

## Modern Design of Protection, Control Devices (IEDs) and Functions

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### KEYWORDS

Energy system, smart grid, protection devices, IEDs, modularity of hard- and software, IEC61850 influence, communication interfaces and protocols

### 1 DEVELOPMENT OF ELECTRICAL ENERGY SYSTEM

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 has a deciding impact on the electrical-power-system.

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.

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] illustrates the changes in the electrical power system.

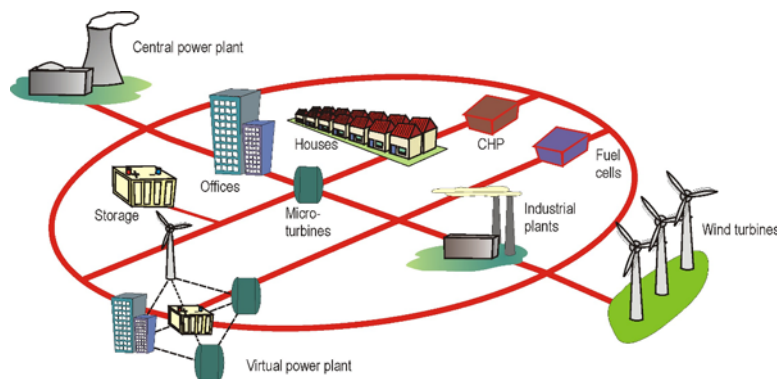


**Figure 1:** Illustration of changes in the electric energy system [1]

Alongside conventional power plants, renewable energy sources will play a deciding role. They can however only be used where they are available. For example, wind resources may be located in close proximity to shores and in the ocean. In the case of Off-Shore Wind parks, the energy has to be transported on-shore and to the consumer. This necessitates a network expansion with combined transmission via cable and overhead line and possibly leads to an increase in DC current transmission, which requires intelligent energy management. The deregulation and the trading 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 innovative protection and control technology makes a significant 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 IED

The microprocessor evolution 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. FPGA) are apparent. A further trend is the rapid developments 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 ( $\frac{1}{3}$  19 inch width) which can be extended by expansion modules ( $\frac{1}{6}$  19 inch width). The robust and specially designed housing increases the safety (excellent heat dissipation and EMC design avoids interference). Depending on the application different front panels for visualisation (large and small graphic 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 as an IED (intelligent electronic device), a name introduced by IEC 61850.

However functional integration does 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). Efficient communication to a control system, between the devices or with a PDC (phaser 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 (signals from nonconventional or conventional transformers) are made available via the Merging Unit (MU) over a direct Ethernet connection or network.

