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GUEST EDITORIAL

Guest Editorial: Situational awareness of integrated energy systems

1 | INTRODUCTION

The increasing necessity of tearing down the barriers between different energy-related disciplines and developing effective means to coordinate and integrate various energy systems has given rise to the concept of integrated energy system (IES), which have received great attention from multiple technical communities in recent years. While electricity, gas, heat/cooling, water, energy storage, communication, and transportation systems all have respective legacy monitoring and control paradigms, they have not been coordinated or unified to provide global situational awareness of IES. Several fundamental challenges are present in this area, including various forms of legacy mathematical models, different time scales of subsystem dynamics, asynchronised measurement streams with different sampling rates and accuracy classes, large volume and heterogeneity of data assets, limited information exchange between different subsystem operators, cross-domain cyber security, and information privacy etc.

This special issue aims to explore concepts, methodologies, technologies, and implementation experience for the situational awareness of IES. There are in total eleven papers accepted for publication in this special issue through careful peer reviews and revisions. The selected papers are broadly categorised into five topics. The summary of every topic is given below. However, it is strongly encouraged to read the full paper if interested.

2 | TOPIC A: MULTI-ENERGY FLOW ANALYSIS FOR IES

Zheng, et al., in their paper "A Variant of Newton–Raphson Method with Third-Order Convergence for Energy Flow Calculation of the Integrated Electric Power and Natural Gas System" propose a variant of Newton–Raphson method with third-order convergence for the energy flow calculation of integrated energy systems (IES) containing the natural gas system (NGS). The proposed method is based on a conditional optimal two-step iterative method which is at least third-order with one function and two derivative evaluations in each iteration. Experiment results reveal that the proposed method is superior to the classical Newton–Raphson method and its other variants in terms of computational efficiency.

Ju et al., in their paper "Power Flow Analysis of Integrated Energy Microgrid Considering Non-Smooth Characteristics" propose an integrated energy microgrid model considering non-smooth characteristics used for power flow (PF). In order to tackle with the non-smooth characteristics such as distributed generations (DGs) limits, converter stations limits and the unknown direction of pipeline mass flow, which can easily lead to the failure of PF convergence. This paper establishes an integrated energy microgrid model including three-phase unbalanced AC/DC hybrid microgrid and heating system. For heating system, firstly, the dynamic characteristics of pipeline model considering time and space factors are described by partial differential equation; then, for the non-smooth characteristics caused by the unknown direction of pipeline mass flow, they introduce complementary constraints to describe it, and use Fischer–Burmeister (FB) function to smooth it, which effectively avoids the non-convergence of the power flow. For AC/DC hybrid microgrid, the correctness of converter station model is verified by electromagnetic transient simulation. Then, for the non-smooth complementarity problem caused by DG limits and converter station limits in AC/DC microgrid, they also effectively deal with it based on the FB function. Simulation results verify the rationality of the model and the effectiveness of the proposed non-smooth characteristics treatment method.

3 | TOPIC B: SHORT-TERM GENERATION/LOAD FORECASTING OF IES

Ge et al., in their paper "Short-Term Load Forecasting of Integrated Energy System Considering the Peak-Valley of Load Correlations" propose an integrated energy system (IES) short-term load forecasting method based on load-correlation peaks and valleys. In order to consider the difference in the energy coupling relationship between peak and valley phases, this paper proposes a method that considers the correlation of power, thermal, and cold loads at different times of the day and chooses different predictive model input vectors, as well as the

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idea of self-learning in situational awareness into the optimisation of threshold parameters. The system constantly perceives the internal situation during the prediction process and feeds back the perception content to the prediction model. Combining the above-considered peak-valley correlation difference, the application of situational awareness in this article is specifically explained as follows. The initial correlation threshold parameters are obtained using the proposed marine predator algorithm with integrated grey wolf optimiser (MPAIGWO). After the prediction of a stage is completed, the prediction result is fed back to the system, and the system uses a self-learning method to change the threshold coefficient. Simulation results prove that the MPAIGWO has the highest optimisation performance under the same conditions.

4 | TOPIC C: EVENT DETECTION AND FAULT LOCATION IN IES

Wu et al., in their paper "A Cyber-Attack Detection Method for Load Control System Based on Cyber and Physical Layer Crosscheck Mechanism" propose a cyber-attack detection method for load control systems based on the cyber and physical layers crosscheck mechanism. First, backpropagation neural network (BPNN) is used for cyber-attack detection, and the particle swarm optimisation (PSO) algorithm is adopted to improve the convergence of the BPNN to enhance the detection accuracy. Then, based on the operation state in the physical layer, an index system for evaluating the risk level of the physical node is proposed. The risk level of the physical node will be assessed by the criteria importance though intercriteria correlation-based grey relational analysis (GRA). Finally, based on the incidence matrix model of the DCPS, a crosscheck mechanism based on the information of the cyber layer and the physical layer is proposed. When the decision in the cyber layer is wrong, it can be verified by the node risk level in the physical layer and ensure that the result in the cyber layer is more reliable to the operator. Therefore, the proposed mechanism can reduce the false alarm of the attack detection, and improve the credibility of the instruction in the load control system. Simulation results have verified the validity of the proposed method to detect the denial of service attack.

