Seamless data communication and management over all levels of the power system

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***Abstract*-- The enhancement of distribution networks into smart grids is accompanied by new functions e.g. smart metering and technologies e.g. energy management. Consequently, the information and communication technology (ICT) must penetrate the distribution systems down to the end customers on the low voltage network what is not the case in today system. Also on the different control levels of electric networks various communication protocols and information systems are applied which do not allow seamless information exchange.**

Resulting, there is a strong need for uniformity of the data models and the services of the communication system for the overall network control and data acquisition. This uniformity can be achieved by the application of IEC 61850. Additionally, there is a need for harmonizing IEC 61850 with the standards for gateways in home automation and smart meters and also with data base systems using Common Information Models (CIM / IEC 61968). A pilot application in the framework of a European beacon project is shown in this paper.

I. The Distribution System becoming smart

The establishment of Smart Grids in the distribution level is driven today word wide e.g. in Europe by the Targets 20-20-20 in 2020, which means 20 % reduction of carbon emissions, 20 % share of renewable energy in the primary energy balance and 20 % increase of energy efficiency. Those require an improved coordination of electrical grids, to approach problems like intermittent energy feed-in of distributed energy resources (DER) by wind and photovoltaic. This will change the role of the distribution system from a passive to an active one. In the future the distribution will have an important role in keeping the local balance between energy production and energy consumption. The enhancement of distribution networks into smart grids is accompanied by new functions and technologies like:

- Smart metering,
- Energy management on the distribution level,
- Distribution system automation,
- Smart building automation and involvement of consumers into the energy market.

The pillars of a smart distribution grid are realized by appropriate capabilities of the devices, which are installed in the power grid. These capabilities and their classification to the pillars are shown in Fig. 1.

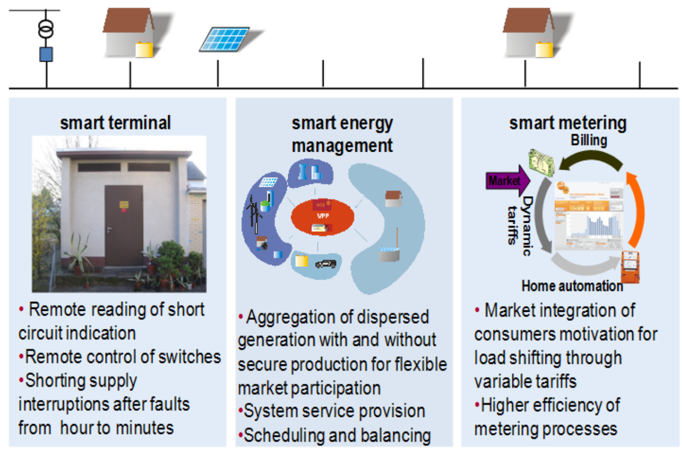

Fig. 1. Pillars of a smart distribution network

An intensive exchange of data is required to realize all these technologies, since a lot participating units send and receive information that is necessary for their smart operation. As a consequence, the information and communication technology (ICT) must penetrate the distribution systems down to the end customers on the low voltage network. The presently used SCADA systems are not able to provide all the functionality needed to realize the mentioned tasks of a smart grid. These can only be achieved by creating a new SCADA.

The new SCADA system will make the integration of new stakeholders possible. The “Virtual Power Plant” (VPP) as a stakeholder will benefit from the surplus of information provided by the system. By aggregating this information the VPP can schedule energy generation and consumption, playing a role in the market for operating reserve. Additionally, a cost optimal operation for the components bound together in the VPP area can be achieved. A prerequisite for the realistic operation of a VPP is the ability to control generating and consuming units. This ability of controlling generation and consumption will also allow a better utilization of renewable energy resources.

The role of the VPP relies on the stable ICT infrastructure, the operation of which is the main task of the “ICT provider”. This entity’s business will be to make the information exchange that is needed by the VPP available. One more stakeholder, called “Metering service provider”, will take care for the installation, operation and meter-reading of the metering units, needed for billing purposes of the costumers.

