The three pillars of Smart Distribution realized by IEC 61850 communications

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***Abstract*-- The enhancement of distribution networks into smart grids is accompanied by new functions and technologies like network automation, smart metering and de-centralized energy management. Consequently, the information and communication technology (ICT) must penetrate the distribution systems down to the end consumers 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 the European lighthouse project WEB2Energy [1] is demonstrated.

***Index Terms*— Power Distribution System, Automation, Communication, Energy Management, Metering, Standards, Pilot**

I. THE PILLARS OF SMART DISTRIBUTION

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 power plants. This will change the role of the distribution system from a passive to an active one. The enhancement of distribution networks into smart grids is accompanied by new functions and technologies like:

- Advanced distribution system automation,
- Energy management on the distribution level,
- Smart Metering and consumer market participation partly supported by building automation facilities "Smart Home".

The pillars of a smart grid are realized by information and communication technologies, covering all levels of the network. The new functions are considered in

First of all, the operations of dispersed generation (e.g. photovoltaic cells, small CHP – cogeneration of heat and power plants) may cause voltage problems in the low voltage networks up to limit exceeding.

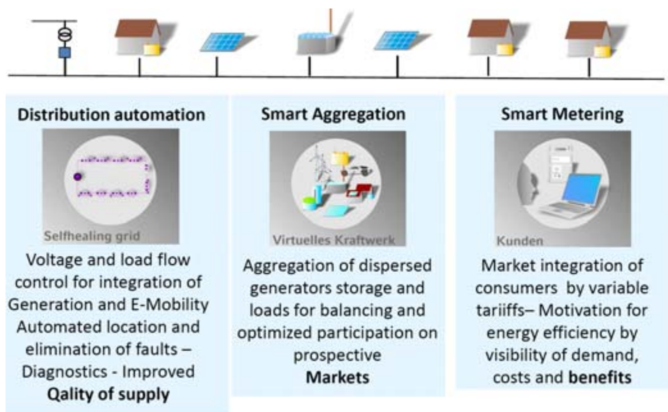

Fig. 1. Three pillars of smart distribution networks

On the other side, the charging of E-mobiles may lead to an overloading of lines or transformers. New monitoring and control facilities have to be installed. Furthermore, the detection and elimination of faults in the medium voltage networks is executed manually. It takes in the average 1 hour. In the future the remote control via communication facilities can help to short the interruption time after faults significantly.

The Smart Aggregation by "Virtual Power Plants" (VPP) as the second pillar 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 markets for energy, for operating reserve and carbon certificates. Additionally, a cost optimal operation of 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 units and controllable loads. This ability of controlling generation and consumption will also allow a better utilization of renewable energy resources and the increase of the energy efficiency.

Thirdly, the consumers will be involved into the energy market by various tariffs. In this way they may save or shift consumption from high tariff time into low tariff time. The pre- requisites for the participation of consumers are home automation facilities, a better visibility of tariffs, demand and costs.

An intensive exchange of data is required to realize all these functions. As a consequence, the information and communication technology (ICT) must penetrate the distribution systems down to the end consumers 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. Normally, their function ends at the busbars of the 110 kV/ MV substations.

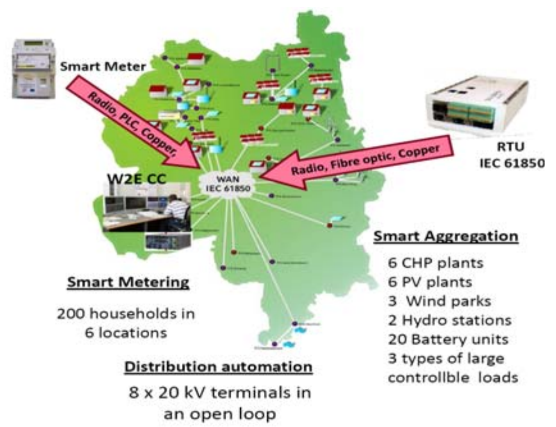

Fig. 2. The allocation of smart customers in the 20 kV supply area of HSE

The three pillars of Smart Distribution are realized in the practice of the network operations in the supply area of the HEAG Südhessische Energie AG (HSE AG) in accordance with Figure 2.

