Modern Design of IEDs and Functions – Impact of IEC 61850

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1. THE ELECTRICAL ENERGY SYSTEM IN FLUX

The expected shortage of energy resources and the increasing environmental burden are a booster for a global change of thought in the field of energy politics. This changes of thought toward renewable energy resources and new modes of usage such as for example the electrically powered car (E-Car offensive of the automotive industry) has a deciding impact on the electrical-power-system. Electrical energy is developing into a deciding energy resource for the user.

Therefore a change is taking place in the naturally grown power system of the last decades, where energy production took place in close proximity to the user as well as according to user requirements, thereafter fed into the transmission network, and was then distributed. A structure of this kind is typical for Central Europe.

The intention to effect a change is shown by the SMART GRID Initiative [1], [2], which deals with the new challenges regarding the individual voltage levels. The electrical power system is developing into a network, comparable to the Internet. The main difference to the Internet is the transmission of electrical energy instead of information. This constitutes an entirely different quality, as the balance between production and use has to be maintained. An imbalance necessarily leads to reduction in the reliability of supply, which may result in local blackouts or supply shortages. Figure 1 of [1] visualises the changes in the electrical power system.

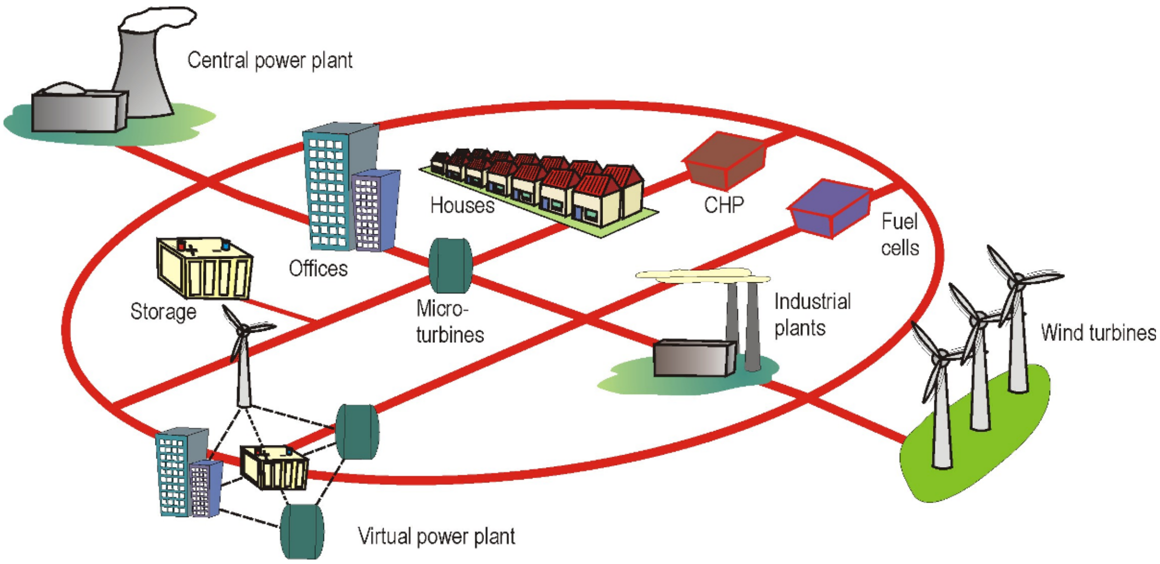


Figure 1: Illustration of changing in the electric energy system

Alongside conventional power plants, renewable energy sources play a deciding role. They can however only be used where they are available. Considering the resource wind, it is available with certain constancy only close to shores and in the ocean. In the case of Off-Shore Windparks, the energy has to be transported on-shore and to the consumer. This makes a network expansion with combined transmission via cable and overhead line necessary, and possibly leads to an increase in DC current transmission, which requires intelligent energy management. The deregulation and the trade with the commodity “electricity” result in a diverse power flows, which the systems have to control. Furthermore Figure 1 clearly shows the future diversity of power producers. Producers may be found at all voltage levels, so that each network quasi assumes transmission tasks. In order for everything to work properly, intelligent control and monitoring solutions are essential. The protection and control technology makes a deciding contribution to this.

The requirements regarding the protection and control technology and essential changes will be discussed in the following chapters.

2. INTELLIGENT AND MULTIFUNCTIONAL BAY UNITS

The microprocessor technique also will be the defining technology in future. The necessities for real time processing as well as severe environmental requirements (e.g. EMC) will lead to embedded devices. Further development of technology toward higher processor performance (several 100 MHz are available), larger memory size and higher memory density (from Mega to Gigabytes), high resolution and fast analogue/digital converters (e.g. 24-bit resolution) as well as the utilisation of customer specific circuit technologies (e.g. FPGAs) are undisputed. A further motivation is the rapidly developing in the communication technology.

Due to the current as well as the new structures, the electrical power system will become even more heterogeneous, so that the classic interfaces such as binary in-and outputs as well as voltage, current and analogue inputs will be still required especially for refurbishment projects. On the other hand different communication interfaces are necessary. A flexible and a modular hardware design meet the application requirements. Figure 2 shows such a possible system. The basis housing is a so called base module ($^1/_3$ 19 inch width) which can be extent by expansion modules ($^1/_6$ 19 inch width). The robust and special designed housing increases the safety (excellent heat dissipation and EMC design avoids interference). Depending on the application different front plates for visualisation (large and small LCD display or without display) are available. With such a modular design a high degree of flexibility can be reached. Customized and application orientated devices can be easily manufactured.

