Guest Editorial: Smart Meters in the Smart Grid of the Future

I. Introduction

While the past 50 years have been dominated by the so-called communication revolution, today, we are at the dawn of the energy revolution. The entire economy is energy driven, being electricity its most important energy vector. By the end of 2040, electricity is expected to contribute up to 40% of the increase in final energy consumption, and concepts, such as smart grid or internet of energy, are now commonplaces in our lexicon. The Paris UN climate change conference agreement has imposed three major changes into the electrical grid paradigm: the need to reduce carbon emissions; the need to decentralize electrical energy production, and the need to increase transport electrification.

To overcome these challenges, the smart grid concept has been used in order to achieve a smarter electrical distribution infrastructure. One of the first smart grid definitions can be found in the Energy Independence and Security Act of 2007 approved by the U.S. Congress in January 2007, and advance metering infrastructure emerges as one of the smart grids key elements, which incorporates software and hardware components, distributed energy resources (DER), monitoring systems, data management, and smart meters (SMs). SMs will play a fundamental role within smart grids and their rollout is already an unstoppable process. The USA reported around 37 million SMs deployed between 2011 and 2014. By the end of 2018, almost 100 million SMs were installed in Europe. In addition to their basic metering function, SMs will allow the deployment of advanced functions aiming grid support, easier commercial relations, improved security and privacy, as well as better integration of renewable generation. SMs are a typical case of a win–win situation, with mutual benefits for service providers and end users. SMs can provide quasi-real-time data, dynamic tariffs, and remote monitoring, thus deferring grid investments and optimizing current grid resources. SMs help end users developing higher energy awareness, obtaining improved billing information, and enhanced the quality of service, thus potentiating energy rational usage and consumption habits adjustment.

II. Overview of the Accepted Articles

In this context, the special section on "Smart Meters in the Smart Grid of the Future" of the IEEE Transactions on Industrial Informatics covers a number of new aspects related to the role of SMs, targeting the impact of SMs, success SMs case studies, unbundled smart meters' (USMs) developments, and new functionalities for SMs.

Seven high-quality contributions to this special section have been selected for publication in the IEEE Transactions on Industrial Informatics in a strict peer-review process supported by reputed international experts. These contributions address a wide range of SM topics ranging from the use of SM data to the development of innovative algorithms.

Using SM measurements as inputs, the article, *A fair incentive scheme for the participation of smart inverters in voltage control* by Dewangan *et al.* [item 1) in the Appendix], congregates SM data with smart inverters and incentive schemes. They propose a fair incentive scheme either for utilities and renewable energy producers or for active power curtailment.

The article, *Unbundling smart meter services through spatiotemporal decomposition agents in DER-rich environment* by Qin *et al.* [item 2) in the Appendix], makes explicit use of unbundle SMs and presents the benefits of extracting relevant technological information from unbundle SMs. The USM concept, based on commercially existing SMs, enabling end users to directly access its data and services, is able to promote the development of third-party added value services, leading to deployment cost reductions and real-time support. They propose a new agent, to be uploaded into the SM extension of the USM, to decompose SM data through estimation and forecasting the behind-the-meter (BTM) DER power output. Without any extra devices, this allows utilities to aggregate these data and have a better knowledge of BTM PV production, and provides end users with better knowledge about their renewable contribution.

The article, *Smart meters enabling voltage monitoring and control functionalities: The last-mile voltage stability issue* by Duan *et al.* [item 3) in the Appendix], exploits the monitoring and control capabilities of SMs to mitigate voltage stability issues at end-user sides. A new voltage stability control scheme is proposed, applying the voltage stability margin as the control objective.

The article, *Smart meter based two-layer distribution system state estimation in unbalanced MV/LV networks* by Khan and Hayes [item 4) in the Appendix], addresses a very important issue in distribution systems state estimation. By using a limited number of SM measurements, a detailed framework is developed in order to increase the state estimation accuracy and reduce the need for medium voltage level monitoring.

