Increasing Grid Visibility on the Basis of Smart Meters as a Building Block for Grid Integration of Electromobility

Schaugar Azad
Evgeny Schnittmann
Markus Zdrallek
Institute of Power System Engineering
University of Wuppertal
Wuppertal, Germany
schaugar.azad@uni-wuppertal.de

Boris Brandherm
Alassane Ndiaye
Matthieu Deru
German Research Center for Artificial Intelligence
Saarbrücken, Germany
boris.brandherm@dfki.de

Julian Zimpel
Marcus Hörhammer
Voltaris GmbH
Maxdorf, Germany
julian.zimpel@voltaris.de

Alexander Schalk
VSE AG
Saarbrücken, Germany
schalk-alexander@uni-wuppertal.de

Christian Breuer
STEAG Technischer Service GmbH
Berlin, Germany
christian.breuer@steag.com

Nils Neusel-Lange
SPIE SAG GmbH
Oberhausen, Germany
nils.neusel-lange@spie.com

***Abstract*— In the course of the ongoing transition of the energy supply towards a renewable and decentralized system, the number of electric vehicles in Germany is also increasing. The growing number of electric vehicles is an important part of the energy transition, along with the expansion of decentralized generation facilities. While there is sufficient measurement technology available at the transmission grid level to calculate the state of the grid and the calculation algorithms focus more on the redundancy of the measured values and their measurement errors, there is hardly any measurement technology available below the 110 kV level. As a result, the observability of medium-voltage and low-voltage grids is severely restricted. This situation is historically conditioned and can be traced back to the power supply by means of central large-scale power plants. This paper highlights the added value of smart meters in the context of the integration of electromobility. Furthermore, it will be presented how the combination of smart meters and decentralized distribution grid automation systems can cost-efficiently increase the transparency in the grid. Within this framework, an intelligent Smart Meter Converter is presented, which provides the decentralized grid automation system with scenario-specific Smart Meter data in a usable form. The advantages and relevance of such a module in the context of digitization and industry 4.0 will be highlighted. Based on this, first steps for the practical realization of an intelligent Smart Meter Converter will be presented.**

Keywords—Smart Meter, Smart Grid System, Electromobility, Grid Automation System, Energy Transition

I. Introduction

The transition of traffic initiated by the German government has an increasing influence on the structures and supply tasks in today's distribution grids [1]. Due to the low number of electric vehicles, the effects are currently not widespread. According to the Federal Motor Transport Authority, a total of 47.1 million passenger cars were registered in Germany as of 1 January 2019. Of these, 83,175 were electric vehicles, an increase of 54.4 % over the previous year, and around 341,000 were so-called Hybrid vehicles, an increase of 44.2 % [2]. Thus, the share of purely electric cars is currently around 0.18 %. Through government incentives and subsidies, such as the 0.5 % rule for company car taxation, combined with the increasing development of charging infrastructure and the increasing range of vehicles on offer, the National Platform for Electric Mobility (NPE) assumes that the target of one million electric vehicles will be achieved in 2022 [3].

Today, local grid bottlenecks are already occurring, for example where a large number of charging points are bundled together, such as in car parks or modern residential areas. A positive example of a modern residential quarter where local grid bottlenecks are avoided is the "Dörnberg-Quartier" in Regensburg, which, according to ChargeIT [4], currently represents the largest charging infrastructure and load management project in Germany, with 260 charging points being installed in the first construction phase. With an output of 22 kW per charging point, 5.720 MW would theoretically be possible. Usually, these 260 apartments are supplied with a grid connection of approx. 1 MVA. Intelligent charging management will ensure that as many charging points as possible are served and at the same time the power supply of the connected apartments and commercial units is guaranteed. The way in which the available power is distributed among the charging points can be determined by different prioritizations of the users, considering the principle of non-discrimination. The solution comes from a single source and coordinated hardware and software components that are compatible with each other were already selected during the planning phase. Since everything necessary can be regulated on site, communication with the network operator is not necessary.

By contrast, the situation in the public sector is usually different. Various components from different manufacturers are already installed here, and the distribution grid is already in place and may need to be enhanced. In contrast to the residential area, decentralized feeders can also lead to internal overload situations which are not detected by the traditional grid protection technology installed in the local grid transformer. As in the neighborhood solution, the distribution of the available power should be non-discriminatory and based on different user priorities.

