SiNED-Ancillary Services for Reliable Power Grids in Times of Progressive German Energiewende and Digital Transformation

Jonas Wussow[1], Davood Babazadeh[6], Vanessa Beutel[3], Sebastian Buchholz[8], Stefan Geissendörfer[3], Jana Gerlach[4], Neelopal Majumdar[5], Karsten von Maydell[3], Anand Narayan[6], Melanie Hoffmann[1], Lily Kahl[1], Thomas Leveringhaus[5], Marc René Lotz[1], Alexandra Scheunert[8], Payam Teimourzadeh Baboli[6], Paul Hendrik Tiemann[2], Nils Huxoll[6], Oliver Werth[4], Carsten Agert[3], Michael H. Breitner[4], Bernd Engel[1], Lutz Hofmann[5], Martin Könemund[7], Michael Kurrat[1], Sebastian Lehnhoff[6], Astrid Nieße[2], Hartmut Weyer[8]

[1]Technische Universität Braunschweig, elenia Institute for High Voltage Technology and Power Systems, Braunschweig, all parties located Germany
[2]Carl von Ossietzky Universität Oldenburg, Department of Computing Science, Digitalized Energy Systems Group, Oldenburg
[3]German Aerospace Center, Institute of Networked Energy Systems, Oldenburg
[4]Leibniz Universität Hannover, Institute of Computer Science for Business Administration, Hannover
[5]Leibniz Universität Hannover, Institute of Electric Power Systems, Electric Power Engineering Section, Hannover
[6]OFFIS, Institute for Information Technology, Oldenburg
[7]Ostfalia - University of Applied Science, Institute of Electrical Systems and Automation Technology, Wolfenbüttel
[8]Technische Universität Clausthal, Institute of German and International Mining and Energy Law, Clausthal-Zellerfeld

Corresponding Author: Jonas Wussow, J.Wussow@TU-Braunschweig.de, (+49)531/391-7707

Abstract

Within SiNED research project, several members of the ***Energy Research Centre of Lower Saxony*** (Energieforschungszentrum Niedersachsen, EFZN) are working on various issues relating to the future provision of ancillary services and to future congestion management. The questions include energy technology, economic and energy law aspects as well as information and communications technology (ICT) and data. The investigations are based on Lower Saxony and the framework conditions there. The temporal focus of the investigations is the year 2030.

1 Introduction

In order to achieve climate targets, all sectors will switch to increased renewable share in the coming decades. For this reason, the electricity generation will increasingly be based on a large number of decentralized and fluctuating photovoltaic arrays and wind turbines. In conventional power systems, ancillary services (ASs) for the reliable operation of power grids were provided centrally by large-scale power plants. In the transformed system though, these ASs have to be provided by a plenty of decentralized energy resources (DERs), *i.e.* distributed generators (DGs), renewable energy resources, loads, storage units and electric vehicles, which are highly distributed in the distribution grids. Thus, the information, communication and energy flow with and inside the distribution grid will therefore increase. This increases the need of grid operation management for provision of ASs from DER. This also leads to increased requirements regarding resilience of the digital transformation of the energy system, as well as to new demands concerning the economic and legal framework conditions of future electricity supply systems.

The joint research project ***SiNED***, conducted by Energy Research Centre of Lower Saxony and consisting of nine reasearch areas (RA), is established in order to further develop the existing ancillary services to prepare for future power systems and to adapt these to new requirements and opportunities presented by digitalization and the progressing Energiewende. Solutions for a reliable future grid operation are developed and examined in an interdisciplinary way by several partners, which are all members of EFZN (see Figure 1).