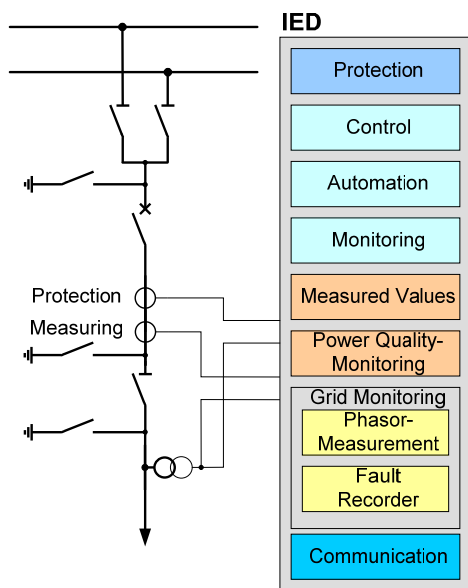


**Figure 3:** Overview functional integration

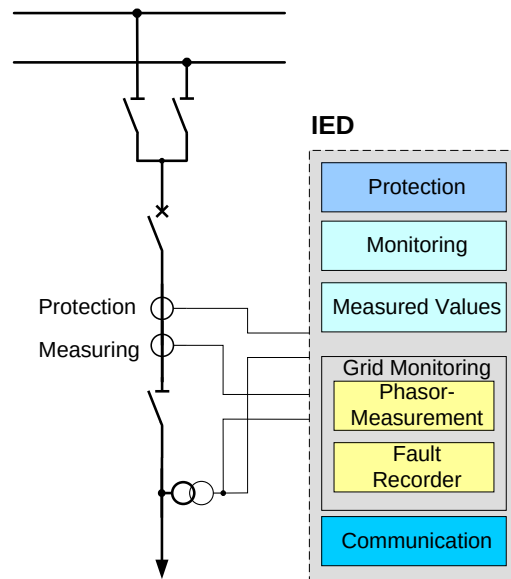


**Figure 4:** IED-Protection with functional integration

### 3 FLEXIBLE COMMUNICATION A KEY FEATURE

#### 3.1 Introduction, Basic design

Flexibility in communication is one important requirement of modern IEDs. On the application side there is a requirement that different hardware interfaces as well as protocols are supported. In substation automation Ethernet was adapted as the preferred communication medium several years ago; since then there has been constant developments in network technologies yielding higher throughputs (from Mbit to Gbit). On the protocol side a large number of different protocols must be supported. The install-base influences the decision of the users, so the migration towards new protocols (e.g. IEC 61850) is progressive.

There are two main streams in communication: Communication of the IEDs with a substation automation system or control centre and the communication between the devices (e.g. line differential protection via protection data interface or Goose-Communication between different IEDs) as well as communication with intelligent sensors (process bus). These requirements influence the hardware design of the communication hardware/interfaces and the handling of different protocols. Figure 5 gives an example for design of the communication interfaces in modern IEDs. Like a Laptop there are different plug-in modules with different designs. As shown in figure 5 they can easily be replaced without

opening the device. There are two basic designs: modules for serial communication via asynchronous protocols (e.g. IEC870-5-103, DNP 3, protection interfaces) and modules for Ethernet communication (e.g. IEC61850, DNP 3 TCP, time synchronization via SNTP,...). The electrical connector is RJ45 and for the optical interfaces ST (820 nm) or LC (1300 nm, 1550 nm) connectors are used. To support different distances from 24 km up to 100 km different optical modules for synchronous serial data exchange of protection communication (e.g. differential protection) via multimode optical fibres or single mode fibres are available. They are designed with 1 or 2 interfaces/channels.

During the engineering for a selected hardware the right protocol must be selected. This protocol will be loaded into the plug-in module. This enables easier handling of the device and field upgrades. On an Ethernet module (electrical or optical) all IP based protocols are implemented. The protocol type has no relevance: it doesn't matter if IEC61850, DNP 3 TCP, PROFINET or others will be used. Figure 6 illustrates the basic concept.

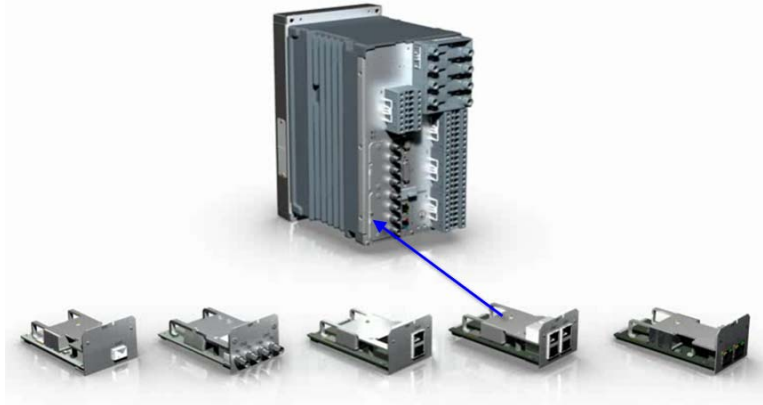


**Figure 5:** Flexible communication via plug-in modules

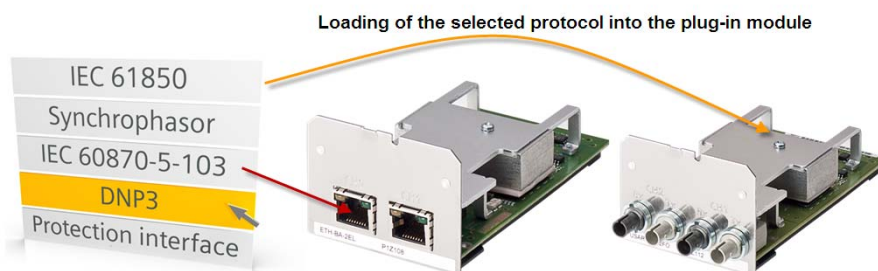


**Figure 6:** Protocol selection during the engineering

### 3.2 Benefits of IEC 61850

IEC 61850 is more than a substation control protocol. It comprehensively defines functions, data and the communication systems for communications 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 levels.