The implementation of the new functions and the communication facilities is executed in the framework of the European project WEB2Energy (W2E) funded by the European Commission. The consortium consists of 11 partners from Austria, Germany, Poland, The Netherlands and Switzerland.

II. The New ICT systems at the distribution level

Today there are various communication protocols and information systems applied in different domains. Consequently, the data models and services of the communication protocols are not compatible and a seamless information exchange between the levels is not given:

- 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.

The current situation causes high engineering efforts for converting between the various communication levels.

The application of a homogeneous protocol between and inside all levels of the distribution system is necessary to ensure the seamless data exchange within the network and to save engineering expenses. The protocol IEC 61850 offers all benefits of the object oriented engineering approach. It is open for extensions and for several physical and link layers. Furthermore, this protocol is accepted worldwide and has mature experiences in substation communication since the last 8 years. First time, IEC 61850 will be applied for distribution in the project WEB2Energy [1]. This solution corresponds also with the European strategic deployment document [2].

Fig. shows how the responsible working groups of IEC prepare the uniform use of the common services and data models by extensions of the standard for the different applications and levels of the electric power system.

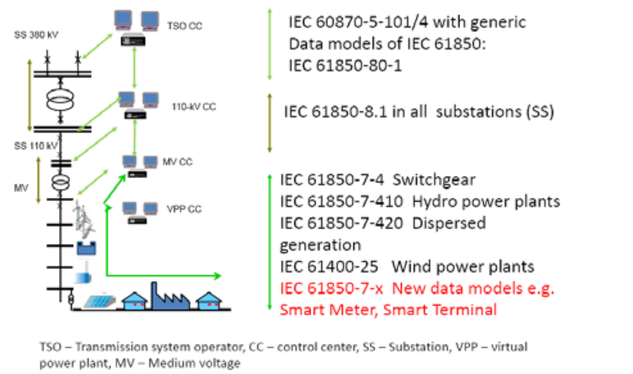

Fig. 3. Seamless communication inside the power system by IEC 61850

Further analysis defines the demand of information exchange that the system must provide for the three mentioned pillars in accordance with Figure 4:

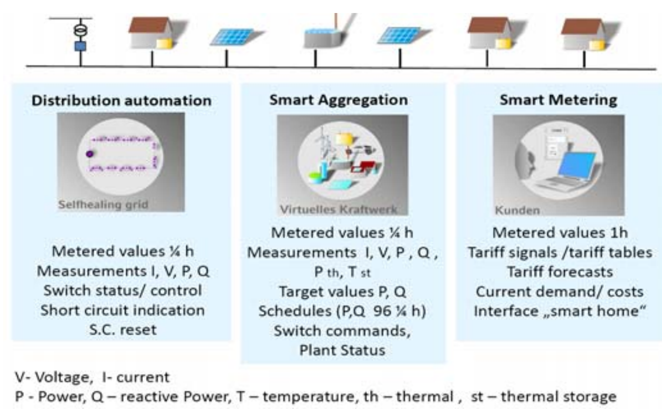

Fig. 4. Information to be communicated in a smart distribution network

- The smart MV/0,4 kV terminals provide data necessary for safe system operation. This includes status and control information (switches, short circuit indicator), metered and measured values and diagnostic information on demand. Utilization of those parameters enables the functionality of self healing grids and increases the overall system safety.
- Secondly, 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 a smart aggregation of the VPP components.
- Thirdly, there is the data on the consumer 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 trader as well as the current energy consumption must be communicated.

This information allows computing the needed amount of control required for efficient smart grid operation.

III. Meter and Smart Home protocols

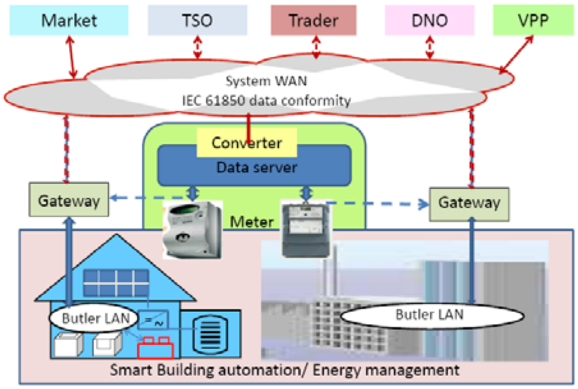

Fig. 5. Gateways between meter/ building automation and the system WAN based on IEC 61850

Currently there is no chance to implement IEC 61850 at the communication levels of meters and building automation. The communication at these levels should be simple – services and large amount of proprietary solutions and standards was developed and is applied by different vendors and companies.

