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Guest Editorial: Introduction to Special Section on Big Data Computing for the Smart Grid

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With the increasing deployment of new monitoring devices and advanced measurement infrastructures, such as phasor measurement units (PMUs) and smart meters, the smart grid is collecting large amounts of energy-related data at an unprecedented granularity, speed, and complexity. The smart grid has become data-driven, which calls for intelligent big data computing methods and solutions (such as predictive data mining, robust data analytics, artificial intelligence, distributed and high performance computing, efficient data management, database and data warehousing, and cloud computing techniques). With the growing volume, speed, and types of big data from the energy industry, data-intensive computing is imperative to guarantee critical functionalities in the smart grid, such as real-time wide-area situational awareness, dynamic energy management, demand response, vehicle-to-grid technology, load prediction, and renewable production forecasting.

The focus of this special section is on the improvement of smart grid operations and applications with emphasis on big data computing, aiming to solicit and publish original research papers on the technologies, algorithms, and methodologies that highlight emerging computation technologies for smart grid big data. This special section received 13 submissions, and five papers were ultimately accepted for publication.

The first paper is by W. Hou *et al.* titled "*Temporal, Functional and Spatial Big Data Computing Framework for Large-Scale Smart Grid*." The future large-scale smart grid will run over the Internet of energy where the dataset will be sent to a specific destination along power routers hop-by-hop. The traditional approach of data extraction improves the computing efficiency in temporal dimension, but it is made for only one task in the smart grid. Moreover, the existing solutions neglect the geographical distribution of computing capacity in a large-scale smart grid. To address these issues, in the functional dimension, the authors divide every dataset into sub-groups, each of which has data items shared by different tasks. In the spatial dimension, they determine which location the power router should be placed to harvest computing resources used for extracting the sub-group of data items. Their method achieves a promising computing efficiency approaching to the optimal solution with 95 percent convergence ratio, and it saves the in-path bandwidth with 81 percent improvement ratio over benchmarks.

The second paper is by W.-T. Li *et al.* titled "*Data Driven Electricity Management for Residential Air Conditioning Systems: An Experimental Approach*." Effective control of air conditioning systems (ACs) has the potential of significant electricity savings and demand response for the entire smart grid. The authors in this paper demonstrate some key experimental results on controlling the electricity consumption of ACs. In particular, the degree to which energy can be throttled for energy management purposes without affecting end-user comfort level is described. The testbed is set up in a residential building, in which the set point temperature of ACs installed within each apartment unit is controllable from a remote server. The main objectives are to reduce the consumption of electricity by the compressors, and to investigate the feasibility of having residential ACs as interruptible loads to participate in the electricity market. The algorithm used for controlling is explained in detail, and the end-user experiences during the experiments are briefly discussed. Extensive data collected throughout the experiment are provided to show the effectiveness of having ACs as flexible loads in reducing the power consumption by the compressors as well as the potential of offering ACs as interruptible load into the market without compromising user comfort.

The third paper is by S. J. Matthews and A. St. Leger titled "*Leveraging MapReduce and Synchrophasors for Real-Time Anomaly Detection in the Smart Grid*." The rapid detection of anomalous behavior in SCADA systems of the smart grid is critical for system resiliency and operator response in cases of power fluctuations due to hazardous weather conditions or other events. The rapid deployment of PMUs enable improved real-time situational awareness to grid operators through wide area measurement systems. Efficient algorithms for processing large-scale PMU data and notifying operators of anomalies is critical for real-time system monitoring. To this end, the authors in this paper propose a novel, two-step anomaly detection approach that processes raw PMU data using the MapReduce paradigm. The authors implement their approach on a multi-core system to process a dataset derived from real PMUs containing 4,500 PMUs ($\sim$18 million measurements). Their experimental results indicate that the proposed approach detects constraint and temporal anomalies in under three seconds on 8 cores. Their work demonstrates the applicability of

MapReduce for designing anomaly detection algorithms for the smart grid, and motivates the creation of novel MapReduce approaches for other SCADA applications.