Figure 2: Hardware kit – Modular hardware meets application requirements

In the case of new plants, the advantages of technology, especially the consistent communication from the bay to the substation level will be implemented (process bus + station bus). The diversity of requests requires a flexible hard- and software design to optimally respond to the changing conditions. With the introduction of the communication standard IEC 61850, the object oriented approach for the selection of protection and control functions started. Depending on the requirements, the desired functionality is selected and assigned to the relevant device. This leads to a further functional integration. Figure 3 shows a possible functional scope. There are no longer classical protection and control devices. Future devices will be referred to an IED (intelligent electronic device), a name introduced by IEC 61850.

Functional Integration does however not mean that all functions shown in figure 3 have to be always contained in one device. Depending on the application and the requirements, functionalities can be combined in different ways. When selecting a device, the classic design criteria apply, such as the adherence to the n-1 principle. For protection applications in the transmission networks, a main protection 1 and a main protection 2 with different functional principles is required. This means for example the application of distance and line differential protection.

In practice, functional integration means that one IED protection contains additional functions, such as monitoring (monitoring of the plant, circuit breakers, line, GIS plant), highly accurate measurement (classic measured values and operational metering) and detection of phasors, as well as fault recording (see figure 4). An efficient communication to a control system, between the devices or with a

PDC (phasor data concentrator) will be state of the art. The highly accurate measurement guarantees the connection to the measurement transformers (especially current transformers). In the case of process bus applications the sampled values (protection and measurement transformer signals) are made available via the Merging Unit (MU) over an Ethernet connection.

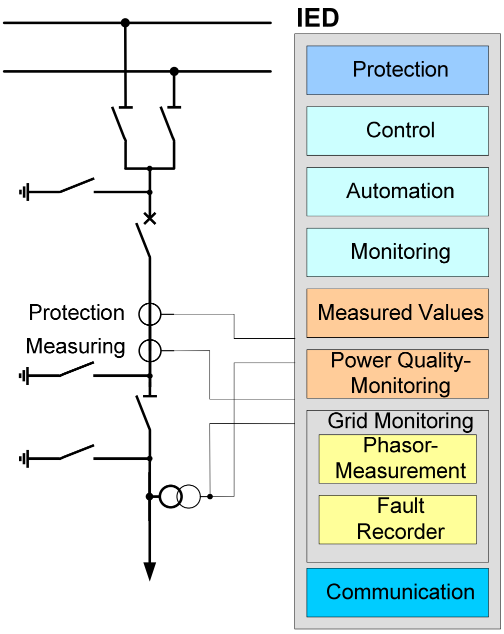


Figure 3: Overview functional integration

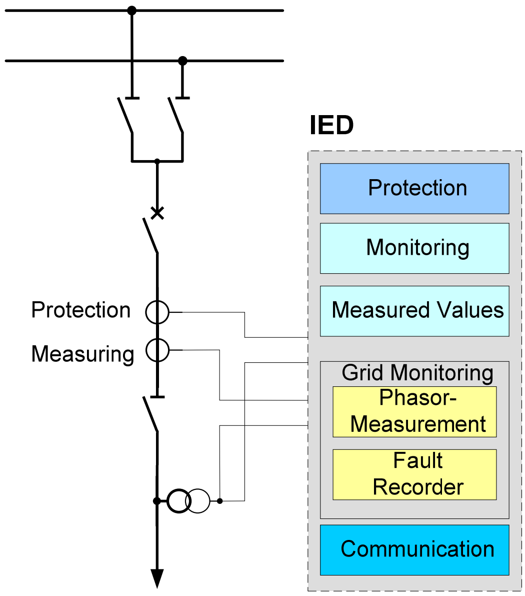


Figure 4: IED-Protection with functional integration

3. FLEXIBILE COMMUNICATATION IS THE KEY FEATURE

In future almost all devices will provide fast Ethernet communication interfaces. The previous serial communication to a Master unit is replaced by IP-based communication so that in a few years the serial method will only be relevant for maintenance/ repair/ refurbishment of devices. In an IP – infrastructure, the device acts as server that transfers its data to one or more clients. Via fast Ethernet interfaces a number of protocols and services can be transferred in parallel. In this manner, the server executes various tasks in the network with regard to its functionality as data provider for super ceding systems. It can autonomously execute protection and monitoring functions and then provide the results to various super ceding systems.

3.1 Benefits of IEC 61850

IEC 61850 is more than a substation control protocol. It comprehensively defines functions, data and the communication systems for communication in networks of the power supply industry. Edition 2 extends the influence of the standard to further branches of the power supply industry, so that a consistently homogenous communication and technical data description of objects is available. Where the standard is at present still mostly being used as a classic substation control protocol, the new processes will in future be used at the communication and engineering level.