On the other side, the amount of data which is common on the lower levels of meters or building automation and network control at the higher level is low. In principle, it contains the metered values, the price signals and the tariff forecast – much less in comparison with the thousands of data required for power system control.

The energy butler in the buildings in principle needs only the tariff signal and the tariff forecast from the system level. It can be received directly from the WAN or through the meters as shown in Figure 5.

The meters communicate inside a closed system to a data server. Meters of other media like water, gas, heat are incorporated in this system.

Therefore, in the project Web2Energy the converter for IEC 61850 based communication of metered values of households to the stakeholders like VPP or distribution system operator (DNO) is allocated in the data server of the trader.

Nowadays, there run activities to define a common simple and efficient communication structure for the multi- utility metering [3-5]. In Europe the favorites are the M-Bus (wire and wireless) with SML in the application level. Hopefully, in the field of building communication favorites like KNX [6] or Bacnet [7] can achieve in mid- term the status of common standards in Europe as well.

IV. Applying the standard IEC 61850 for distribution

The high variety of protocols for meter and smart home communication has a significant impact on the communication system architecture inside the WEB2Energy applications as shown in Figure 6.

The core elements of the IEC 61850 communication system are the remote terminal unit RTU as the server and the W2E Control Center as the client. The RTU is installed in all plants participating in the VPP and in the terminals of the 20 kV network. For these applications the RTU serves as the converter from a meter protocol into the IEC 61850 protocol.

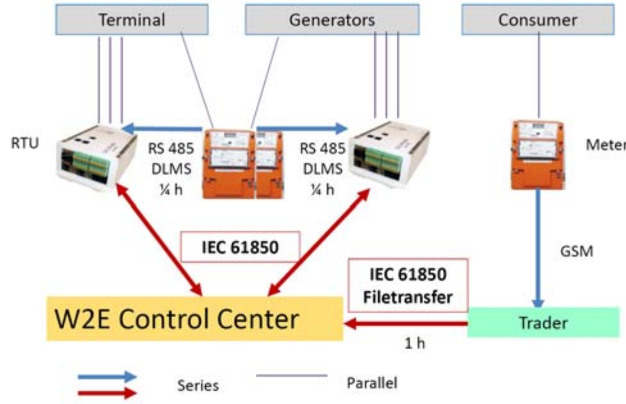

Fig. 6. Architecture of the W2E communication system

The meters communicate the metered energy values, the active and reactive power in quarter hour intervals via a RS 485 link using the DLMS protocol layers 2-7 to the RTU.

The RTU acts as the converter to IEC 61850.It provides I/O contacts for binary and analog signals. It communicates via the IEC 61850 WAN with the W2E control center.

The household consumers are equipped with smart meters which communicate their data using a typical meter protocol with radio communication GSM to the trader. The Trader sends the data of the 200 selected consumers participating in the project each hour via IEC 61850 file transfer to the control center. In this way the gateway between meter protocol and IEC 61850 is solved.

The consumers can call the information about the tariffs, the demand and the costs by support of WEB services from the control center to their WEB connected PC or on the mobile phone. For the first view the tariff forecast is presented in the colors red (advantageous to save or shift demand) and green (cheap energy). He can call more information by interest up the load profiles for days, weeks or months. The whole picture of the consumer data provision is presented in Figure 7.

The data base of the Control Center uses the Common Information Models CIM in accordance with IEC 61968/70.

A converter for the data models IEC 61850 – IEC 61968/70 is developed. Corrections and extensions of the CIM descriptions are defined and recommended to IEC.

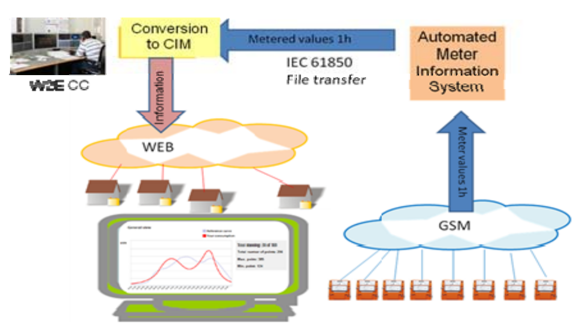

Fig. 7. Information provision for the household consumers

For economical reasons in the distribution level public communication networks should be used adapting the locally available and most economical communication physics e.g. power line carrier, telecommunication cables, fiber optics or radio links. In the project W2E commercially available adapters are used for this purpose as shown in Figure 8.