The fourth paper is by S. Singh and A. Yassine titled "*Mining Energy Consumption Behavior Patterns for Households in Smart Grid*." Household energy consumption patterns, which provide great insight into consumers energy consumption behavioral traits, can be learned by understanding user activities along with appliances used and their time of use. Such information can be retrieved from the context-rich smart meters big data. However, the main challenge is how to extract complex interdependencies among multiple appliances operating concurrently, and identify appliances responsible for major energy consumption. Furthermore, due to the continuous generation of energy consumption data, over a period of time, appliance associations can change, and therefore they need to be captured regularly and continuously. To overcome these challenges, the authors in this paper propose an unsupervised progressive incremental data mining mechanism applied to smart meters energy consumption data through frequent pattern mining. This can establish a foundation for efficient energy management while ameliorating end-user participation. The details and evaluation results of the proposed mechanism using real smart meters dataset are also presented in this paper.

The last paper is by H. Guo *et al.* titled "*Big Data Acquisition under Failures in FiWi Enhanced Smart Grid*." In order to fulfill diverse communication requirements of various energy-related data in the smart grid, it is obviously impractical to rely on a single communication technology, and a hybrid communication architecture of low-latency fiber optic and cost-effective wireless technologies could be a promising solution. Note that low-latency data acquisition under failures is of particular importance to the smart grid reliability, considering that the smart grid is vulnerable to various failures. Therefore, the authors in this paper provide a hybrid smart grid communication architecture integrating fiber optic and WiFi-based mesh networks, i.e., the fiber-wireless (FiWi) enhanced smart grid, and study the problem of data acquisition under failures in the FiWi enhanced smart grid. The problem is first formulated as a constrained optimization problem, and then three algorithms are proposed as the solutions, i.e., an optimal enumeration routing algorithm (OERA), a greedy approximation routing algorithm (GARA), and a heuristic greedy routing algorithm (HGRA). Numerical results reveal that both GARA and HGRA can achieve near-optimal solutions to the problem of data acquisition under failures, and have higher computational efficiency compared to the benchmark, i.e., OERA.

In closing, we are aware of the fact that the five papers selected for this special section represent just a small fraction of the huge amount of work that is being carried out in the field of big data computing for the smart grid. We wish to thank both authors and reviewers for their great contribution to this special section. We are also grateful to Paolo Montuschi, Editor-in-Chief of *IEEE Transactions on Emerging Topics in Computing*, for his keen support to this special section.

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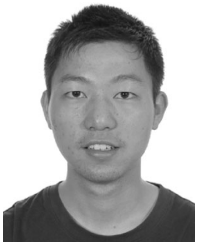
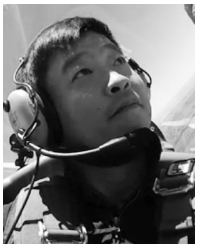


RUILONG DENG (S'11-M'14) received the BSc and PhD degrees in control science and engineering from Zhejiang University, Hangzhou, Zhejiang, China, in 2009 and 2014, respectively. He was a research fellow with Nanyang Technological University, Singapore, from 2014 to 2015; and an AITF postdoctoral fellow with the University of Alberta, Edmonton, AB, Canada, from 2015 to 2018. Currently, he is an assistant professor with the School of Computer Science and Engineering, Nanyang Technological University, Singapore. His research interests include smart grid, cyber security, and wireless networking. He serves/served as an editor for IEEE Access and Journal of Communications and Networks, and a guest editor for the *IEEE Transactions on Emerging Topics in Computing* and IET Cyber-Physical Systems: Theory & Applications. He also serves/served as a Symposium chair for IEEE SmartGridComm'19 and a Publication chair for IEEE VTS APWCS'19. He is a member of the IEEE.



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