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Editorial: Advanced data-driven methods and applications for smart power and energy systems

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Editorial on the Research Topic
Advanced data-driven methods and applications for smart power and energy systems

Introduction

With the rapid development of renewable wind and solar energy, energy storage, and energy markets, as well as with the integration of advanced measurement, communication and control technologies in modern power and energy systems, a large amount of data can be collected from the generation side, the grid side and also the demand side, which provides great inspiration for a sustainable and green future. Chu and Majumdar, (2012) provided a snapshot of the current energy landscape and discussed several research and development opportunities and pathways that could lead to a prosperous, sustainable and secure energy future for the world. Gijzen, (2013) advocated more "big data" at the United Nations General Assembly in New York to help secure a sustainable future. Kusiak, (2016) developed a data-and-knowledge sharing platform for renewable energy, which allows wind farms to be optimized through data mining. However, how to effectively utilize the big data of various entities to ensure energy adequacy, energy efficiency and energy security remains a great challenge in the field of power and energy system research.

The implementation of various advanced machine learning and artificial intelligence technologies is essential to solving the planning, operation and control problems in the whole process of energy supply and demand. Data-driven techniques have been successfully developed and widely used to address the classification, regression and clustering issues in the power and energy area. Such problems are often complex and difficult to solve with traditional model-based techniques, therefore, the advanced big data, machine learning and artificial intelligence techniques are required.

This Research Topic aims to provide a platform to promote state-of-the-art research methods and results in data-driven methods and applications for smart power and energy systems, such as: Modelling and Control, Energy Forecasting, Energy Efficiency, Fault Detection, Stability Assessment, etc. It is hoped that these articles can provide valuable references for academic researchers and power industry engineers in related fields.

Modelling and control

As more and more distributed renewable energy resources being integrated into modern power and energy systems, it is important to accurately model the electromagnetic and electromechanic transient process of the entire system, so as to better understand the fluctuation characteris of the renewables and conduct appropriate controls. In this sector, four papers dedicate to improving the modeling and control issues of the multiphase converters, renewable energy uncertainties, inverter controls and adaptive maximum power tracking, etc. And high-accuracy modelling and efficient control methods can generate more operation data for subsequent forecasting and analysis, and also ensure a more reliable and secure operation of power energy systems.

Hao et al. proposed an efficient real-time simulation modeling method of multiphase converters based on high-order approximation in a micro-grid scale, in which simulation data were used to test the efficiency and accuracy of the model; it turns out that the proposed model outperforms the traditional multiphase frequency converter models. Zhou et al. developed a model-data hybrid-driven modeling approach based on Digit Twin technology, the hybrid-driven model can accurately describe the unmodeled and uncertain dynamic characteristics of the AC/DC power system with high-penetration of renewable energy. Huang et al. of National Chin-Yi University of Technology, presented an online control of smart inverter for photovoltaic power generation systems in a smart grid, they have demonstrated that the dynamic response and steady-state performance of photovoltaic power generation systems were better than the traditional perturb and observed (P&O) method. Yin et al. provided a nonlinear control method of photovoltaic power generation LVRT based on adaptive maximum power tracking, and this method can quickly and effectively control the power output of photovoltaic (PV) cells by providing appropriate reactive power support.

Energy forecasting

Energy forecasting is a generally accepted area for data-driven applications. In this sector, 4 novel renewable energy and load forecasting approaches are proposed, including PV forecasting, wind speed forecasting, multi-energy load forecasting, and data-driven demand response profiling. Accurate prediction of renewable energy and load curves can provide better information for subsequent energy opmizations so as to improve the energy utilization efficiency.

Liang and Bai presented a data-driven ultra short-term PV forecasting method with sky images, in which the complete dataset was extracted from sky images, historical data, and hardware systems; and a Bi-LSTM neural network was contructed to predict the output power of PV systems with different feature data extracted. Sun et al. developed an interval prediction method for wind speed based on ARQEA optimized by Beta distribution and SWLSTM; the interval prediction was crucial for the economic and secure operation of wind farms, which provides a robust perspective for energy optimization rather than the common-used point prediction of wind speed. Yao et al. proposed a novel data-driven multi-energy load forecasting model in integrated energy systems, using a uniform manifold approximation and projection method for feature data extraction and a combined TCN-NBeats model for high-accuracy joint prediction of multi-energy loads. Chen et al. proposed a multi-dimension refined profiling method for demand-response adjustment capabilities, based on the load characteristic data analysis and social-survey-driven user's subjective consciousness data mining.

Energy efficiency

Intelligent energy management frames and methods can help improve energy efficiency, reduce energy consumption and save energy. In this sector, eight contributors provide insightful thoughts for different aspects, such as: energy system economic dispatch, transmission loss monitoring, transmission limit optimization, distribution system monitoring, etc.

Firstly, four papers are focused on the energy system economic dispatch issues. Wang et al. proposed an optimal dispatching model for regional power-heat-gas interconnection based on multi-type load adjustability, according to the predicted daily load curve and the output forecast of wind turbine and PV units. Ma et al. also proposed a dispatch method for energy efficiency improvement of an integrated energy system, which considered multiple types of low carbon factors and demand response data. Wang et al. presented a configuration-dispatch dual-layer optimization model for multi-microgrid-integrated energy systems, which took into account the energy storage and the demand response data. Cheng et al. developed a power balance partition control method based on topology characteristics of multi-source energy storage nodes, using both standard and real-world test systems.