Intelligent load management makes sense for this high number of charging points. Currently, this requires communication between the charging points with a higher-level, decentralized control system. Here the control can be taken over by a decentralized grid automation system. Depending on the current load factor of the grid supply, the charging capacity is limited by the medium-/low-voltage transformer that supplies the grid.

A decisive advantage of such a residential area is that the charging points in the underground car park can be connected to a central control system via a network, as the paths and distances are short. In addition, such projects usually involve the use of hardware from a single manufacturer. Communication with the grid operator is not necessary, as decentralized control takes place.

In a classic local grid, this spatial proximity is often missing and the charging infrastructure used is not uniform. Nevertheless, these low-voltage grids are also affected by grid bottlenecks due to electromobility. Standardized communication protocols and an interface to the distribution grid operator are prerequisites for interconnecting the various charging infrastructures. Smart meters with control boxes could perform this task in future in combination with grid automation systems, so that the grid operator knows the grid state in the low-voltage grid through smart meters and can thus influence the charging behavior of the vehicles in terms of grid stability. In the course of the smart meter rollout and the associated digitalization, a steadily increasing volume of extensive data streams can be assumed in the medium to long term, which need to be processed sensibly. To this end, the data must be processed and converted into a form that can be used by the grid automation system. In addition, three scenarios will have to be anticipated in the future in which smart meter data types (high-resolution grid state data and meter readings) of varying granularity are made available to the decentralized distribution grid automation system. For this purpose, case distinctions and scenario-specific solution concepts must be developed.

In the context of this contribution, the University of Wuppertal, together with its partners DFKI, SPIE, STEAG, Voltaris and the VSE of the SINTEG showcase project Designetz, will show how the combination of intelligent measurement systems and decentralized distribution grid automation systems can cost-effectively increase transparency in the grid. The work focuses on an intelligent Smart Meter Converter (iSMC), which provides the decentralized grid automation system with scenario-specific Smart Meter data in a usable form.

The work is structured as follows. The scenario-specific concepts have been concretized in earlier publications by the authors involved. Chapter II explicitly mentions the associated publications and concepts. Chapter III examines the advantages and relevance of such a module in the context of digitalization. Based on this, the first steps towards the practical implementation of an iSMC are presented in Chapter IV.

II. Intelligent Smart Meter Converter

Smart Meter data differ in their information content depending on their granularity (resolution). Depending on the granularity of the smart meter data, correspondingly tailored concepts are necessary for their integration. To this end, three scenarios are to be considered which differ in their data resolution and in their data transmission with respect to the time offset to real-time operation. The scenarios consider both the legal framework [5] and the state of technical development. In addition to the legally prescribed minimum technical requirements for smart meters [5] [6], so-called tariff application cases indicate which measured values a certified smart meter gateway must be able to provide. From a purely technical point of view, most devices are capable of measuring a large number of parameters (or better network status data?) such as current, voltage, the current active power or the consumed energy over a certain period of time and transmitting them every second. However, there is currently no obligation to transmit the network status data in a uniform manner and without notice. Scenarios must therefore be developed that allow maximum flexibility in handling smart meter data. The relevant scenarios are briefly described below.

A. Scenarios and Their Data Volume

In the first scenario it is assumed that smart meters in a grid variant provide network status data promptly and feed it to the smart grid via a communication interface for further processing. This data is usually incorporated in the same way as the sensor technology of the Smart Grid (hereinafter referred to as the Smart Grid concept). This Smart Grid concept is already simulated and validated. The added value of the smart meters, which results from the simulation, can be found in [7].

In the second scenario, it is assumed that Smart Meter does not provide the Smart Grid with high-resolution grid state data, but only with meter readings of electrical work determined every quarter of an hour directly or with a short-term delay of one period rolling. Consequently, the meter reading represents the integral of the electrical work. The measured electrical work of the measuring period can be calculated from the feed rate, as the difference between the current meter reading and that of the previous period.

