it might be slightly out of date, instead of failing to meet the deadline. Therefore MELODY defines a dynamic sensibility for tasks scheduled. It is possible to decrease the sensibility of a task while increasing its criticality, so that at a certain point in time it may use a local copy of the data needed instead of waiting for the remote resource to be freed.

To enable MELODY to provide the local tasks with a copy of a remote resource a system of public and private copies was developed.

Private copies are copies that are updated from their source in an eventually manner, while public copies are held mutually consistent. When a local critical task may be dependent on remote data, MELODY can provide it with a local copy of this data. When a task needs to access this data, MELODY tries to update it to the latest value by reserving, not blocking, the remote resource. In case that the remote resource can not be accessed the sensibility of the task for this resource may decrease. When this task comes close to its deadline and its sensitivity decreased under a certain level, MELODY can decide not to wait for an update, but to provide the task with the best information it has, the local copy.

Conclusion

Experiments have shown that this way of integrating a sensitivity measure into the task scheduling has significant advantages over the basic scheduling based solely on criticality. For a substation the trade-off between up-to-dateness and completing essentially critical tasks before their deadline may pay off.

Future communication standards do not yet define a concrete implementation of the IED operating system, thus introduction of an advanced scheduling based on criticality and sensitivity appears promising.

Parts of the distributed real-time operating system MELODY may serve as a blueprint for such an advanced strategy to improve the system reliability under the influence of a concurrent access on distributed resources in a real-time environment and unpredictable occurrence of critical tasks.

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