In addition, Ding et al. proposed a loss prediction of ultra-high voltage transmission lines based on EEMD–LSTM–SVR algorithm, with the active power, reactive power, line current and voltage, and regional meteorological data as the inputs. Ma et al. performed a data-driven optimization and calculation method of the transmission section limits and their adaptability for power systems with high penetration of renewable energy; in which, a data-driven typical demand mode extraction method based on K-means clustering was proposed according to the load forecast, renewable energy forecast and market transaction data. Yuan et al. studied a multi-source data processing and fusion method for power distribution systems with the internet of things technology based on edge intelligence, to solve the problems of confusing storage and insufficient fusion computing performance of multi-source heterogeneous distribution data. Liang et al. proposed a μPMU configuration optimization method considering multiple operation modes of distribution network, which solves the problem of existing measurement devices that cannot cover the needs of distribution network condition assessment.

Fault detection

Besides of the energy forecasting and energy optimization, power and energy systems often face a variety of faults or disturbances. Fast and accurate fault detection is an easy and effective way to isolate the faulted components or areas to reduce the impact of the faults. In this sector, six contributors provide different data-driven approaches for the power system fault detections, including transmission line defect detection, insulator string defect detection, and distribution network fault identification, etc.

Firstly, two papers focus on the system level. Netsanet et al. proposed a cognitive edge computing-based fault detection and location strategy for active distribution networks, in which the fault detection, location, and isolation were accomplished through a combination of virtual mode decomposition (VMD), support vector machine (SVM), and long short-term memory (LSTM)-type deep machine learning algorithms. Zhang et al. in Technical University of Berlin, studied the permanent fault identification for distribution network based on characteristic frequency signal injection, which was also within the distribution system level.

Another four papers specially focus on the transmission line and insulator string defect detections, which are essential power system equipments. Li et al. proposed a pin bolt state identification using the unmanned aerial vehicle (UAV)-based transmission line photos, and the performances of multiple state-of-the-art object detect methods were compared in the context of UAV inspection photos. Yin et al. also investigated a classification model of point cloud along the transmission line based on group normalization, the model was verified to have a smaller model size and faster identification time without losing much accuracy. Xu et al. presented an end-to-end insulator string defect detection in a complex background based on a deep learning model, the authors introduced a transformer structure in the insulator defect detection area, and the final results shown that the self-attention mechanism and encoder–decoder structure had great potential in computer vision tasks. Ding et al. proposed a high accuracy real-time insulator string defect detection method; they used YOLOv5 as the backbone model, and developed a series of advanced techniques to improve the performance, including EIoU, AFK-MC2, and Cluster-NMS.

Stability assessment

It has been widely recognized that power system transient stability assessment can be modelled as a typical binary classification problem, using most of the popular data-driven machine learning algorithms. Fast and accurate transient stability assessment can save time for the subsequent stability control measures, so that the system can recover from severe faults and disturbances. In this sector, four oustanding papers propose different data-driven approaches for the power system transient stability assessment issues; and the other four papers mainly study the system security, electromechanical oscillation, voltage stability, and commutation failures.

For the transient stability assessment issues, Lin et al. built a new data-driven transient stability assessment model based on fault severity assignment; firstly, an improved cost-sensitive coefficient assignment method was proposed based on fault severity; then, the fault severity of each unstable sample was calculated accordingly; finally the correction coefficient of the loss function for the data-driven machine learning models of the unstable sample can be linearized with different fault severities. Zheng et al. investigated the significance of samples in deep learning-based transient stability assessment, they combined the stability scores with the significance index to provide an auxiliary criterion for the degree of stability. Wang et al. proposed a sparse dictionary learning model for transient stability assessment, in which the stable and unstable dictionaries were developed based on the K-SVD approach. Liu et al. presented a time-adaptive transient stability assessment based on the gating spatiotemporal graph neural network and gated recurrent unit, and an improved weighted cross entropy loss function with the K-nearest neighbor (KNN) idea was used to deal with the unbalanced training samples.

Yuan et al. proposed a quantitative method for security situation of the power information network based on the evolutionary neural network, and network vulnerability, network reliability and network threat indicators were constructed accordingly. Cai et al. proposed a data-driven electromechanical oscillation mode parameter identification model, through a quasi-real-time method based on randomized-DMD-multilayer artificial neural networks. Zhu et al. proposed a data-driven short-term voltage stability assessment model, in which a cascaded LightGBM model was constructed to mine STVS informatization, and focal loss (FL) was embedded into both offline and online phases of the model to mitigate the loss of accuracy caused by sample imbalance and overlapping. Wang et al. proposed a spatio-temporal convolutional network based identification of voltage-coupling commutation failures in multi-infeed HVDC systems; and they extracted the crucial factors that lead to the cascading relationship of multiple HVDCs, by classifying them into time and space signals, and then used the data generated in case of faults with diverse severity to train a STCN machine learning model.

Perspectives

In conclusion, this Research Topic provides multidisciplinary data-driven studies in the field of power and energy systems, focusing on relevant data-driven modelling and control, energy forecasting, energy optimization, fault detection and stability assessment issues. Data-driven machine learning technology has become a necessity to supplement the disadvanges of traditional model-based approaches in the power and energy system area. Nevertheless, there are still challenges in data cleaning, feature engineering, hyperparameter optimization, and model generalization, etc. Hopefully, the model-data dual-driven techinique will bring us to a more sustainable and green energy future.

Author contributions

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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