The third scenario is based on the same assumptions as the second scenario, with the exception that the meter readings are not sent to the Smart Grid individually and with a small delay, but collected as a data package (e.g. at the end of a day). The added value resulting from the developed concepts for the second and third scenarios as well as a detailed explanation of the respective concepts can be found in [8].

Based on smart meters, new business opportunities can be developed and offered on the market or the aggregated information can be used to introduce new services and improved processes in the energy industry. The advantages for energy suppliers are, for example, optimized grid control, lower costs for meter reading or faster detection of partial failures or malfunctions in the distribution grid [9] [10]. Furthermore, the current requirements for smart meters provide for the implementation of dynamic electricity tariffs in order to be able to influence the consumption behavior of end customers in a targeted manner.

Beyond the potential benefits, however, there are also various challenges. These include, above all, guaranteeing data security in terms of IT security and protection against manipulation of aggregated data. For smart meters, these requirements are defined by the Federal Office for Information Security in corresponding technical guidelines [6] [11]. The guidelines cover hardware, software and process requirements for smart meters and communication via smart meter gateways.

A further challenge is the large amount of data, as an appropriate infrastructure is required to transport the data at the required speed. Thus, a network with sufficient band-width is the basic requirement for the communication of the future large quantities of smart meters with a network participant, such as a distribution system operator (DSO).

In order for a distribution grid operator to be able to optimize the control of the monitored grid, a suitable process is required to enable the use of the collected data in already established grid control systems.

III. Relevance of the intelligent Smart Meter Converter

In the course of the increasing digitalization of the distribution grids and the automation of local network stations as a replacement for the formerly largely performed operation by control rooms by means of tele control technology, the amount of data to be processed and the requirements for recording, processing, transmission and storage are increasing. On the one hand, distribution grid automation offers the added value of a less complex and cost-intensive infrastructure and simpler operation, but on the other hand it demands a reliable handling of large amounts of data as sensors and actuators become more and more equipped. It is important to keep the error susceptibility of critical systems, such as a decentralized grid automation system (DNA), as low as possible, since a failure of such a system can have considerable economic consequences. Therefore, it is necessary to find and implement innovative solutions for the controllability of these complex data sets without changing the basic functionalities of the underlying highly sensitive systems. This ensures that the susceptibility to errors is reduced to a minimum. The iSMC forms the link for the future integration of different smart meter data by (1) converting the previously unusable smart meter data into a format that can be used for DNA, (2) relieving the distribution grid automation of the computational effort and (3) helping to avoid further development effort for alternative forms of smart meter integration.

ad (1): The aim of the additional data is to generate technological and entrepreneurial added value. Smart Meter data offer both as high-resolution grid state data and as energy measured values in 15-minute resolution an added value for the grid state calculation [7] [8]. The smart meter data help to improve the results of the substitute value calculation, as these are directly related to the quality and information content of the input data provided. Distribution grids only offer insufficient sensor equipment, therefore the calculation of the knot-sharp replacement power in DNA is done by the linear distribution of the power. Here, smart meters can be interpreted as additional sensors and made usable by the iSMC. Up to now, however, the data types provided by smart meters via Smart Meter Gateway could not be retrieved in a compatible format, which is why it is not possible to use them directly. The iSMC enables the integration of smart meter data by converting the available data into a format that can be used by a distribution grid automation to calculate the grid state, independent of the data type.

ad (2): This approach allows a relief of the distribution grid automation system against the background of the problems. and at the same time reduces the computing effort of the core application by outsourcing the computing operations to an external module. Thus, time-critical calculations remain unaffected and the error susceptibility of the system is not increased by the outsourcing of the additional function.

ad (3): In addition, the avoided development effort for alternative forms of smart meter integration should be included. The iSMC is designed in such a way that it can communicate with any distribution grid automation via standardized interfaces and transmission protocols. This makes the development of isolated solutions for a DSO avoidable and future further developments for additional Smart Meter data types beyond the three out-lined scenarios take place exclusively in the environment of the iSMC.

IV. Integration of the intelligent Smart Meter Converter into a grid Automation System

The process illustration in Figure 1 shows the necessary integration steps of the iSMC module into a DNA. The graphic illustrates the position of the iSMC in the overall data processing process from the smart meter gateway (SMGW) to the DNA.