II. The New SCADA for the Rising Demands of the Distribution Level

The proper operation of future distribution systems heavily depends on the smooth cooperation of the system components, even across the boundary of each control level to components positioned in different control levels. Today there are several different communication protocols and information systems, which are applied according to their properties. The consequence is that different control levels of electric networks use different communication protocols and information systems. Also the data models and services of these systems are different and do not allow seamless information exchange between the levels:

- Network control center ←→ substations, traders, power plants and virtual power plants
- Inside the substations,
- Substation ←→ MV and LV distribution networks and their consumers and power producers,
- Inside homes and industrial enterprises.

There is not even a guarantee for seamless information flow inside one control level, since the various component standards could have different properties. What makes things more difficult is the problem of only limited application of ICT in the medium and low voltage level of the power system.

So, the next generation of SCADA systems – the new SCADA - will need to use a uniform ICT, which must be able to handle the amount of data arising from the many participating components of a smart grid. The application of a homogeneous protocol between and inside all levels of the distribution system is necessary to ensure the seamless data transport within the network. Fig. 2 shows graphically a comparison of today's system ICT (the left side of the picture) and the one of tomorrow, discussed above (the right side of the picture).

A more detailed view of the distribution system is necessary to define the data that the ICT system has to transport. The three main aspects of such a system are smart terminals, smart energy management and smart metering, as can be seen in Fig. 3, and each of them has specific data to handle for ensuring the proper system operation, while offering the advantages a smart grid is supposed to do.

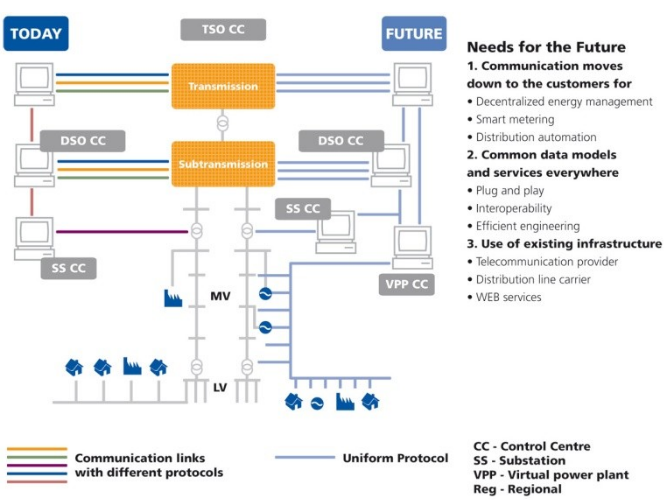

Fig. 2. Information and communication status quo and future needs [1]

Further analysis shows the demand of information exchange that the system must provide and which can be categorized according to three mentioned pillars:

- First, there is the data on the customer side, using smart metering, necessary for billing and tariff communication. Here the metered values for a defined period (up to 1 second), tariff signals and forecasted tariffs from the energy provider as well as the current energy demand must be communicated. This information allows computing the needed amount of control required for efficient grid operation.
- Second, the smart energy management requires the communication of measured values (voltage, current) and the desired values of power generation (active and reactive power). The transmission of switch commands and status indication is necessary for monitoring and controlling functionality. Metered values of energy production and consumption as well as a 24 hour profile of those values allow for a smart coordination of the power distribution system.
- Third, smart terminals communicate data necessary for safe system operation. This includes status and control information (switches, short circuit indicator) and metered and measured values, too. Utilization of those parameters enables the functionality of self repairing grids and increases the overall system safety.

III. The Smart Grid and The standard IEC 61850

For the realization of a new SCADA system a communication standard should be used that fulfills the requirements of a Smart Grid. The IEC 61850 seems to be well suitable for this task. Nowadays some additional work is necessary to adjust it for the new challenges. A new release, being on the way, will include data and service descriptions, designed for the use in DER dominated systems and for the needs of smart grid communication. Since it is a standard for the communication in substations, the strict application of it will ensure the interoperability in the network, independent of the manufacturer of devices. This standard offers definitions for data formats and services for communication between several devices.