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 subscribe to all data points, which the server can potentially publish. 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. It is customary to establish and transmit data records via fixed communication links today; however this will be replaced by dynamic processes in the near future. This facilitates a clearly increased flexibility during opera-

tion, as only immediately required data is read. Setting values of functions can also be changed via the protocol.

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 philosophies, which will require peer to peer communication across wide area networks, will be a reality. With Edition 2 of IEC 61850 it will be possible to describe exchanged data using a Substation Exchange Description (SED – File).

## 4 STRUCTURE OF FUNCTIONS AND THEIR COMPOSITION

### 4.1 Influence of IEC 61850 and design of functions

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. 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).

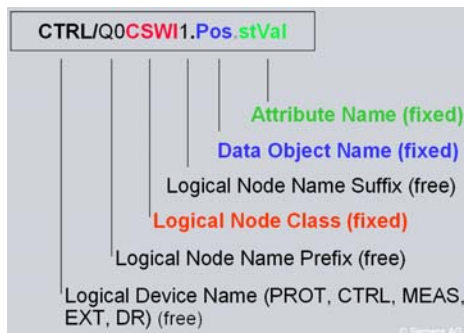


**Figure 7:** Structure of LD (control)

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 manage the information at the object layer instead 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 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. 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 flexibility when designing products.

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 8 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 PDIS1**). 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.

Many users are not so deeply involved with 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's view a clear text indication is shown. Figure 9 shows an extract of setting parameters for the impedance zone 1.