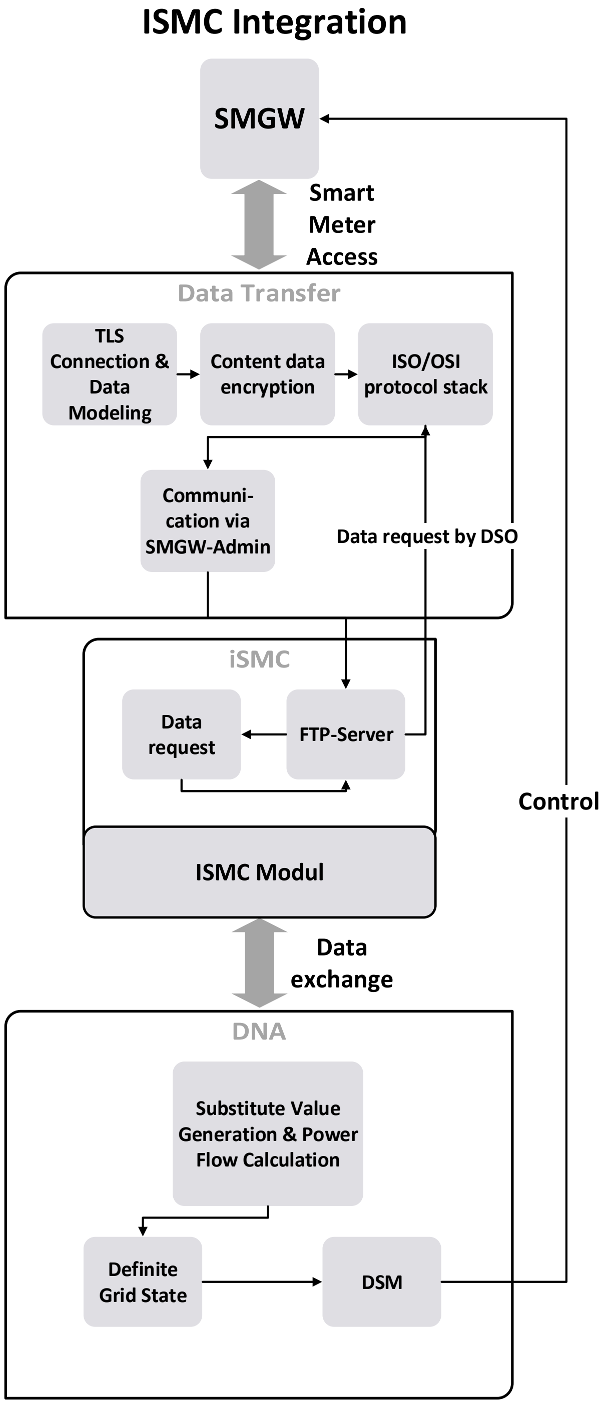

Figure 1: Process representation of the integration of the intelligent Smart Meter Converter

The communication between the external market participant and the Smart Meter takes place directly or via the intermediate step of an SMGW administrator. Since the DSO itself, as an authorized external market participant, must receive the data or read the data from the SMGW in a corresponding relation-ship, the data must also be made available to the iSMC module.

An answer to the question about the design of an iSMC as software or hardware has not yet been finally decided. The data can be made available to the iSMC by the DSO in two ways.

(1) On the one hand, this may take the form of integrated software. For this purpose, an executable application is created on an application server of the VNB or locally in a local network station. The smart meter data is either trans-mitted directly to the iSMC or made available on an FTP server to which the iSMC has access.

(2) On the other hand, this can take the form of hardware which is installed as an independent module comprising all relevant interfaces as well as a computing unit. This is currently being implemented by the University of Wuppertal on the basis of a WAGO SPS and validated with the help of partners within the framework of the project Designetz in the Saarland network of VSE AG in the municipality of Freisen.

The transferred measured values are converted by the iSMC and made available to the downstream distribution grid automation. The integration into the station control system is carried out according to IEC 60870 or IEC 61850.