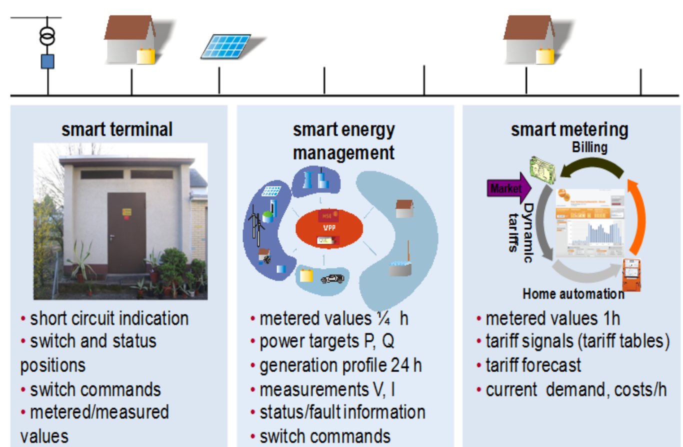

Fig. 3. Information to be communicated in a smart distribution network

A standardized Substation Configuration Description Language (SCL) makes it possible describing the system configuration and structure in a unified format. In addition to the client-server model the services can use, a definition for the transmission of generic substation events is given as well as for the sending of sampled values from so called merging units. Requirements concerning performance, convenience and security are fulfilled by the standard.

The application of IEC 61850 to data models and services throughout the network ensures the interoperability between all involved components. This is realized by uniform data classes and service models. Those service models can be mapped to existing underlying communication protocols like the Manufacturing Messaging Specification (MMS) or others, if necessary. Because of this uniformity independent from the underlying communication system used, every device, which provides or receives information, can be accessed in the same way. For instance a device providing measured values would be accessed via the logical node (LN) MMXU, which would be part of a particular logical device (e.g. a decentralized energy resource). Fig. 4 shows the hierarchy of common data classes, assigned to the logical node MMXU. As can be seen, the LN contains several data classes, for which each provides information of one measurement aspect, like frequency, power, voltage, current, power factor or impedances.

Again each of those classes contains other data classes to represent all properties of the measured value. This includes information about the measured values itself, its time stamp and also indicators for the quality of the measured value. Data fields for specifying physical units used are available as well as data fields that can be used for filtered (dead banded) value transmission. So excessive data traffic can be avoided when using value triggered reporting. The measured physical value itself is mapped to some atomic data type, which is defined in the appropriate common data class [8]. For a complex value like voltage this means that both magnitude and angle are mapped to float or integer values.

Although the IEC 61850 standard is the most adequate one for application in smart grids, there are still some drawbacks. In the level of communication of meters and building automation the convenient data models and services described by the standard are not common. There simple data transfer models suffice and a large amount of possible protocols arose. It will be a future task to make those protocols interoperate with the IEC 61850 protocol.

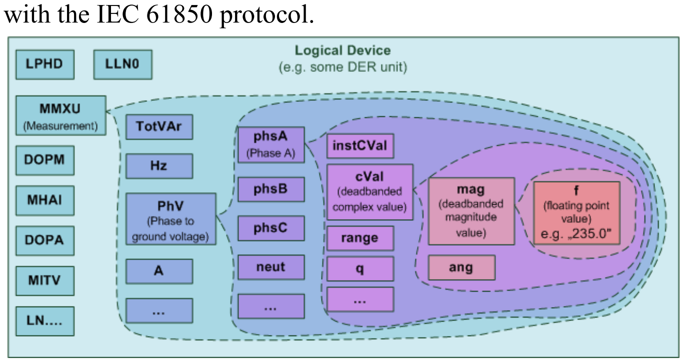

Fig. 4. Example of assigning a given measured value to the designated space in IEC 61850 communication protocol: The measured value of 235.0 V of phase A is assigned to the float field, contained inside the class hierarchy of the logical node MMXU.

IV. Complementing IEC 61850 based systems

Since the communication with meters and home automation devices is not realized using the standard IEC 61850, gateways have to be employed to close this gap. These gateways can be provided by the mapping of metered values to IEC 61850 (including timestamps, load profiles) on the one hand, and on the other hand, by forwarding tariff and tariff forecast signals from the grid to the intelligent meters.