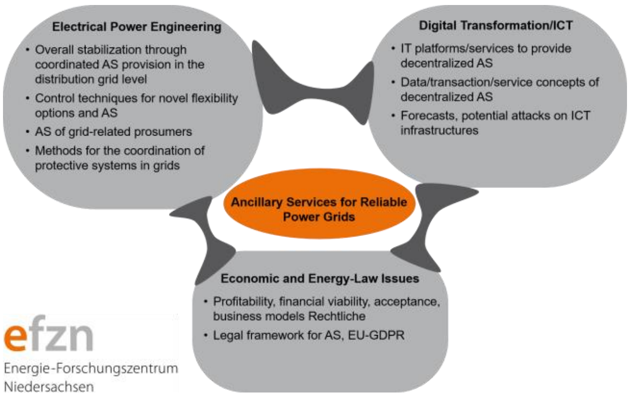

Figure 1 Project overview

ETG-Kongress 2021 . ISBN 978-3-8007-5549-3 . ©VDE VERLAG GMBH . Berlin . Offenbach

2 Electrical Power Engineering

The increasing integration of renewables, electromobility and inverter-based DG leads to a significant impact on the provision of AS, creating the demand for the adaption of components, structure, and operation of the existing power system. These challenges are addressed in four research areas, which are depicted in Figure 2.

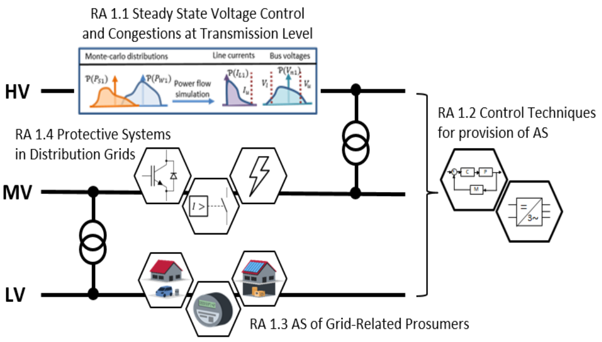

Figure 2 Research areas of the field of competence "Electrical Power Engineering"

The RA cover the impact of AS provision in all voltage levels and are interlinked.

2.1 Steady State Voltage Control and Congestions at Transmission Level

Increased penetration of renewables introduces intermittency of power flows and reduces reactive power reserves due to decommissioning of thermal power plants. Fluctuating power flows cause uncertainties in bus voltages and line currents leading to possible technical constraint violations (voltage limits and thermal line current limits). Therefore, it is necessary to consider varying renewable infeed scenarios apart from the base renewable power injection. Subsequently, an assessment of the steady state voltage violations and congestion problems in the transmission level is discussed in this section.
In this project, an integrated transmission-distribution grid model based on Lower Saxony is used, that contains power flow data in hourly resolutions (generation and load time-series) [1]. The power flow data is adapted to the corresponding average renewable penetration and the load increment for 2020 and 2030. The adapted power flow is considered as the mean operating point for generating monte-carlo based scenarios, to represent intermittency of renewable power infeed.
Monte-carlo scenarios introduce possible deviations from current operating point due to renewable uncertainties in power infeed. This requires corresponding adaptation of thermal power dispatch, achieved using an economic load dispatch algorithm. Subsequent power flow simulations are performed post-dispatch of thermal power plants to analyze steady state conditions e.g voltage limit breaches or congestions. Increased renewable generation requires decrease and, in some cases, shut down of thermal plants This reduces reactive power reserves that influences bus voltages. During high as well as low renewable infeed, varying power flows also affect the voltages and currents.
In order to supplement reactive power reserves, control bus voltages and congestion alleviation at transmission level, active and reactive power flexibilities at the distribution level require consideration. Statistical study of technical limit violations and investigations on distribution flexibilities require exploration in further works.