Furthermore Figure 1 shows the transmission path from an SMGW via the iSMC module to a distribution grid automation. Communication between the SMGW and the iSMC or distribution grid automation is bidirectional, so that controllable equipment can be connected to the LMN of the SMGW. The data transmission block forms the link between iSMC and distribution grid automation. The data transmission contains the most important requirements for the communication between an external market participant and an SMGW. This includes the TLS connection as a basic requirement for communication. The connection between the file transfer protocol (FTP) server, on which the iSMC accesses, can be made via the SMGW Administrator and on the other hand there is the possibility that an SMGW makes data directly available to a trustworthy external market participant and thus sends it to the corresponding address of the FTP server. The iSMC module in turn performs a data retrieval of the Smart Meter data and thus receives the necessary CSV files.

As you can see in figure 2, the communication between the distribution grid automation and the iSMC is also bidirectional, as both can provide data to each other. These include, for example, the determined replacement performance or dynamic and static grid parameters.

The distribution grid automation block consists of the substitute value generation and power flow calculation, as well as the subsequent resolution of the unique grid state. Based on this grid state, a connected Demand Side Management System can initiate a control intervention on controllable resources connected to the SMGW in the event of a critical grid situation. For example, a heat pump can be controlled if required.

Figure 2 illustrates the design of the communication between iSMC and a distribution grid automation. The focus is

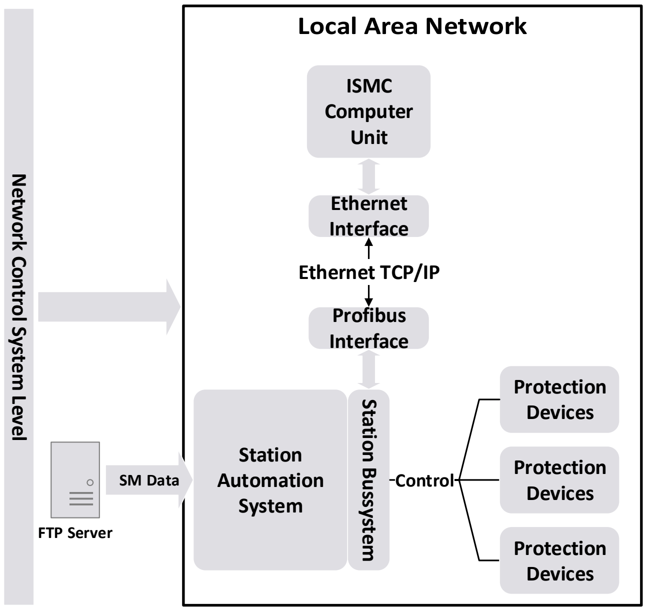

Figure 2: Communication between the intelligent Smart Meter Converter and the distribution grid automation system

on the physical interfaces of an iSMC computing unit as hardware and the connection to the interface of the distribution grid automation. The iSMC is connected to the station control system via an interface. The station bus serves as a link between the distribution grid automation and the automation components, in this case protective devices. The iSMC can be connected either as an automation component via a Profibus interface or via an Ethernet interface. Since Profibus does not use a TCP/IP protocol and is primarily designed for control purposes [12], the connection via an Ethernet interface is an option.

The Ethernet interface enables the communication of integrated external devices at station level. Data and information are exchanged via the local computer network (LAN) according to the Ethernet TCP/IP protocol. In this way, the iSMC can be integrated at the station level.

As the iSMC is not intended as a hardware module for communication with an external FTP server due to the increased security requirements within the station control system, the smart meter data must be provided via the distribution grid automation. Access to public networks is secured via a firewall.

The data exchange between the iSMC and a distribution grid automation is shown in Figure 3. The iSMC processes data in three main areas. First, all relevant data is read in. These include static and dynamic grid parameters of the distribution grid automation, or grid districts, and sensor data and smart meter data. The smart meter data can be made available in the LAN or transferred directly from the respective VNB to the iSMC. The data of the distribution grid automation are needed for the topology, for the substitute value generation and for the power flow calculation.