This feature will make the meters really intelligent and allow the VPP to balance energy generation and consumption, since tariff signals will enable load shifting. The gateways to meters and home automation devices do not need the full functionality of the IEC 61850 specification. Simplified data models and services can be applied in this field and allow a more economic solution than a full IEC 61850 implementation. Only the data models to implement meter-specific logical nodes must be used and not the whole palette of services, the IEC 61850 offers, is necessary in this context. One possibility of implementing a meter gateway is the usage of IEC 61850 file transfer, which enables forwarding aggregated meter data from a concentrator to the utilizing body. The standardization efforts for gateways shall take the needed functionality into account and make sure a harmonization to IEC 61850 is given. Research on this topic in the kind of a preliminary realization is done within several research projects.

Gateways to home automation and meters are one part of the needed gateways. The other type of gateways needed are gateways to a common database, which will provide information for all participating bodies. This database must be able to receive and keep the information as well as to provide the information, when it's needed. The gateway takes the key role of communication in both directions between the database and the IEC 61850 based communication system.

This database mentioned above uses the Common Information Model (CIM) according to the standard IEC 61968 [5][6]. Here, too, the standardization efforts shall respect the harmonization between IEC 61850 and CIM. The advantage of a common database for the energy distribution management is obvious, if you look at Fig. 5.

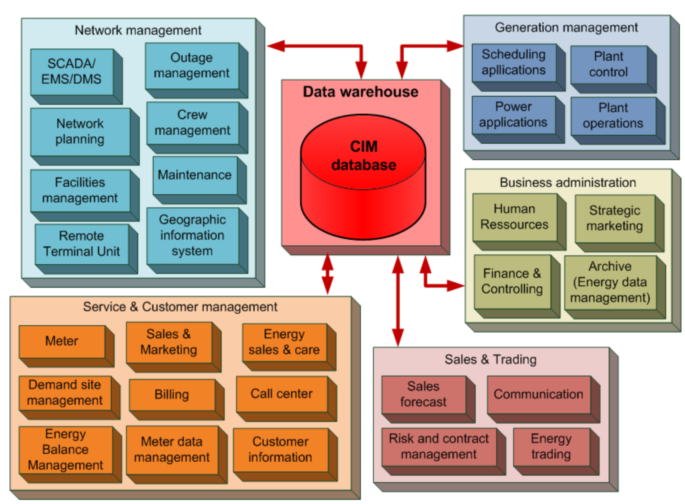

Fig. 5. CIM database as a tool for the coordination of involved enterprises [1]

A distribution system generally is a place where a lot of participating market players do their job. There are enterprises for the network and generation management as well as business administration units, sales and trading and other services. Each of these categories again has several subdivisions that have their special task in the system management. For a proper system operation all those units need to rely on a consistent database, which is identical for every unit, although not every unit needs every data. The consequence is that there must be one common database for all participating enterprises. If you use a standardized data base format like CIM, you avoid the problem of having a countless amount of adapters between data formats.

Fig. 6 shows the relationship between the amount of (bidirectional) adapters and the number of units to connect with and without the usage of a common database. It is obvious that a rising number of units causes a rising number of necessary adapters. The question is, in which degree the number of necessary adapters rises. Assuming that every unit shall be able to communicate with all other units directly (without a common database) the relationship between the number of adapters and the number of units is given by a quadratic equation. The number of adapters when using a common database in contrast is given by a linear equation. Every unit needs only one bidirectional adapter.

An example for the usage of data schemes, as they are defined in the draft CIM standard IEC 61968-11 [10] is shown in Fig. 7. The defined data scheme is based on an object oriented approach, whose classes keep the values to store in their attributes. The illustrated classes are a snapshot of the "Metering" package included in the CIM standard. In the shown example values from a reading process of a smart meter shall be mapped to the appropriate CIM attributes. As the arrows show each of the transmitted parameters has a dedicated space to store the values. CIM attributes that do not get values from some real world device do not need to be filled, since the attributes are optional. The differentiation of general parameters and the measured value of a specific parameter of the meter are represented in the CIM model by assigning the values to the different classes.