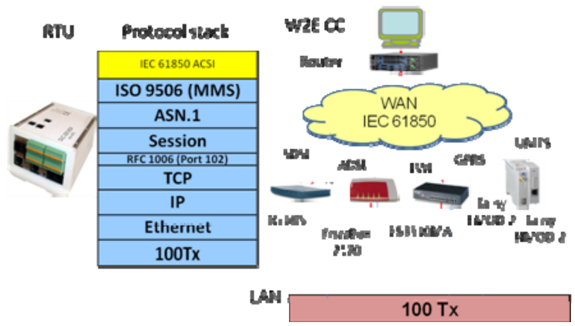

Fig. 8. Adaptation of the 100 MBd Ethernet interface of the RTU to various physical and link layers (DSL on copper cables, fiber optics, radio)

The W2E system uses SDL on telecommunication cables, optical links and radio channels (UMTS, GPRS).

In the last years the standard IEC 61850 was extended for various applications as shown in Figure 2. However, the application for distribution functions (red marked) requires some additional work to adjust it for the new challenges. New data models will be needed. However, the analysis within the project WEB2Energy shows that the adaptation needs are not very high. Figure 9 shows the I/O contact configuration for a 20 kV terminal with 3 feeders. The data models of the existing standard parts are mostly applied.

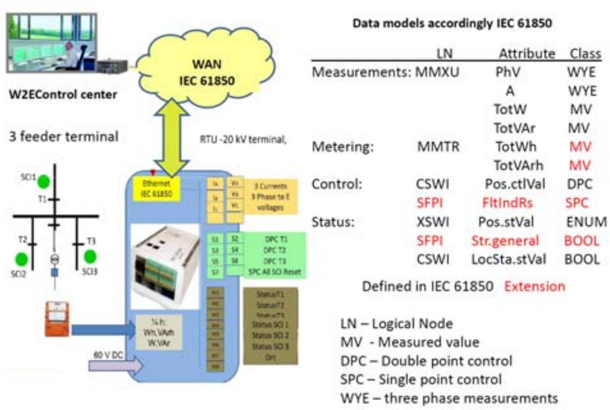

Fig. 9. RTU configuration and data models for a 20 kV terminal

The red marked model bricks are still not defined in a part of the standard. The meters up to now understand only impulses for presenting metered values in the model. However, smart meters have a digital measurement principle and require the presentation of the metered values as measurements (MV). The short circuit indications and their reset command have to be taken over into the standard as well.

Figure 10 describes the data model for a CHP with 2 generator units. In principle only the thermal parameters like power or storage capacity need to be extended. Here analog outputs to set the targets for active and reactive power are used additionally.

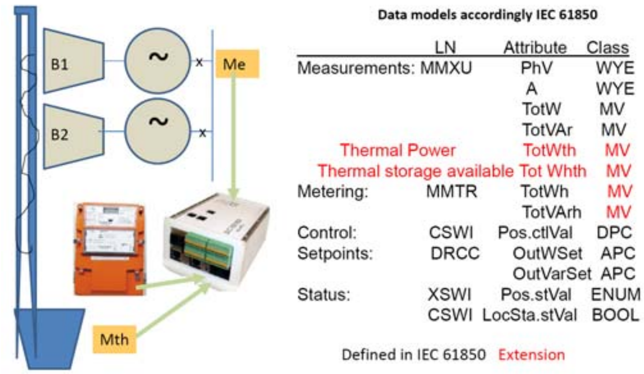

Fig. 10. Data models for a CHP plant

Besides the measured values for energy presentation in the logical node meter MMTR the meter communication requires a logical node "Dynamic tariffs" the current tariffs, the tariff forecasts for 24 hours day- ahead and the tariff correction intraday as attributes.

The newly defined data models for smart distribution will be recommended directly to the IEC standardization bodies by W2E consortium members who are participating in the related working groups of TC 57.