The dynamic reporting establishes itself in communication between Client and Server. Using a configuration file (ICD or SCD – file) or online, by establishing a connection to the server, the client is able to read all data points, which the server can potentially provide. The Client selects the information from the Server that he wants to subscribe to. The extent of this data can be altered during the lifecycle of the system, without re-configuring the Server. In this way the Client can read specific monitoring data, alarms or measured values of a Server for a certain period of time. Where it is today still customary to establish and transmit data records via fixed communication links, this will be replaced by dynamic processes. This facilitates a clearly increased flexibility during operation, as only immediately required data is read. Setting values of functions can also be changed via the protocol. The switching of fixed parameter setting groups is no longer necessary, if a threshold in the device can simply be changed during operation. With super ceding systems, setting values can be checked and adapted to the condition in the Smart Grid.

With the GOOSE – Message the IEC 61850 defines the interoperable communication between Servers in the network. In this way wiring between devices can be replaced with communication links. Not only binary values can be exchanged, measured values can also be transmitted. GOOSE – Messages are also exchanged between substations. New protection procedures, which will require peer to peer communication, will prevail. With Edition 2 of IEC 61850 a possibility will be created, using a Substation Exchange Description (SED – File), to describe this exchanged data interoperable. The GOOSE – Message will replace proprietary point to point connections for signal comparison or directional comparison, and facilitates the data exchange between devices of different manufacturers, including between substations.

3.2 Developments in network technology

Network components with a very high availability are a prerequisite for IP based protocols both within a substation and outside the substation. Today different forms of ring or star shaped network topologies and well as various methods to achieve redundancy are applied. These methods lack interoperability and a short interruption in the range between 30 ms – 2 s is possible in the event of failure of a component. For critical applications such as the transfer of trip commands via GOOSE or the transfer of sampled measured values according to IEC 61850 9-2 for process bus applications these interruption intervals are not acceptable. In the IEC 62439 a High availability Seamless Redundancy Protocol (HSR) and the Parallel Redundancy Protocol (PRP) is described. It allows for interruption free switching in the network with ring or star configuration. This technology will become established as standard for substation networks and process bus applications.

Furthermore there is a trend to higher bandwidths. At present station networks are operated at 100 MBit/s. The trend is towards 1 GBit/s, if the applications such as e.g. process bus require this. Cost effective components for this are already available in the market place so that 1 GBit/s technology will become available in the bay devices.

3.3 Cyber Security as basis for secure operation of networks

Because of the application of network technology the security within the network becomes a critical task. Security against internal threats and security against external attacks must be considered. Also in private networks it is possible that as a result of an accidental mal-operation the functioning of the network is placed at risk. The BDEW – Whitepaper [4] and Nerc – CIP [5] address these topics. With IEC 62351 a standard is made available that describes methods for the end to end encryption as well as authentication between participants on the network in substation automation systems. Parts of these standards will be implemented by the manufacturers in their devices and substation automation protocols will be extended with security features.

Figure 5 shows a blue print of an energy automation system with secure access to the devices in the substation. For remote access the user must be authenticated at the gateway as well as at the device. This Client Server Authentication ensures that only authorized persons or clients have access to specific services in the devices. Remote access operates then via encrypted connections. The operators and manufacturers must focus on the security of the networks as the Smart Grid will be of strategic importance. The degree to which encryption will also be applied to fast services e.g. GOOSE or SMV (sampled measured values) depends on the degradation of performance as a result of these procedures or the developments of special encryption hardware. One solution would be to provide the time critical services on segregated network segments on bay level and dedicated communication links.