As Fig. 7 shows, the class "ElectricMeteringFunction" describes the properties of the meter, "ReadingType" covers the parameters for the style in which the metered values are represented, and the metered value and the timestamp are stored as attributes of the classes "Reading" and "MeasurementValue". Since the classes use object oriented associations between each other, all the attributes are linked together.

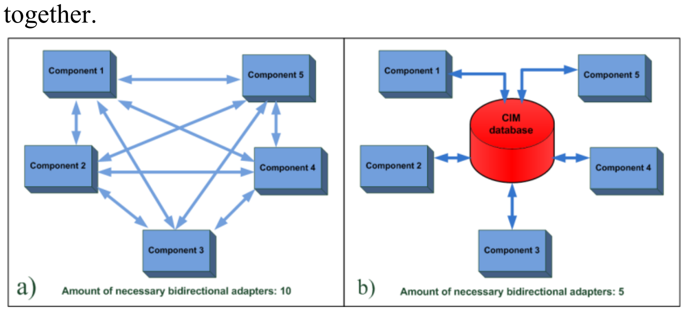

Fig. 6. Amount of necessary data conversions between several SW-components a) without and b) with CIM. Each arrow represents a bidirectional adapter.

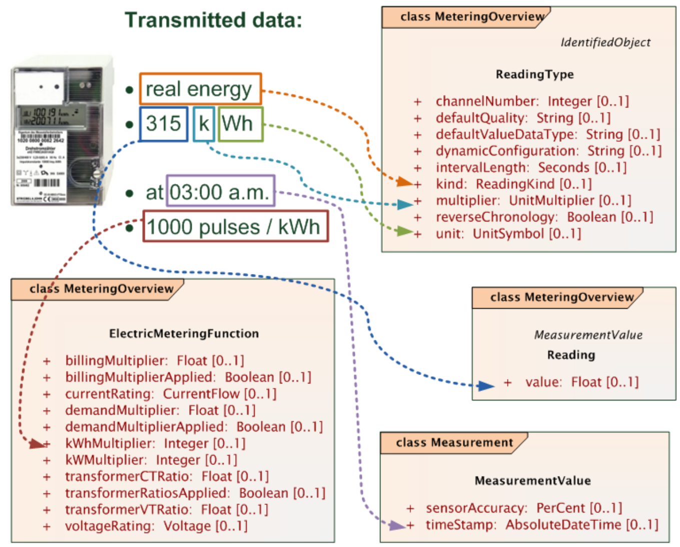

Fig. 7. Mapping of meter data to the appropriate CIM classes

The task of the gateway is now to link the IEC 61850 to the CIM database. A conceptual approach is shown in Fig. 8. The transmission of the metered value via IEC 61850 communication has to be mapped to appropriate data fields inside the CIM database. On the left the data fields of the IEC 61850 protocol and places of the exemplary metered values are demonstrated. On the right, the CIM classes of the data that need to be stored are illustrated. The possible mapping process is indicated by the arrows. The data to be mapped is positioned somewhere inside the IEC 61850 data class hierarchy and should be available in an unstructured data type format (like float or integer), which can be mapped to the CIM data class description. However not all data fields can be mapped directly, since there are differences in the data types or formats of stored data. In those cases adapters are necessary, which realize the mapping in real time during the system operation. One challenge in the mapping process is the correct semantic analysis that the adapter has to execute for a correct data assignment.