V. The W2E Control center

The Control Center is especially designed for the W2E project purposes. Figure 11 shows the whole system with a detailed presentation of the W2E Control Center (CC) with its components in the grey field.

The W2E CC consists of the converter CIM – IEC 61850 data models, the CIM data base and the HMI.

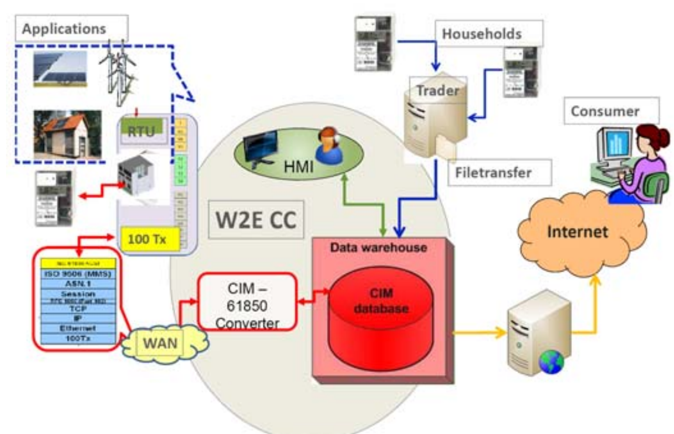

Fig. 11. The W2E CC and its components in the centre of the W2E system

The CIM data base serves the HMI and the consumers via WEB services with data. The usage of a common information model for data management offers great benefits. Today, several enterprise management systems apply different data formats. A change of a data shall be executed in parallel in all the management systems like SCADA, GIS, Planning tools etc. Under such circumstances, the danger that the consistency will be lost is high. The application of CIM helps to enhance the efficiency in engineering and operations.

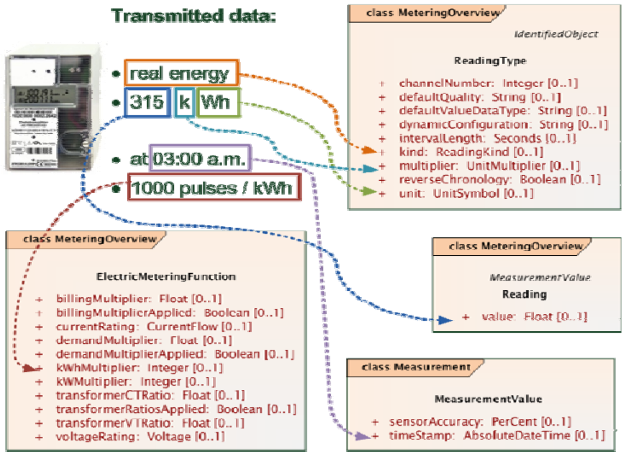

Fig. 12. Mapping of meter data to the appropriate CIM classes

Fig. 13. The HMI start menu and the opening screens of the 3 pillars

Each data can be changed in only one system and will be automatic adapted in the other data bases.

An example for the usage of data schemes, as they are defined in the draft CIM standard IEC 61968-11 [11] is shown in Fig. 12. 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 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. 12 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.

The task of the converter is now to link the IEC 61850 to the CIM database and reverse. The transmission of the metered value using IEC 61850 data model has to be mapped to appropriate data fields inside the CIM database.

The HMI offers in the start menu the 3 pillars of smart distribution in 3 fields. A mouse click on one of the fields allows the entrance into the functional details as presented in Fig. 13. In the centre of the Figure the three signs of the pillars are shown. After the click on "self healing grid" the scheme of the open 20 kV loop (upper side left) appears with indication of the switch status and the short circuit indicators. Using this scheme the control operations may be carried out interactively.

The VPP selection field in the middle creates the overview of the VPP and its components with diagrams regarding the balancing and the costs of unbalances (under the field). Finally, the screen with the load profiles of consumers in comparison with reference profiles, the tariffs, the demand and the costs are presented over the selection field "consumer".

The screen offers a calendar function to select the data of different days, weeks, months or sequences. A special screen and dialogue are foreseen to set the tariff forecasts day ahead and in critical situations after events (e.g. red in case of power station outage, green in case of more wind energy production as forecasted) intraday as well. The screens of the consumer data in the W2E CC and the consumer accessible screens (through internet or SMS, password protected) are different. The consumer screens are more simple and understandable for all people. The trial operation with dynamic tariffs for 200 pilot consumers was started 1st August 2011.