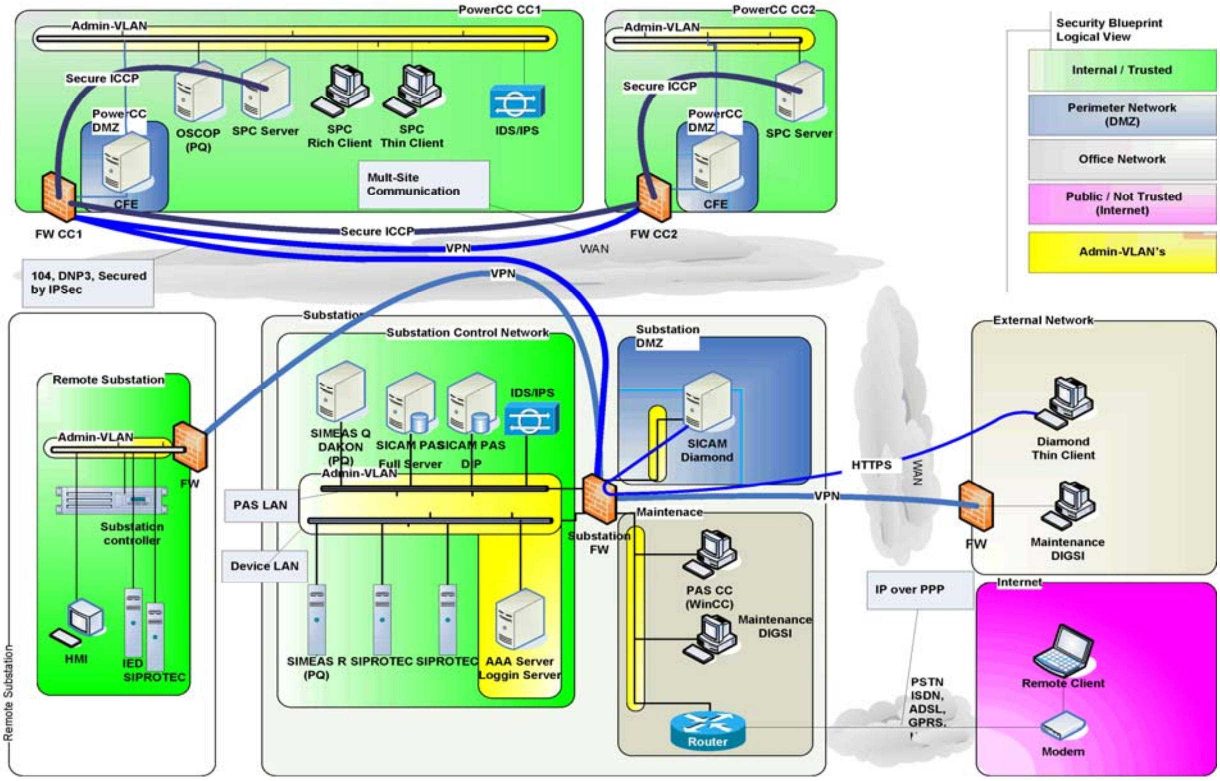


Figure 5: Secure operation in energy automation systems through network segmentation

3.4 Synchronism and matching real time in the network

Different methods are applied to obtain time synchronism. Local long wave real time receivers achieve an accuracy of 5 -10 ms. Via GPS and the derived IRIG-B protocol accuracies of < 1 ms are achieved. The highly accurate impulse per second (PPS) from the GPS – system provides an accuracy of 1 µs. This technology is already applied today with the differential protection e.g. 7SD5, 7SD6 and 7SD8 [6], when the channel delay times in the communication system are not constant. The µs accuracy is also required for synchro-phasors according to IEEE C37.118 and the process bus.

In future, the time synchronisation will be done via the Ethernet network. Within the IEC61850, SNTP (simple network time protocol) is applied and can achieve an accuracy of less than 1ms. Redundant clocks can be easily applied in the network and the channel delay times of the telegrams between Client and Server can be measured and compensated in the devices. Devices with an Ethernet interface can therefore be easily provided with time synchronisation so that their event records and measured values may be evaluated with millisecond resolution.
With IEEE 1588 Edition 2 procedures are described, which can achieve < 1 µs accuracy within a local Ethernet network. This accuracy must be supported by measures taken in the hardware of the Ethernet interfaces e.g. in switches and other network devices [7]. Activities to make IEEE 1588 with highly accurate time synchronisation available are in preparation at the manufacturers. Suitable switches and time receivers are already available. In future, time synchronisation via Ethernet will replace the classic methods via dedicated interfaces and all equipment works with the same time.

4. FUNCTUAL STRUCTURE ACCORDING IEC 61850

The standard, IEC 61850 Communication networks and systems for power utility automation, provides a detailed and highly structured description of the functions and associated data models.

Wherever information is handled the IEC 61850 can be applied within the context of the protection IED. This is symbolically shown in the figure 6.
Naturally the “address” of the information is a key to a successful structure. This follows the structure “tree” mentioned earlier. Here illustrated with the status value of a circuit breaker in the context of controlling the CB (figure 7).

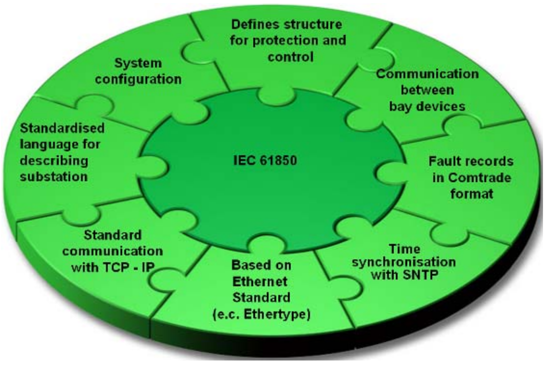


Figure 6: Standard overview IEC61850

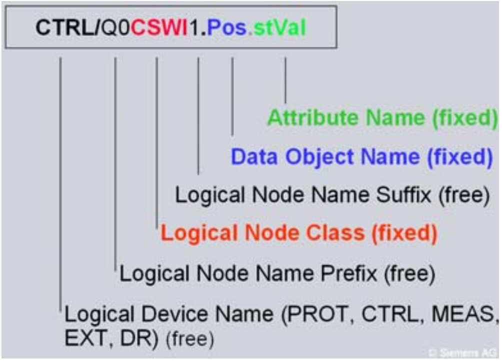


Figure 7: Structure of LD (control)

The data object Pos is of data class double point control (DPC) providing more than 20 attributes. The attribute status value (stVal) has type CODED ENUM which can indicate the states: intermediate/ off / on / bad-state. More transparent and less engineering effort is possible by allowing the engineering tools and logging instruments to mange the information at the object layer in stead of having to deal with each attribute separately in the configuration matrix.

It would however not make sense to restrict the implementation of the IEC 61850 structure to the data model. The approach of the IEC 61850 standard series is to break down processes into Logical Nodes (LN). The function (and sub-functions) contained in the LN can then be standardized as far as possible, thereby facilitating the prime objective of the standard which is interoperability. This is illustrated in the figure 8.