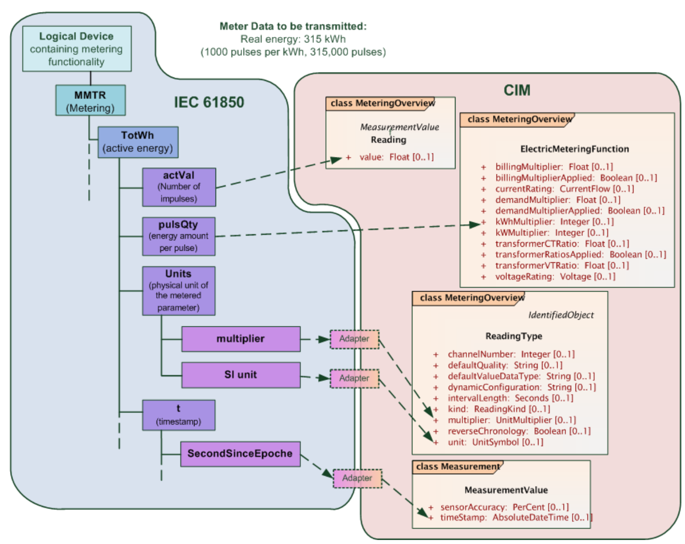

Fig. 8. Mapping of data communicated in IEC 61850 to CIM database scheme

V. Using IEC 61850 definitions in Smart Distribution systems

The prerequisite for the application of the communication according to IEC 61850 is the existence of the required data models that a smart distribution system needs, i.e. logical nodes and associated common data classes. The three pillars of a smart distribution network specify the demand of logical nodes. For smart metering there are already models that describe the energy consumption at a given time for a specific meter. But additionally the realization of a smart distribution system also depends on the tariff forecast that must be transmitted to the smart meter unit. A logical node providing the functionality of defining the current tariff and its duration as well as a 24 hour forecast still has to be defined in the standards. This logical node, can realize the mentioned functionalities by using some new attributes. These attributes can be based on already existing common data classes. Proposals for this already exist, which usability is investigated by a realization within current research projects.

The pillar of smart terminals which shall offer self repairing capabilities depend on the application of models providing monitoring of measured values and control over the breaker. These two features can be realized by well known logical nodes defined in IEC 61850. But there is still a model missing, which contains data models for short circuit indication. Here proposals exist, too, which will be implemented for research purposes, but further work has to be done.

For the smart energy management data models for measurements, control of distributed generation and schedules are necessary. Models for all of these already exist. What is still missing and in a proposal state are models for several detailed representations of distributed energy sources. There are models under construction for digester gas plants and controllable loads, and they will find their way to standard IEC 61850-7-420. The already existing models for hydro power are contained in the standard IEC 61850-7-410 and are available as are the models for wind power in IEC 61400-25.

VI. Conclusions

In the context of Smart Grids an interoperable data exchange over all levels from the electricity socket up to the network control center is a reachable target today. The activities in the IEC working group are furthering the application of the standards IEC 61850 and IEC 61968/70 which standards are also well suitable for Smart Grid. These standards are being further developed and maintained by the IEC TC 57. Interoperability for communication and for the new SCADA is the main topic of concern for this group along with trying to harmonize these standards with other existing standards within the reference architecture [4].

The standard IEC 61850 required still some pilot applications which must be realized for:

- qualify the standardization work,
- investigate new approaches and services including the relevant business models,
- recognize legal and regulatory barriers and demonstrate alternatives.

In the frame of some federal programs in Germany pilot applications of Smart Grids have been under development. The so called E-Energy program funds several projects that realize some aspects of testing and improvement of IEC 61850 applications. This will be special addressed by the projects “RegModHarz”, “MeRegio”, “eTelligence” and “E-DeMa” (www.e-energy.de). Generally in the scope of those projects the integration and coordination of distributed energy resources should be improved, using the communication rules of the IEC 61850 standards.

The European beacon-project “Web 2 Energy” applies also the standards IEC 61850 and IEC 61968 for the realization of a Smart Grid with its three pillars mentioned above. The special objective of this project is the connection between the communication (IEC 61850) and the CIM database (IEC 61968). Appropriate interfaces are under development and will be implemented soon. The preliminary lessons learned in this and other projects show that there is still a lot of work to do. Research efforts for data models that make a conversion possible between the communication protocol and CIM are necessary, as well as efforts for the harmonization with common meter communication standards.

The operation of a VPP and automated terminals in the medium voltage level still requires CIM data management structures, which have to be developed. The extension of existing CIM standards with the needed data classes and their appropriate attributes and associations to the already existing classes is a necessary step towards the real smart grid.

At the moment there are several new parts of the standards under development. The IEC 61850 will be released in edition 2 in the near future and will include parts for the communication in distribution systems with a high amount of renewable energy sources. The CIM standard for distribution systems (IEC 61968-11) is also under development taking into account the new requirements of Smart Grids and will also be released in the near future.

VII. References

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