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 functionality is the main topic of concern for this group along with trying to harmonize these standards with other existing standards within the reference architecture [9].

The standard IEC 61850 requires still some pilot applications with various use cases which must be realized to:

- 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 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 "E-DeMa", "RegModHarz", "MeRegio" and "eTelligence" [10]. 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 lighthouse project "WEB2Energy" applies also the standards IEC 61850 and IEC 61968 for the realization of an ICT system for Smart Grid control with its three pillars mentioned above. A 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 are implemented. 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 data model and CIM are necessary, as well as efforts for the harmonization with common meter and building communication standards.

The operation of a VPP and automated terminals in the medium voltage level still require further 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 application.

At the moment there are several new parts of the standards under development. The IEC 61850 will be released in edition 2 and will include parts for the communication in distribution systems with a high amount of renewable energy sources. The new name of the standard *"Communication network and systems for power utility automation"* expresses its universal applicability for all levels of the power system.

The CIM standard for distribution systems (IEC 61968-11) is also under development taking into account the new requirements of SmartGrids and will also be released in the near future.

First time, the Project WEB2Energy realizes all 3 pillars of SmartDistribution in practice. In this way, the project supports the detection of lacks or inconsistencies in the current versions of the standards. The close cooperation with the standardization bodies helps to improve the standards in short time and offers consistent models for complete use cases.

The SmartGrid functions for distribution are ready for implementation in practice.

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VIII. Biography

Bernd Michael Buchholz was born in Eisenach in the former GDR, on November 4, 1948. He received his MS and PhD at the Power Engineering Institute in Moscow in 1973 and 1976 respectively. After that he was assigned project manager, department manager and since 1987 director at the Institute of Energy Supply in Dresden (GDR). In 1990 he joined the Siemens AG and took over the head of the R&D department of the division "Protection and Substation Control Systems" in Berlin and Nuremberg. Between 1995 and 2000 he was the editor of the IEC 61850 standard parts 4 (System management) and 7-4 (Data models). Between 2000 and 2005 he was president of the business unit "Network analysis & Consulting" in Erlangen, since 2005 "Power Technologies International" with locations in Erlangen (D), Schenectady (USA), Manchester (UK) and worldwide Centres of Competence. He was the German member of CIGRE SC C6 between 2002 – 2008 and worked as an executive member of the European Advisory Council "SmartGrids" from the beginning until 2009. Retired in 2006 for health reasons he is still active as a chief consultant with NTB Technoservice. He is engaged in the German Power Engineering society as the task force leader "SmartDistribution 2020" and "Active electricity networks". Since 2010 he acts as the technical and strategic advisor of the European Project Web2Energy (www.web2energy.com). Furthermore, he is the technical consultant for the E- Energy projects "RegModHarz" and "Harz.EE-Mobility" (www.e-energy.de). He teaches at the University of Magdeburg and within the education program of the German Society for Electrotechnology, Information and Communication Technologies and Electronics. He is the author of 150 international publications in 6 languages.

Zbigniew Antoni Styczynski (1949) received his PhD in Electrical Engineering in 1977 and finished his professorial dissertation at the Wroclaw University of Technology (Poland) in 1985. He was 8 year with the Stuttgart University and 1999 become the Professorship for Electric Power Network and Renewable Energy and joint the Otto-von-Guericke-University Magdeburg. He was a Dean of the Faculty (2002-2006). 2006 he was voted to the President of Centre for Renewable Energy Saxony-Anhalt e.V. and 2008 he became Executive Director of the Institute of Electric Power Systems at the Otto-von Guericke University. Since 2002 he is also member of the Senate at this University.

As a co-founder and scientific coordinator of Joint Fraunhofer-IFF-Otto-von-Guericke University Competence Centre of Power Systems and Renewable Energies and founder and Director of Steinbeis Foundation Transfer Centre ENRE in Magdeburg. Further on, he is an active Member of ETG, CRIS, CIGRE and IEEE and an expert at FNN-Berlin. Since 2004 the Fellow in the Conrad Adenauer Foundation and since 2010 he is also the President of CRIS. He coordinated numerous of national and international project (e.g.. Harz-EE-Mobility). He is author or co-author of more than 200 papers in international journals and international scientific conferences.