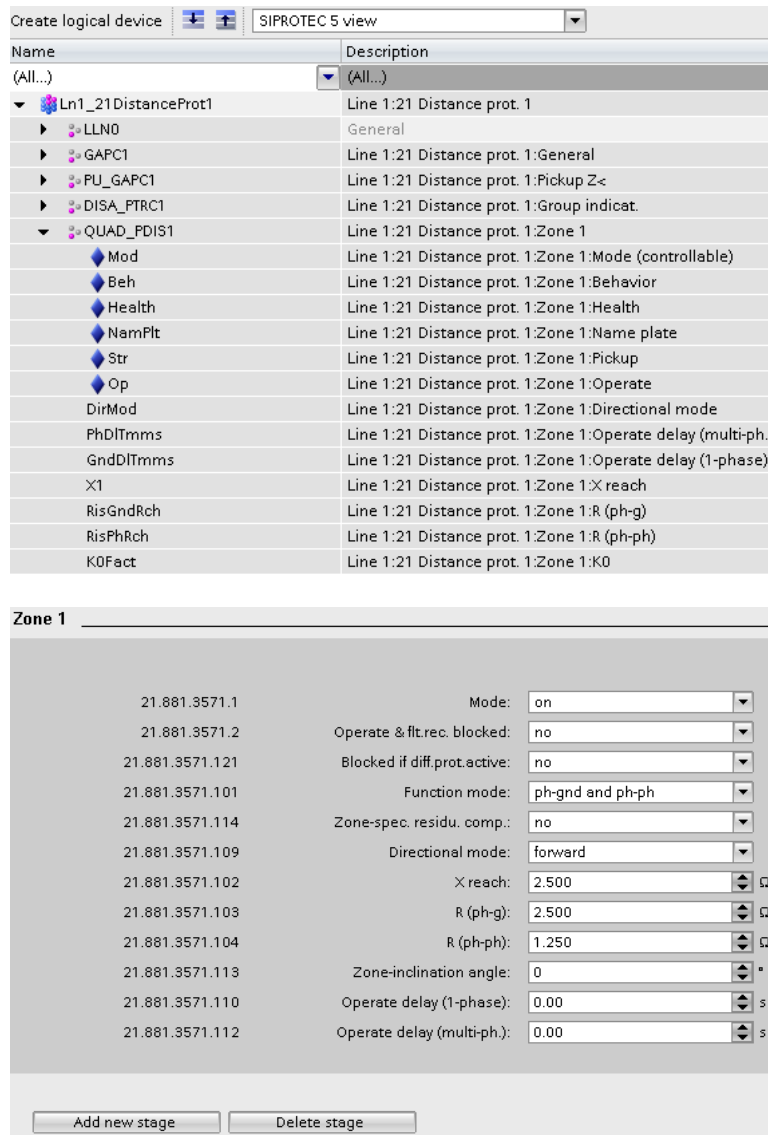


**Figure 8:** Functional view of protection function **Figure 9:** Setting sheet distance protection [6] in a configurator (design according edition 2)

The user view of signals illustrates the internal structure as per the IEC 61850 standard (see figure 10). In the routing matrix this structure is visible. The user naming convention is according IEC 61850. Due to the hierarchical structure a tree design allows 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.

| Information         |                |     | Source |       |       | Destination |       |               |  |      |   |   |   |   |
|---------------------|----------------|-----|--------|-------|-------|-------------|-------|---------------|--|------|---|---|---|---|
|                     |                |     | BI     | F     | CFC   | BO          | LED   | Fault records |  | Logs |   |   |   |   |
| Signals             |                |     | Number |       | Type  | Signal      |       |               |  |      |   | O | F | G |
| (All)               | (All)          | ... | (...)  | (...) | (...) | (...)       | (...) | (All)         |  |      |   |   |   |   |
| 21 Distance prot. 1 | 21.881         |     | *      |       |       | *           |       |               |  | *    | * | * |   |   |
| Z ph-g              | 21.881.2311... | WYE |        |       |       |             |       |               |  |      |   |   |   |   |
| Z ph-ph             | 21.881.2311... | DEL |        |       |       |             |       |               |  |      |   |   |   |   |
| Group indicat.      | 21.881.4501    |     |        |       |       |             |       |               |  |      |   | * |   |   |
| General             | 21.881.2311    |     |        |       |       |             |       |               |  | *    | * | * |   |   |
| Zone 1              | 21.881.3571    |     | *      |       |       | *           |       |               |  | *    | * | * |   |   |
| >Block stage        | 21.881.3571... | SPS | H1     |       |       |             |       |               |  |      |   |   |   |   |
| >Block ph-g loops   | 21.881.3571... | SPS |        |       |       |             |       |               |  |      |   |   |   |   |
| >Block ph-ph loops  | 21.881.3571... | SPS |        |       |       |             |       |               |  |      |   |   |   |   |
| Inactive            | 21.881.3571... | SPS |        |       |       |             |       |               |  | X    |   |   |   |   |
| Behavior            | 21.881.3571... | ENS |        |       |       |             |       |               |  | X    |   |   |   |   |
| on                  |                | SPS |        |       |       |             |       |               |  |      |   |   |   |   |
| test                |                | SPS |        |       |       |             |       |               |  |      |   |   |   |   |
| off                 |                | SPS |        |       |       |             |       |               |  |      |   |   |   |   |
| Health              | 21.881.3571... | ENS |        |       |       |             |       |               |  | X    |   |   |   |   |
| ok                  |                | SPS |        |       |       |             |       |               |  |      |   |   |   |   |
| warning             |                | SPS |        |       |       |             |       |               |  |      |   |   |   |   |
| alarm               |                | SPS |        |       |       |             |       |               |  |      |   |   |   |   |
| Pickup              | 21.881.3571... | ACD |        |       |       | *           |       |               |  |      |   |   |   |   |
| general             |                | SPS |        |       |       |             |       | U1            |  |      |   |   |   |   |
| phs A               |                | SPS |        |       |       |             |       | U2            |  |      |   |   |   |   |
| phs B               |                | SPS |        |       |       |             |       | U3            |  |      |   |   |   |   |
| phs C               |                | SPS |        |       |       |             |       | U4            |  |      |   |   |   |   |
| gnd                 |                | SPS |        |       |       |             |       |               |  |      |   |   |   |   |