Making use of SM data, the article, *A Fourier-based phasor estimator with a modified MAF and its application in distribution*

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networks by Ibarra *et al.* [item 5) in the Appendix], presents a new estimator method for grid monitoring and fault location. The new Fourier-based filter has better dynamic performance and overshoot than the conventional techniques, with no increased complexity, thus proving to be a good option to be deployed under the SM context.

The article, *Preserving privacy of smart meter data in a smart grid environment* by Gough *et al.* [item 6) in the Appendix], addresses SM end-user privacy issues. A novel differential privacy-compliant algorithm is presented, being able of protecting consumers' data privacy and, at the same time, keeping the impact over the power system at a manageable level. The presented algorithm is scalable and computationally efficient, allowing the aggregation of SM data without significant impacts.

The article, *A container-driven service architecture to minimize the upgrading requirements of user-side smart meters in distribution grids* by Liu *et al.* [item 7) in the Appendix], tackles two important issues when addressing smart metering rollout: communication and upgrading. A container-driven service architecture was developed in which containers are used to create a virtual dedicated agent (digital twin) for each user-side SM. The developed agent was deployed in the cloud and on an edge system, satisfying the time requirements of smart grid applications related to user-side SMs.

This special section gathered articles covering important aspects of SMs and SM data usage. Being essential assets of the smart grid of the future SMs usage is of utmost importance. Important issues were covered, such as the use of unbundle SMs, for smart functionalities deployment and the usage of SM data for the establishment of novel functionalities (technical, economical, and privacy) benefiting both utilities and end users. It is important to notice that this special section covers a subset of the many ongoing activities related with smart metering. The Guest Editors believe that this special section can also act as a stimulus for enhancing the ongoing research and pave the way for new areas of discussion.

As a final remark, the Guest Editors wish all readers a pleasant reading of this special section's contributions.

Acknowledgment

The Guest Editors would like to thank all authors of the submitted papers, the reviewers for their support and constructive comments, and to the IEEE Transactions on Industrial Informatics Editorial Board for their great support and patience as well as for accepting this special section; especially to the Editor-in-Chief Prof. R. C. Luo, the Administrator of the Journal Ms. L. Jess, as well as the Editor-in-Chief's Secretary Ms. L. Lee, for their excellent support during all the phases leading to the present publication. The Guest Editors would like to apologize to those authors whose excellent papers were not included due to limited space and the competitive selection process.

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Appendix
Related Work

1) C. L. Dewangan, S. Chakrabarti, S. N. Singh, and M. Sharma, "A fair incentive scheme for participation of smart inverters in voltage control," *IEEE Trans. Ind. Informat.*, to be published, doi: 10.1109/TII.2021.3053757.
2) C. Qin, A. Srivastava, and K. Davies, "Unbundling smart meter services through spatio-temporal decomposition agents in DER-rich environment," *IEEE Trans. Ind. Informat.*, to be published, doi: 10.1109/TII.2021.3060870.
3) N. Duan, C. Huang, C.-C. Sun, and L. Min, "Smart meters enabling voltage monitoring and control functionalities: The last-mile voltage stability issue," *IEEE Trans. Ind. Informat.*, to be published, doi: 10.1109/TII.2021.3062628.
4) M. A. Khan and B. Hayes, "Smart meter based two-layer distribution system state estimation in unbalanced MV/LV networks," *IEEE Trans. Ind. Informat.*, to be published, doi: 10.1109/TII.2021.3079267.
5) L. Ibarra, D. Guillen, J. Aviles, P. Ponce, and A. Molina, "A fourier-based phasor estimator with a modified MAF and its application in distribution networks," *IEEE Trans. Ind. Informat.*, to be published, doi: 10.1109/TII.2021.3061133.
6) M. Gough, S. Santos, T. Alskaif, M. Javadi, R. Castro, and J. P. S. Catalao, "Preserving privacy of smart meter data in a smart grid environment," *IEEE Trans. Ind. Informat.*, to be published, doi: 10.1109/TII.2021.3074915.
7) L. Liu, Y. M. Ding, X. H. Li, H. Wu, and L. Xing, "A container-driven service architecture to minimize the upgrading requirements of user-side smart meters in distribution grids," *IEEE Trans. Ind. Informat.*, to be published, doi: 10.1109/TII.2021.3088135.

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