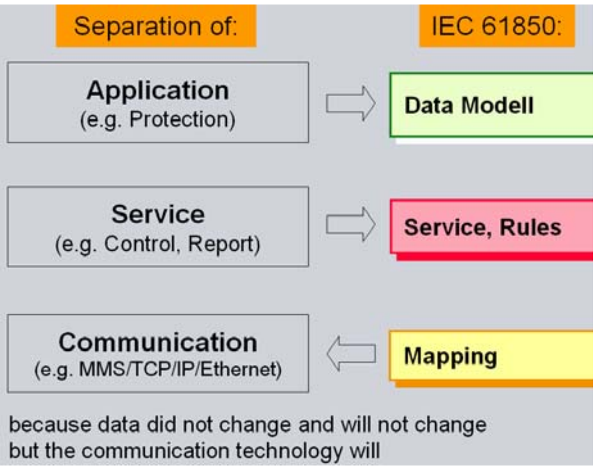


Figure 8: Separation of functionality in a device

The standard also emphasizes that the combination of functions into physical devices (IED's) is totally flexible and not regimented in any way. This allows the vendor of protection relays a lot of freedom when designing his products. The following figure 9 illustrates this:

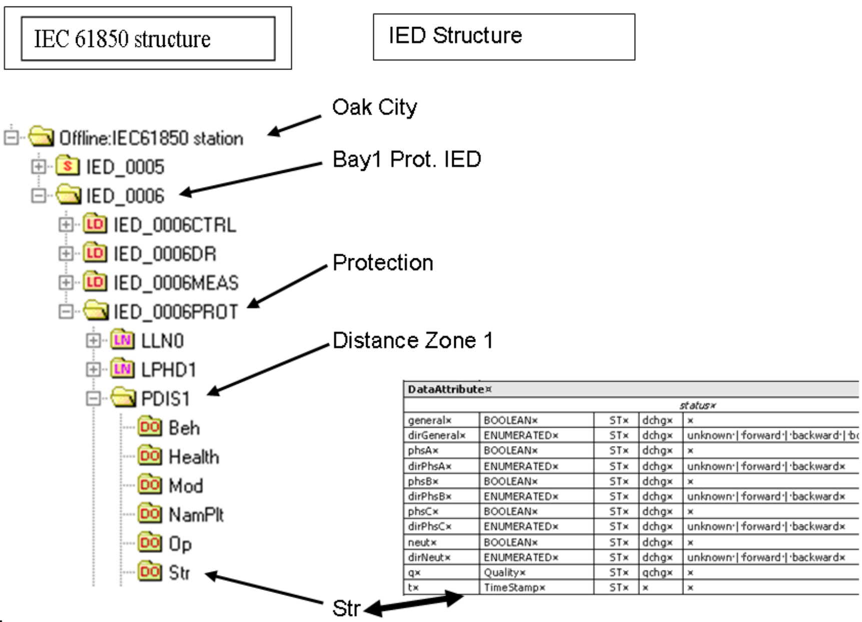
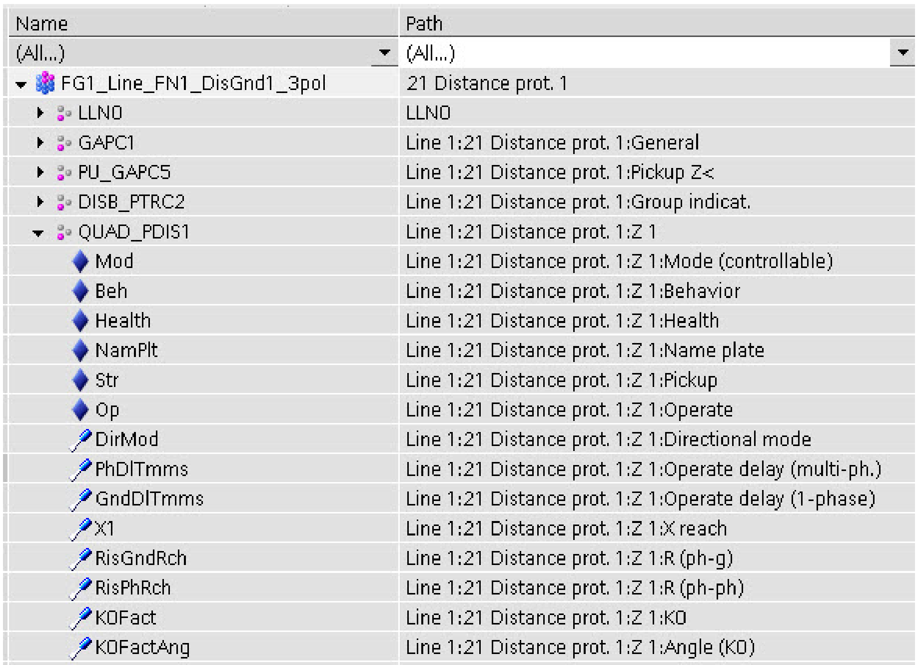


Figure 9: Structure of a function (e. g. distance protection)

The IED structure now matches the structure defined by IEC 61850 and fills out the gaps at the lowest level. All the various clients served by the protection IED can now be optimally served without laboring the application engineer with information and structures that are not needed in his discipline.