**Figure 10:** Routing of signals according IEC 61850 structure (example distance protection zone Z1)

#### 4.2 Grouping of functions

IEC 61850 uses a structured description of functions. This approach was the basis for a design of the functions inside the devices. Functions are allocated to containers, which represents a protective object (e. g. line, feeder, transformer side) or primary equipment (e. g. circuit breaker, disconnector). These containers are called function groups (FG). A function group can contain protection and other functions (e.g. measurement, monitoring, control etc.), which are necessary for the protection, control or monitoring of the primary object.

Figure 11 gives an overview this new structure and shows the used function groups. As an example an overcurrent relays with control functionality is selected.

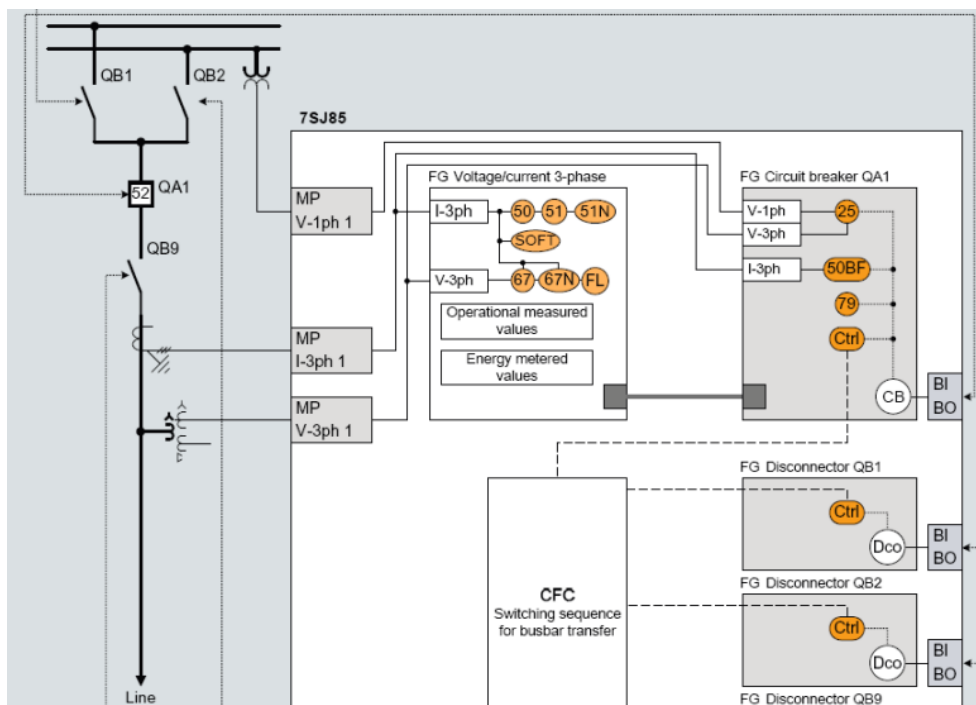


**Figure 11:** Function group concept of a modern IED

The figure shows three different types of function groups (FG) and the interfaces to the primary system (feeder with the switching elements). The current and voltage inputs of the IED are connected with the primary current and voltage transformers. The internal interface to measurement processing is the measuring point (MP). In the MP all relevant calculations are evaluated (resampling of sampled values and frequency tracking, true RMS, phasor and symmetrical component calculation). Depending on the available transformers different MP-types can be selected. The data stream from the MP is linked to the relevant FG. In the example three-phase MP-current and MP-voltage from the feeder is connected to **FG voltage/current 3phase** (FG VI). In the FG VI operate the protection and measuring functions which need as an input signal a current and/or voltage. In the shown application the overcurrent (50, 51), the directional overcurrent (67) and the ground fault protection without (50N) and with direction (67N) as well as different measuring functions are used. In addition the fault locator (FL) is available. During detailed engineering the functions can be selected from a library and inserted into a function (see figure 12), thus enabling easy and a flexible adaption specific to the application. For the interaction with the circuit breaker an **FG circuit breaker** (FG CB) is necessary. This FG is linked with the binary inputs (BI) and binary outputs (BO) to relevant interfaces of the circuit breaker. Internally a connection of the FG VI and FG CB is necessary and automatically the relevant signals are tunneled. The internal structure of the FG CB is according IEC 61850 and contains the LN XCBR, CSWI and CLIO. The FG CB can be allocated circuit breaker related functions like breaker failure protection (50BF) and synchro-check (25). For these functions a connection to the relevant MPs are necessary as shown in figure 11.