The required parameters are first read in by the DNA when calling up the algorithm for network state estimation in the form of static and dynamic grid parameters. The topology is then built up in the DNA, from which the grid districts and the

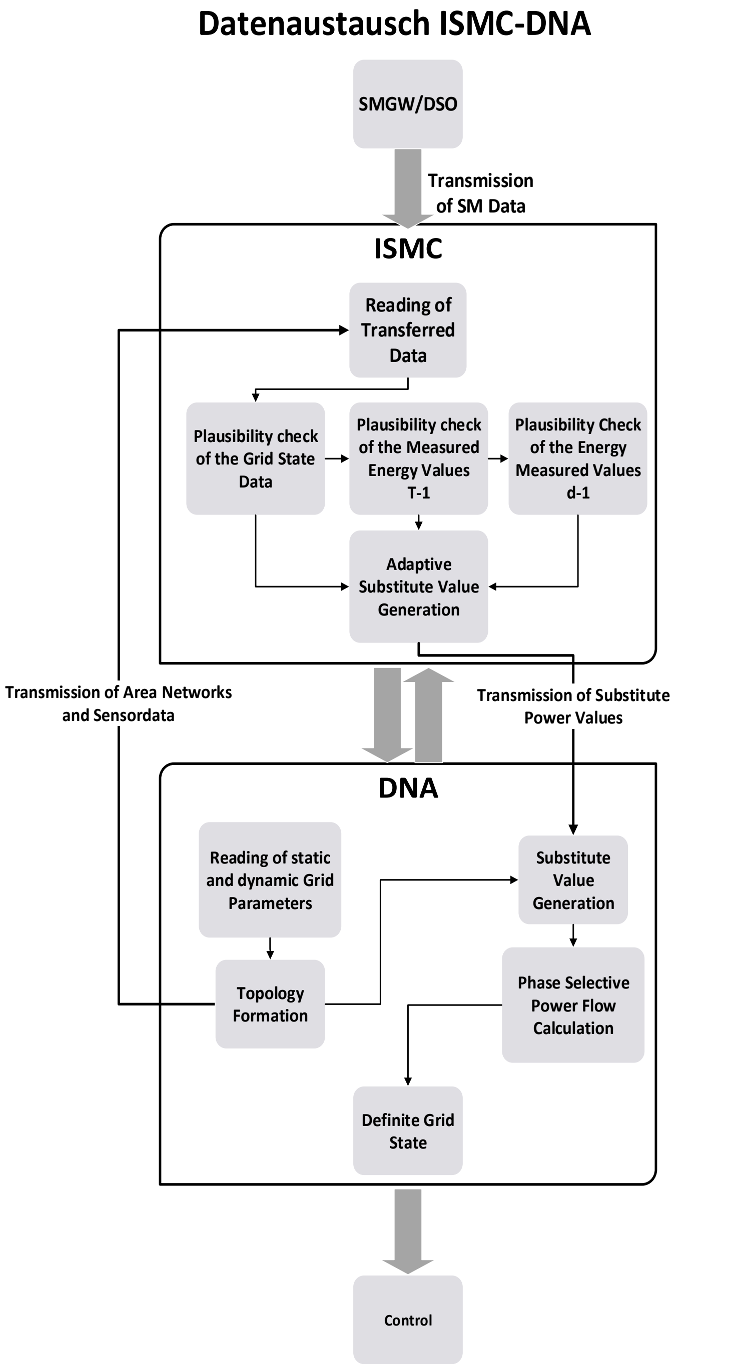

Figure 3: Data exchange between intelligent Smart Meter Converter and distribution grid automation system

assignment of the load nodes to these follow. The output parameters resulting from the processing of the network parameters are made available to the iSMC as input data.

The next step is the plausibility check of the input data including the prioritization of the input data depending on their added value. The calculation method resulting from the plausibility check and prioritization is then applied in the adaptive power distortion. The calculated replacement services of the load nodes are made available to the DNA and are used as new replacement services in the replacement value calculation for the phase-decoupled power flow calculation. The process is terminated with the output of a unique grid state and the resulting control interventions.