2.2 Control Techniques for Flexibility Options and Ancillary Services

With the decommissioning of conventional power plants, the task of grid stabilisation by providing AS will be transferred to the inverter-based DER in the future.
Therefore, it is necessary to determine the demand of fast activated ancillary services. The demand for ancillary services for frequency and voltage stability is investigated and determined, with a particular focus on the reactive power demands and control reserves such as frequency containment reserve (FCR), automatic frequency restoration reserve (aFRR) and manual frequency restoration reserve (mFRR). The demands are available as energy and power values specific to voltage levels for reference years 2015, 2018 and 2030 in Germany and Lower Saxony. It is also differentiated which power or energy share of the respective ancillary services would be requested by the individual DER technologies. Approaches for calculating the reactive power demand are defined and subject to implementation.
In order to realise and coordinate the provision of AS by means of inverter-based DER, an interface design and a secure ICT connection between control components and the inverter platform have to be conceived. Thus, it is necessary to analyse and to consider reaction and transmission times. The elaboration of a superordinate repository structure provides an user interface for the structured management of the developed control algorithms, setpoint specifications, scripts for ICT transfer and the associated grid environment.
In addition to setpoint specifications for the individual ancillary services and technologies, a master control system for the higher-level coordination between the inverter systems of the DERs has to be developed.
The implementation of the interface design, the response time determination as well as the development of the control techniques of fast activating AS are validated using a real-time system and a model inverter. The final evaluation is carried out in the grid laboratory.

2.3 Ancillary Services of Grid-Related Prosumers

Prosumers have controllable power sources based on inverter-controlled components (e.g. PV system, battery storage, heat pump, electric vehicle). This offers the prosumer the possibility to provide system services and actively contribute to the stabilization of the distribution grids.
The objective of the project is to estimate to which extent prosumers are able to reduce local voltage problems or the

asset utilization in the low-voltage grid and therefore to contribute to the global frequency stability.

Extensive preliminary investigations are used to define the optimal simulation periods and grid topologies to be further analyzed. These investigations also contain a detailed description of the building structure in Lower Saxony and a characterization of the commercial, trade and services sector. The behavior of different prosumer groups, penetration levels and potential dimensions of the prosumer components for different scenarios as well as realistic business strategies and the resulting potential for providing additional flexibility is analyzed.

The results of the preliminary investigations will be implemented in the institute's own simulation environment eSE to identify the potential of reactive power provision from prosumers and to compare different business concepts of the prosumers. In addition, the development and implementation of a coordinated active power management of the prosumers for providing further system services in eSE is required.

2.4 Coordination of Protective Systems in Distribution Grids

The currently integrated grid protection systems are facing multiple challenges due to the increasing integration of inverter-based DER.

To ensure a reliable, efficient and selective protection system for the future energy grid, a structured and holistic approach for the design of protection systems is performed via Model Based Systems Engineering (MBSE). It is based on the definition of the system environment, constraints, and requirements, on which the system development process is based. The system design activities are structured from a top-level concept, over a system design to a detailed component selection considering the pre-defined requirements in each step. The developed protection system is afterwards modeled, validated and adjusted.

To derive requirements for modern protection systems that meet the new challenges, a Medium Voltage (MV) reference distribution grid has been implemented, including protection and control systems, inverter dynamics, as well as different placement scenarios of DER infeed, where the focus lies on compliance to currently relevant standards and regulations.

Prior to the protection system development, the currently deployed MV grid protection systems and their environment have been reviewed, and challenges due to increasing DER integration were identified.

The defined requirements and the simulation environment, in combination with the MBSE methodology, allow a dedicated protection system design. Special attention is paid to the simulation of fault dynamics, which enables the simulation of interactions between protection systems and inverter-based DER, while also giving the opportunity of implementing a communication infrastructure and validating modern protection concepts.

3 Digital Transformation/ICT

This section includes three subsections; the first one is about the ICT infrastructure for provision of the AS in the smart grid, the second one is on concepts for distributed and self-organizing provision of AS, and the third is on forecast and attack possibilities on ICT structures.

3.1 Proposed ICT Infrastructure

The proposed ICT architecture for the flexible provision of ancillary services is shown in figure 3. It can monitor the data from DERs, detect anomalies in the system and provide secure data communication and storage using blockchain technology. Various modules of figure 3 are as follows:

Input Data: This module provides the required input data, including historical and real-time market data, electricity price, weather forecast, generation data, transmission congestions, and load point data.