From the usability point of view different users are involved in the engineering process. The IEC 61850 expert knows the terminology and the description. He wants to see a description of information regarding the standard. The following figure shows a few from IEC 61850 configurator. On the left hand side the IEC 61850 structure by using prefix and suffix is shown (e.g. **QUAD** PDIS**1**). The prefix characterizes the type of characteristic (e.g. QUAD = quadrilateral) and the suffix the instance (e.g. zone 1). The right column shows a clear text description. Icons support a user friendly handling of the configurator. The screwdriver characterizes a setting parameter.



Name	Path
(All...)	(All...)
FG1_Line_FN1_DisGnd1_3pol	21 Distance prot. 1
LLN0	LLN0
GAPC1	Line 1:21 Distance prot. 1:General
PU_GAPC5	Line 1:21 Distance prot. 1:Pickup Z<
DISB_PTRC2	Line 1:21 Distance prot. 1:Group indicat.
QUAD_PDIS1	Line 1:21 Distance prot. 1:Z 1
Mod	Line 1:21 Distance prot. 1:Z 1:Mode (controllable)
Beh	Line 1:21 Distance prot. 1:Z 1:Behavior
Health	Line 1:21 Distance prot. 1:Z 1:Health
NamPlt	Line 1:21 Distance prot. 1:Z 1:Name plate
Str	Line 1:21 Distance prot. 1:Z 1:Pickup
Op	Line 1:21 Distance prot. 1:Z 1:Operate
DirMod	Line 1:21 Distance prot. 1:Z 1:Directional mode
PhDlTmms	Line 1:21 Distance prot. 1:Z 1:Operate delay (multi-ph.)
GndDlTmms	Line 1:21 Distance prot. 1:Z 1:Operate delay (1-phase)
X1	Line 1:21 Distance prot. 1:Z 1:X reach
RisGndRch	Line 1:21 Distance prot. 1:Z 1:R (ph-g)
RisPhRch	Line 1:21 Distance prot. 1:Z 1:R (ph-ph)
K0Fact	Line 1:21 Distance prot. 1:Z 1:K0
K0FactAng	Line 1:21 Distance prot. 1:Z 1:Angle (K0)

Figure 10: Functional view of protection function in a configurator (edition 2 design)

A lot of users are not so deep involved in the IEC 61850 standard. They want to see the well known application orientated names. These names are the settings and information. All functions in the device are modeled according the IEC 61850 structure, but in the user view a clear text indication is shown. Figure 11 shows an example of setting parameters.

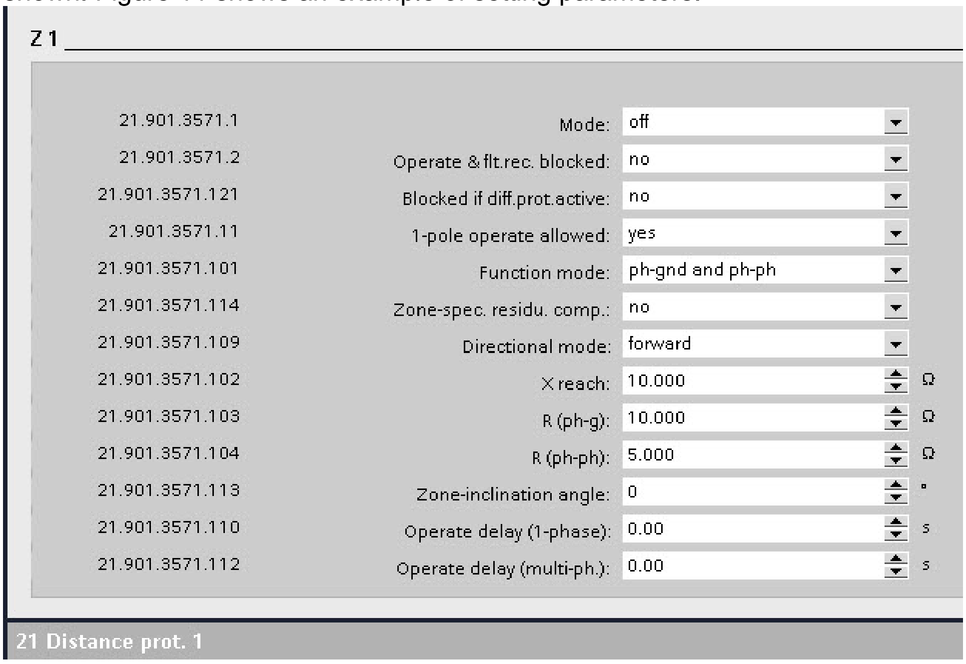


Figure 11: Setting sheet of a distance protection zone 1

The view of signals illustrates the internal structure close to the IEC 61850. In the routing matrix this structure is visible. The used naming is according IEC 61850. Due to the hierarchical structure a tree design allows the access to the different signal levels. Depending on the application, e.g. routing a signal to a physical contact, a single point signal (SPS) must be used. For routing a signal in a log file, structured signal type (ACD or ENS) can be used. The attributes will be automatically added.