A. Business Management View

The use of the iSMC appears particularly attractive from a business perspective, since optimized grid condition estimations and the resulting more precise load flow control lead to cost reductions. The iSMC enables a DSO to derive added value from the aggregated smart meter data. The information contained in the data only has an added value for a DNA with a suitable preparation. In addition, a suitable process for data acquisition and preparation is necessary. Due to the high demands placed on DNA with regard to its availability and susceptibility to errors, this process must be avoided in the DNA itself. The iSMC as a supplementary module maps these processes in a compact and efficient form without having to adapt the existing DNA to the basic functions. It guarantees the reliability of the transmitted data in terms of quality, correctness and completeness and thus relieves the effort of a DSO when integrating smart meter data.

The added value of the iSMC therefore lies not only in the more precise grid state calculation, but also in the avoidance of high implementation costs on the part of a DSO. Thus, the integration of smart meters as innovative resources can be accelerated in comparison to the process of developing isolated solutions and enables a DSO to use the data to optimize the respective DNA at an early stage. In addition, further savings can be realized with the use of smart meters, because smart meters enable dynamic pricing that reduces peak demand and reduces the need for operating expensive peak power plants. The current value of savings on peak infrastructure could be up to 67 billion euros for the EU [13].

The simulation results from Figure 4.2 show a significant improvement compared to the calculation without additional Smart Meter measurement values from Figure 4.1. This applies especially to the case of measured grid state data (available results). A more precise determination of the grid condition confirms that grid conditions classified as critical and in need of control are actually within the respective tolerance range. Additional costs for these control interventions are thus eliminated.

The use of smart meter data also opens up the possibility of directly assigning grid states to specific nodes. With the

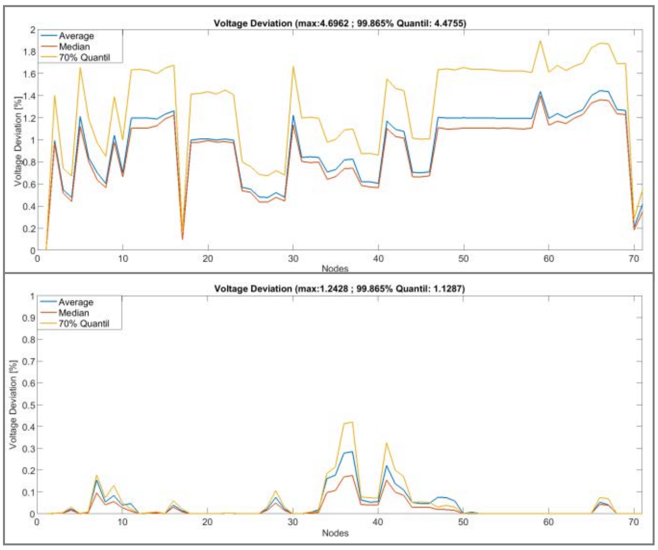

Figure 4: Relative voltage deviation (1) without smart meter grid state data (top) and (2) with smart meter grid state data (bottom)

help of this information, control interventions can be carried out in a targeted manner. Targeted controls make it possible to operate the distribution grid with a lower cable capacity. It is also possible to remunerate end customers for grid services. In the case of a critical grid condition, targeted control of renewable energy systems and innovative operating resources, such as storage, serves to maintain system stability and will in future be associated with monetary incentives, as end customers are more willing to control their current consumption situation if they participate in the avoided grid expansion and operating costs.

Furthermore, the efficient use of available renewable energy systems and controllable consumers holds a large long-term savings potential of gases harmful to the climate, since CO_2 neutral renewable energy systems can use their maximum feed-in potential in critical load situations thanks to the precise control of innovative resources at the distribution grid level. Since the feeds from renewable energy plants only have to be throttled in highly critical load situations, their share of total energy generation in Germany is increasing. As a result, conventional power plants with a poor climate balance have to generate less energy and thus lead to an overall better climate balance for German energy generation.

V. Conclusion and Outlook

On the basis of the results obtained, the present work allows conclusions to be drawn about the added value of intelligent measurement systems with regard to the integration of electromobility. The work makes it clear that grid transparency is increased with the help of smart meters and that the effects of electromobility can thus be anticipated more precisely, thus facilitating integration.

In addition, a concept for integrating smart meter data into any distribution grid automation system was presented. The concept of the intelligent Smart Meter Converter takes over the collection of different Smart Meter data and converts them into a DNA compatible format. The intelligent Smart Meter Converter is to be offered in the future as a supplementary Plug & Play module. This is connected upstream of a DNA in order to make the added value of existing Smart Meter data usable for distribution network operators.