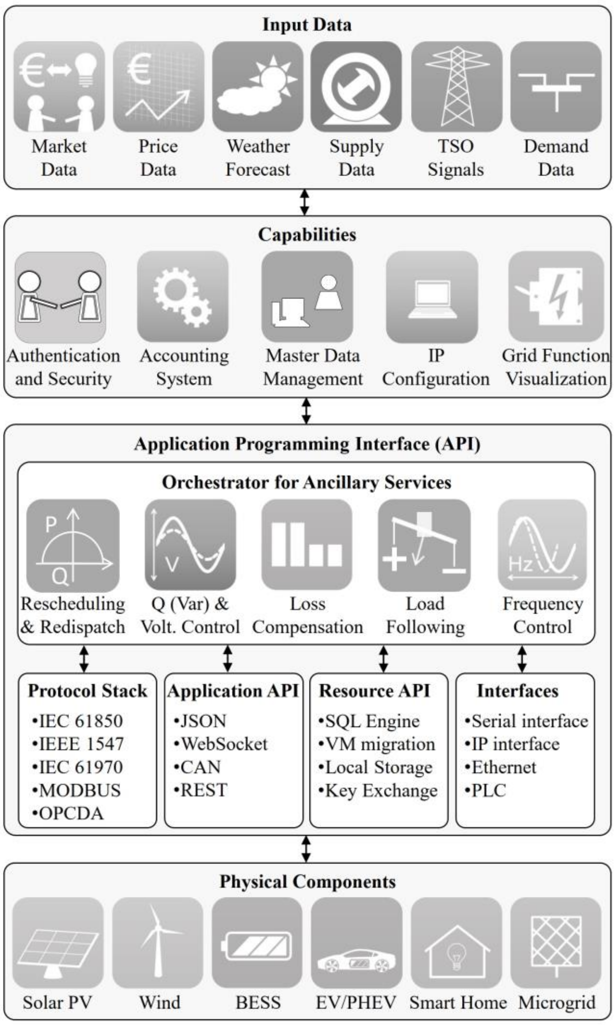

Figure 3 Proposed ICT architecture for provision of ancillary services by DER

Application Programming Interface (API): This is the heart of the proposed architecture. All components in the API are located in a virtual infrastructure (e.g. virtual machines). Based on the service requirements, resource allocation can be optimized. This serves multiple requests reducing the response time and free network resources by switching on/off virtual functions. The central component of the API is the Orchestrator, which has a two-way connection to all other modules in the API, and processes the received request to appropriate actions for optimal ancillary service assignment. It communicates with the physical components via the interfaces. To process the requests, it calls upon instances of Protocol Stack, Resource and Application APIs as well as the Interfaces.

3.2 Transaction and market concepts for autonomous system service provision

With a large number of participants in the power sector, coordination mechanisms over automation and digital technology become more important.

Therefore, the goal of this working package is to develop necessary steps towards a transformation of the energy system from a centralized-hierarchical to a distributed and self-organizing control paradigm. A prototype is set up to evaluate a distributed system service provision. Subsequently, a transaction system is developed to account provided ancillary services. Furthermore, it is planned to examine incentives given by the prototypic distributed system to its participants. Findings of the described steps can then support a development of an agent control room to monitor a self-organizing energy system.

Balancing reserve provision is chosen as use case. Today, balancing reserve is provided centrally with respect to the load frequency control (LFC) areas of the European transmission grid, which is a crucial and vulnerable point in the European electricity supply. Failures occur on a regular basis. Even in highly developed countries sometimes parts of the transmission grid fall black (e.g. [2]), although countermeasures are taken, which can prevent outages. At the same time, the risk of cyberattacks is considered to have grown. The application of a distributed and self-organizing control paradigm together with balancing reserve from DER is seen as a possible counter against these threats.