For the control functionality the interface to the process is realized via a **FG disconnecter**. The number of these FG types depends on the number of switching elements. In the example three FG-disconnectors are required (in figure 11 only 2 are visible). The switching sequences are programmed in logic (PLC). The Siemens name for the PLC is CFC (continuous function chart).

The engineering starts always with an **application template** which is an application orientated predefinition of function groups, include functions and the connection to the used voltage and current transformers via the measuring points, as well as the interaction to primary switching elements via the BI and BO. Depending on the present application measuring points, function groups and functions can very easy be added from a library (see figure 14). By adding a function the connections to the necessary interfaces are updated automatically. Further it is possible to delete functions, which are no longer required in a function group. This permits the creation of user specific templates. The shown composition in figure 11 is an example of an application template.

To further 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 procedure is possible with functions inside or between the function groups. Copying of devices is also an engineering workflow.

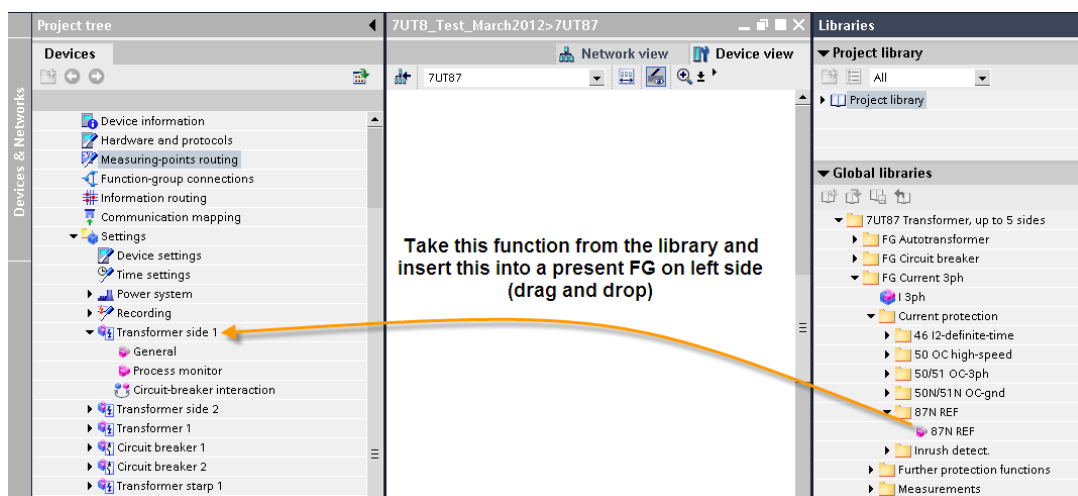


Figure 12: Simple Engineering (add functions from a library)

## **5 CONCLUSION**

Not only the technological progress (processor performance and topologies, memory size, optical components, etc.) but also the changes in power grids influence the development of modern IEDs – devices for protection, control, automation and measurement. The IEC 61850 standard introduced concepts that not only change the communication architectures but also changes 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.

A higher flexibility is required from modern IEDs. A modular, scalable hardware design is one answer. As discussed in this paper 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 offer greater functionality beyond the traditional protection functions. They include a lot of useful functionality such as 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 can be used in different applications, the functions can be grouped according to primary equipment (breaker or disconnector 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 constantly used terminology in the application of the functions as well as related communications.

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