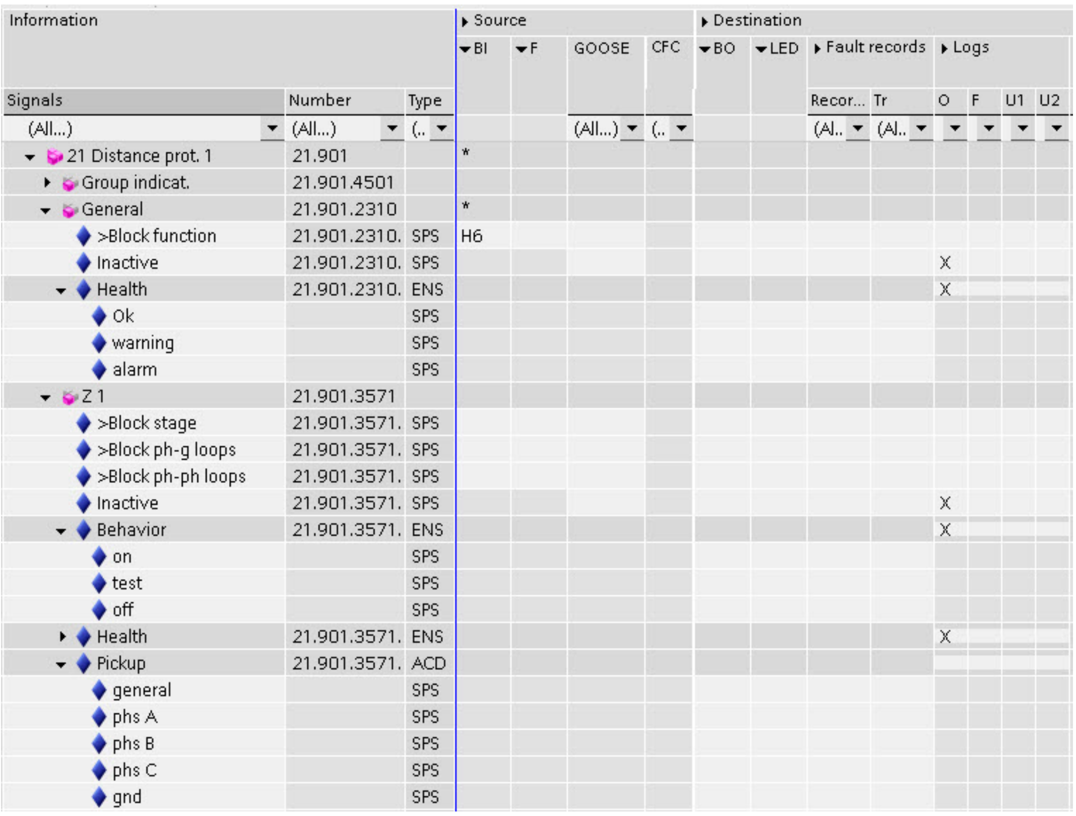


Figure 12: Routing of signals for functions designed according IEC 61850 (example distance protection zone 1)

5. GROUPING OF FUNCTIONS

IEC 61850 uses a structured description of functions. This approach was the basis for a design of the functionality inside the devices. Functions are allocated to containers, which represents a protective object (e. g. a line) or primary equipment (e. g. circuit breaker). These containers are called function groups (FG). The function group can contain protection and other functions (e.g. measurement, monitoring, etc.), which are necessary for the protected object.
Figure 13 gives an overview of such a new structure and shows the used function groups. As an example a one and half breaker scheme was selected.