However, the focus on LFC areas and a minimum bid size on balancing reserve markets is identified as an important obstacle against procurement of balancing reserve from small DER. While the introduction of aggregators into European energy market systems is pursued (e.g. [3]), markets for system services, realized with distributed ledger (DL) technology, have been identified as a research gap. Additionally, in order to aggregate flexibility of DER, a market-based approach is identified, promising to design a system, which fulfills the following requirements: it is compatible with the current regulatory scheme of the European balancing reserve market, it is scalable and it nondiscriminatorily allows its participants to behave strategically independent and keep their privacy.

To develop a prototype of a balancing reserve market based on distributed ledger technology, market engineering approaches are examined. Mengelkamp et al. [4] developed a market engineering approach to set up a peer-to-peer energy market. [5] presents a regional flexibility market to ease (current and voltage induced) grid congestions. In [6] a comprehensive framework to design a national balancing reserve market is described. To the best of our knowledge, peer-to-peer balancing reserve markets have not been addressed in research yet.

Balancing reserve can be aggregated in a market-based way by negotiation or auction. Negotiations on a perturbation-preventing DL systems like blockchains are expected to be time consuming. Preliminary work to realize basic auctions with smart contracts on an Ethereum blockchain is published in [7], which inherently comes with a transaction system. Next, an analysis of game theoretical consequences of an aggregation auction is planned, which is supposed to be compatible with current balancing reserve markets in Europe through a hierarchical design. Afterwards, smart contract-based auctioning methods (see [7]) needs to be developed to perform a multi-object procurement/reverse auction for balancing reserve aggregation.

3.3 Forecasts and attack possibilities on ICT structures

Artificial intelligence (AI) is increasingly gaining prominence and importance in the energy sector, especially to improve resource allocation and self-sufficiency by forecasting electricity consumption and generation. In particular, start-ups, operating on the development of AI applications are joining the energy business. Furthermore, AI applications stretched over all value creation levels of energy and across the respective sectors of electricity, heat, and transportation [8]. Applications include decision support through forecasting and optimization, security and servicing using predictive maintenance, and the field of services in sales and commerce through individualized advertising and products, as well as automation of business processes [8]. In addition to the multiple economic, technological, and environmental possibilities, however, the political, social, and legal perspectives should be considered and constitute a need for research and action.

Possible research avenues include the exploration of trends, developments, and innovations for the next decade. Connecting and communicating with AI start-ups and corporations can generate important insights into future trends and economic, social, technical, environmental, and regulatory directions. However, prototypical tests and assessments of AI tools' applicability and efficiency have to be conducted.

Increasing digitalization and integrating ICT into the energy system are simultaneously resulting in rising opportunities for cyber-attacks, which presents a significant challenge for the security of power supply and quality. Cyber-attacks can be divided into vulnerabilities and threats. Vulnerabilities occur primarily concerning technical and human insufficiencies, such as the increased complexity of systems and applications, in addition to the lack of security awareness on the part of employees or users. Cyber threats are incorrect data injection and communication inefficiencies, resulting in wrong decision-making and harmful operations [9]. Successful cyber-attacks can have severe consequences on the confidentiality and integrity of data and the availability of services, thus, violating critical energy supply infrastructure [9]. Attack possibilities and their risks need to be evaluated in terms of economic costs and information management costs. Besides, measures to increase robustness and resilience must be developed and adapted to the future energy system's decentralized structure.

4 Field of studies in the area of energy law and economics

4.1 Economic and financial efficiency and acceptance

In this RA, economic and legal questions regarding changes in the provision of AS accompanying current developments in the energy sector are discussed.

Besides fluctuating renewable energy infeed, including wind power- and photovoltaic facilities, controllable renewable energy plants such as biogas plants present an essential element in the increasing decarbonized and decentralized energy system. The controllability of these plants enables a contribution to covering the residual load, providing AS in the form of balancing energy, thus contributing to grid stability and supply reliability [10]. In order to achieve controllability and demand-oriented electricity and heat production, biogas plants require flexibilization. This includes a more extensive gas storage, at least one additional combined heat and power plant, and optional heat storage [10]. By introducing schedule flexibility, biogas plants have several opportunities to participate in the electricity market in the form of intraday and day-ahead trading and the control energy market as well as the heat market through heat contracting with public, industrial or private properties [10].