The results of the present work demonstrate a considerable added value of smart meter data in the context of efficient control and utilization of the distribution grid. The possibility of active influence of the individual grid connection users increases with increasing Smart Meter equipment [7]. Information on the grid state of each load node in the monitored grid can, for example, be used in the future to establish high-resolution and demand-oriented demand side management [14]. The future rollout of smart meter technologies will create the basis for this. If smart meters are able to communicate via a smart meter gateway, they can be integrated into autonomous DNA within the framework of operating resources. As a prerequisite for this, the respective grid connection user must have controllable terminal devices, such as the charging station of an electric car, and have agreed to the control of this system via an appropriate control device. Legal framework conditions should create active incentives for this development, similar to the provision of control power in the area of the transmission network.

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SINTEG SMART ENERGY SHOWCASES

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References

[1] C. Oerter, N. Neusel-Lange, P. Sahm, M. Zdrallek, W. Friedrich and M. Stiegler, *Experience wirh first smart, autonomous LV-Grids in Germany,* Stockholm, Sweden: 22nd International Conference on Electricity Distribution, 10-13 June 2013.

[2] Kraftfahrt-Bundesamt, "Bestand an Kraftfahrzeugen nach Gemeinden," Berlin, Germany, 2019.

[3] German National Platform for Electric Mobility (NPE), "Progress Report 2018," Joint Office E-Mobility of the German Government, Berlin, Germany, 2018.

[4] chargeIT mobility GmbH, "chargeIT," [Online]. Available: https://www.chargeit-mobility.com/ueber-uns/referenzen-2/doernberg-quartier/. [Accessed 05 Mai 2019].

[5] German Bundestag, Metering Point Operating Act of 29 August 2016 (Federal Law Gazette I p. 2034), last amended by Article 15 of the Act of 22 December 2016 (Federal Law Gazette I p. 3106), Berlin, 2016.

[6] Federal Office for Information Security (BSI), *Act on the Federal Office for Information Technology 03109 - Version 1.0.1,* Bonn, Germany, 11.11.2015.

[7] S. Azad, E. Schnittmann, K. Korotkiewicz, M. Ludwig, M. Zdrallek, J. Zimpel, A. Schalk and N. Neusel-Lange, *Use of intelligent metering systems to optimize the network state estimation in the distribution network 4.0,* Esslingen, Germany: ETG - VDE, 2019.

[8] S. Azad, E. Schnittmann , M. Ludwig, J. Zimpel, B. Brandherm, M. Deru, N. Alassane, A. Schalk and N. Neusel-Lange, *Grid serving Deployment of Smart Meter Data in the Context of Distribution Grid Automation,* Bucharest, Romania, 2019.

[9] A. Faruqui, "The ethics of dynamic pricing," *The Electricity Journal,* pp. vol. 23, Issue 6, Pages 13–27, July 2010.

[10] C. Flath, D. Nicolay, T. Conte, C. van Dinther, L. Filipova-Neumann, *Cluster Analysis of Smart Metering Data,* Research Center for InformationTechnology, Karlsruhe, Germany: Gabler Verlag 2012, 01.12.2012.

[11] Federal Office for Information Security, *Protection Profile for the Gateway of a Smart Metering System (Smart Meter Gateway PP),* Berlin, Germany, 2014.

[12] A. Wei, Y. Chen and J. Wu, *Simulation Study of TCP/IP Communication Based on Networked Control Systems,* Dalian, China: Proceedings of the 6th World Congress on Intelligent Controland Automation, June 21 - 23, 2006.

[13] A. Faruqui, D. Harris and R. Hledik, *Unlocking the €53 Billion Savings from Smart Meters in the EU - How Increasing the Adoption of Dynamic Tariffs Could Make or Break the EU's Smart Grid Investment,* Energy Policy 38 (10), pages 6222–6231, December 2009.

[14] Guerreiro J., Ferreira L.M., Smart meter integration in an eleectric power system with large renewable energy resources, DSM and energy storage, Instituto Superior Téchnico.