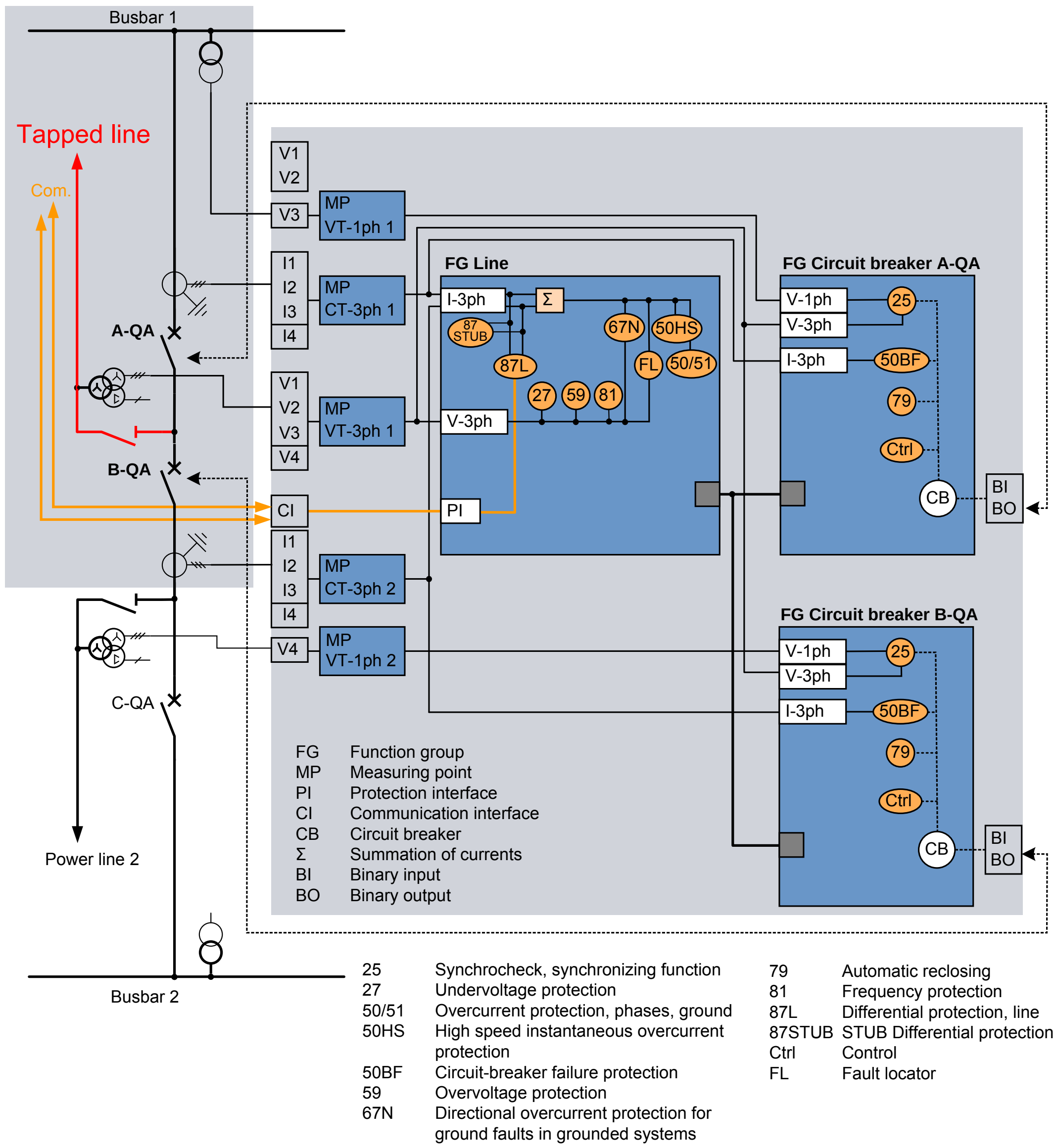


Figure 13: Function group concept of a modern IED (main protection: line differential protection)

FG Line contains the used functions to protect a tapped line. The main functions are the line differential protection (87L) and the stub protection (87STUB). Back-up or additional functions are also shown (see the ANSI numbers). Additional visualized in the figure 13 is the communication interface. The FG Line has a protection interface (PI) which is direct linked to the used communication interface (CI). Via this interface the data with differential protection devices on the other line ends are exchanged. Due to the module concept of the hardware (different types of plug-in modules) a variable adaptation on a different communication infrastructure is simple possible.
The two **FG Circuit breaker** control the two circuit breakers (A-QA and B-QA) and include all breaker related functions like control function, breaker failure protection (50BF), synchro-check (25) and autoreclosure (79).

Also shown in the figure 13 is the interaction with the voltage and current transformers. The interface to these transformers is the function block “Measuring point” (MP). In this block the data acquisition (sampled values) and the preprocessing are realized. The preprocessed data are linked to the function groups. A further processing is realized inside in the function groups, like special calculations for the protection functions and additional measurements.

The engineering starts always with an **application template** which is an application orientated pre-definition of function groups, include functions and the connection to the used transformers via the measuring points. Depending on a present application measuring points, function groups and functions can very easy be added from a library. By adding a function the connections to the necessary interfaces are done automatically. Further it is possible to delete not used functions in a function group. In this way the creation of user specific templates are possible.
To simply the engineering process function groups can be copied with the included functions inside a device or between the devices of same device class. The same is possible with functions inside or between the function groups.

6. SUMMARY

Not only the technological progress (processor performance and topologies, memory size, optical components, etc.) but also the changing of grids influences the development of modern IEDs – devices for protection, control, automation and measurement. Renewable energy resources lead to distributed generation. The IEC 61850 standard introduced concepts that not only change the communication but also change the composition from bit to object “node” orientation of functions in modern protection devices. This allows object and customer view oriented approaches for engineering and system design. Ethernet communication and object oriented engineering based on IEC 61850 will be the key features of future grid applications.

A higher flexibility is required from modern IEDs. A modular hardware design is one answer. As shown in the example depending on the required range the hardware can be individual configured by adding expansion modules to the base module. The communication interfaces can be selected via plug-in modules like in a laptop.

The functionality is mainly determined by the implemented software. Modern IEDs are not only pure protection devices. They include a lot of useful functions like control, automation, powerful measurement (e.g. phasor measurement) and monitoring. Integrated logic functions increases application flexibility. A generic software approach using the user’s language allows a high degree of flexibility and user friendliness. This means for example, the same functions run in different applications, the functions can be grouped according to primary equipment (breaker or disconnected orientated; functions related to the protective object (e.g. overhead line)) and functions can be copied between the devices. The “node-structure” introduced by the IEC 61850 is structurally incorporated in modern bay devices (IEDs) utilizing function groups and stages in a logical hierarchy. The state of the art device adopts the IEC 61850 structure throughout thereby providing consistent use terminology in the application of the functions as well as related communication.

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