Within the SiNED project, a further RA is the use of data regarding the state of the grid and personal data. Especially new actors entering the energy market need to process data and generally increasing amounts of (personal) data will be processed. Potential conflicts of acceptance arise from processing of personal data and new actors' participation in the electricity market [11]. Measured electricity consumption and generation data enable the creation of user-profiles and can violate residents' privacy [12]. Transmission of personal data and commercialization to third parties are approached with caution by consumers, as are potential corporate profit interests involving personalized advertising based on the data [13]. Furthermore, concerns about cyber-attacks, such as interception, manipulation of smart meters, and unauthorized access controls, may result in significant monetary and immaterial harm [14].

4.2 Legal boundary conditions of AS

Legal boundaries for data processing are set mainly in the German Messstellenbetriebsgesetz (MsbG) and – for personal data - the European GDPR. Further regulation especially regarding data processing through new market participants is found in the Directive on the Internal Market for Electricity (Directive 2019/944/EU). The scope of these regulations as well as their effects on each other are discussed within this RA. Part of this is the evaluation of how far national regulations may come into place besides the - generally conclusive - GDPR. This is of special interest considering that the German MsbG lays out a differentiated system for the processing of different kinds of data depending on their relevance to the state of the grid and their impact on privacy. Part of this differentiation is the - potentially conclusive - listing of agents permitted to process personal data collected from grid connection users, leaving out especially new market participants like aggregators. The SiNED project further analyzes how national regulations are influenced by the obligation to implement the Internal Market for Electricity Directive, which includes not only regulations on data management, but also on the legitimacy of data processing by market participants engaged in aggregation. Finally, the project covers the question whether new technologies fulfill the national and European regulations to ensure data security.

Next point of consideration is the regulatory framework for congestion management. The ongoing digitalization process increases the possibility of enabling the implementation of the demand side for the purpose of congestion management. The current congestion management relies on flexibility, which is mostly taken from the generation side. The demand side whatsoever can be accessed to solve network congestions when loads are activated “in front” of the bottleneck as an alternative to a curtailment of renewables. On the other hand, interruptible loads “behind” the bottleneck serve to fulfil the energetic balance.

In order to make the demand side more accessible for congestion management, the SiNED project aims to take a closer look at the technical specifics and the existing and upcoming regulations on EU and German national level with regard to demand side management.

A central focus has been put on switchable and interruptible loads for the purpose of congestion management. Furthermore, the existing German law and the upcoming changes introduced by the NABEG 2.0-package [15] which apply from October 1, 2021 as well as the current regulatory framework of the EU with the main focus on the “Clean Energy Package” is put together. Within the project of SiNED, a further focus of analyzing the regulatory framework is laid on the procurement of demand side flexibility. It is planned to examine the introduction of market-based approaches in the shape of regional flexibility markets, hybrid procurement approaches existing of a market-based approach with regard to the demand side and a non-market-based procurement of the production side, or procurement possibilities through new platform solutions. Further possible RA identified are the development of instruments which enable long-term accessibility rights for the network operator and demand flexibility installations owned by the network operators.

A final RA covers legal questions regarding the use of battery storage in multiple ways. This includes the storage of different types of power (i.e. for conventional power as well as renewable energies), for different purposes, such as the exclusively private use of stored power vs. the injection of power into the general network and finally the potential use of the stored power for the provision of AS.

5 Conclusion and Outlook

The focus of this project is the provision of ancillary services in 2030 based on the example of federal state of Lower Saxony in Germany. Due to the broadly-based project consortium, a large number of research questions can be covered, which can be divided into three areas of competence.

In the field of electrical power engineering, investigations are being carried out at different grid levels, considering the technical changes resulting from the energy transition. In addition, protection systems as a result of new requirements are addressed in this area.

The design of an ICT infrastructure for the provision of ancillary services and the possibility of attacking this infrastructure and forecasting are research topics in the area of digital transformation. In this area, concepts for a distributed and self-organized provision of system services are also being developed.

In the third area of competence, questions concerning economic efficiency and legal framework conditions in the context of a modified provision of ancillary services are dealt with.

In the next steps, a final scenario definition for Lower Saxony in 2030 will be carried out, on the basis of which the individual partners will carry out further investigations.

6 Acknowledgement

The research project 'SiNED – Systemdienstleistungen für sichere Stromnetze in Zeiten fortschreitender Energiewende und digitaler Transformation' acknowledges the support of the Lower Saxony Ministry of Science and Culture through the 'Niedersächsisches Vorab' grant programme (grant ZN3563) and of the Energy Research Centre of Lower Saxony.

7 Literature

[1] Sarstedt, M, Garske, S., Blaufuß, C.,Hofmann, L.:. Modelling of integrated transmission and distribution grids based on synthetic distribution grid models. In 2019 IEEE Milan PowerTech, pp. 1-6. IEEE, 2019.

[2] Xiang, M., Yu, D., Wang, W., Zuo, J., Shen, Y., Xie, X.: The Reason Analysis of Holland Blackout on March 27, 2015 and Lessons for Hunan Power Grid. Journal of Clean Energy Technologies, Vol. 6 (3), (2018)

[3] USEF Foundation: USEF: The Framework Explained. USEF, Arnhem (2015)

[4] Mengelkamp, E., Gärttner, J., Rock, K., Kessler, S., Orsini, L., Weinhardt, C.: Designing microgrid energy markets. A case study: The Brooklyn Microgrid. Applied Energy, 870–880 (2018)

[5] Heilmann, E., Klempp, N., Wetzel, H.: Market Design of Regional Flexibility Markets: A Classification Metric for Flexibility Products and its Application to German Prototypical Flexibility Markets (2020)

[6] Van der Veen, R.: Designing Multinational Electricity Balancing Markets, Delft University of Technology. Next Generation Infrastructures Foundation. PhD thesis. (2012)

[7] Braghin, C., Cimato, S., Damiani, E., Baronchelli, M.: Designing Smart-Contract Based Auctions. Advances in Intelligent Systems and Computing, 895, 54-64. (2020)

[8] German Energy Agency (dena): Artificial Intelligence for the Integrated Energy Transition, online available https://www.dena.de/fileadmin/dena/Publikationen/PDFs/2019/dena-REPORT_Artificial_Intelligence_for_the_Integrated_Energy_Transition.pdf, 2019

[9] Sundararajan, A., A. Chavan, D. Saleem and A. Sarwat: A Survey of Protocol-Level Challenges and Solutions for Distributed Energy Resource Cyber-Physical Security, Energies 11 (9), 2360, 2018

[10] Bost M., Aretz A., Hirschl, B.: Flexible Bioenergienutzung als Schlüsselelement zur Integration der Erneuerbaren Energien in das Energiesystem.uwf 22, 71–78, 2014

[11] Vitunskaite, M., He, Y., Brandstetter, T., Janicke, H.: Smart cities and cyber security: Are we there yet? A comparative study on the role of standards, third party risk management and security ownership. In: Computers & Security 83, 313–331, 2019

[12] Le Ray, G., Pinson, P.: The ethical smart grid: Enabling a fruitful and long-lasting relationship between utilities and customers. In: Energy Policy 140, 2020

[13] Huang, Z., Palvia, P.: Consumers' Privacy Concerns about Smart Meters, Twentysecond Americas Conference on Information Systems (1), 1–10, 2016

[14] Barbosa, P., Brito, A., Almeida, H.: Privacy by Evidence: A Methodology to develop privacy-friendly software applications. In: Information Sciences 527, 294–310, 2020

[15] Gesetz zur Beschleunigung des Energieleitungsausbau, BGBl. Jahrgang 2019 Teil I Nr. 19, 706.