Ehsani et al., in their paper "Convolutional Autoencoder Anomaly Detection and Classification based on Distribution PMU Measurements" propose a method that utilises convolutional autoencoders (Conv-AE) for the sake of anomaly detection based on the distribution phasor measurement units (DPMU) measurements in distribution systems (DMS). The challenging problem of anomaly detection within the large volumes of DPMU measurements is tackled by an unsupervised data-driven method called Conv-AE. Conv-AE detects abnormal behaviours in the dynamic performance of the distribution network based on comparing the current state of the system with normal conditions learned previously. The new technique does not rely on the characteristics of the system or events and just processes the data captured from limited nodes of the network. Conv-AE can deal with the high-dimensionality of data by converting non-linear computational complexities into a series of simpler calculations while being robust to the loss or inaccuracy of part of the data. Conv-AE compresses measuring data to a lower dimension where all the correlations are removed and informative features are extracted, and by this means eliminates an essential step in the conventional methods, i.e. pre-processing. The detected anomalous sequences are then classified using convolutional neural networks to identify the type of anomaly. Due to the scarcity of fully-labelled data to train the model, this paper use Bootstrap Aggregating to reduce the classification error and prevent the model from overfitting. Simulation results confirmed effectiveness of the proposed technique to be used in future DMS platforms.

5 | TOPIC D: DEMAND RESPONSE POTENTIAL AND RENEWABLE HOSTING CAPACITY ESTIMATION FOR IES

Zhang et al., in their paper "Hybrid-Adaptive Differential Evolution with Decay Function Applied to Transmission Network Expansion Planning with Renewable Energy Resources Generation" propose a model of transmission network expansion planning (TNEP) which the investment cost of new lines and the market-based annual congestion surplus are selected as objective functions. Then a probabilistic DC power flow based on a semi-invariant method is used to describe uncertainties of renewable energy resources generation. A new algorithm, hybrid-adaptive differential evolution with decay function, is applied to solve the model of TNEP for the first time. The performance of the algorithm is verified by comparing with two variants of DE and a swarm intelligence optimisation algorithm, including differential evolution algorithm with ensemble of parameters and mutation strategies, Differential evolution with multi-population based ensemble of mutation strategies, and comprehensive learning PSO. Simulation results on the 52-bus system of an area of Sichuan Province has shown the investment cost obtained by the new algorithm is at least one or two orders of magnitude lower than other algorithms.

Gong et al., in their paper "Integrated Scheduling of Hot Rolling Production Planning and Power Demand Response considering Order Constraints and TOU Price" propose a multi-objective optimisation model for the optimal scheduling of hot rolling load considering the actual production operation conditions. The model was abstracted into a vehicle routing problem, which is a typical combinatorial optimisation problem. To minimise the cost of electricity and the risk of delivery order default, this paper considered the jump penalty value between adjacent slabs simultaneously, constructed an integrated scheduling model of hot rolling shop scheduling and power demand response, and designed a multi-objective production scheduling algorithm based on NSGA-II to solve the problem. The results showed that the proposed method can realise the reasonable distribution of production load under the constraints of electricity price and production.

Wang et al., in their paper "Capacity Sizing of the Integrated Wind-Solar-Storage System: A Nested Game Approach"

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propose a nested game model to study the capacity sizing problem of the integrated wind-solar-storage system. The nested game model aims to describe the situation in which cooperation and competition coexists. The outer layer is a non-cooperative game among the wind power plant, the solar power system, and the energy storage (ES). Each of them targets at obtaining the maximum revenue which is calculated from the imputation method in the inner cooperative game. The reformulated model can reflect the competition among three players and provides a fair profit allocation to determine the revenue of each player. An iterative algorithm is proposed to calculate the optimal capacities of the three players. In each iteration, a linear programming method is used to obtain the nucleolus in the inner cooperative game. In the outer layer, each players' problem is solved by a golden-section search algorithm, and the Nash equilibrium is obtained by fixed-point iteration. Simulation results demonstrate the effectiveness of the approach compared to other methods.

De la Cruz-Loredo et al., in their paper "Dynamic Simulation and Control of the Heat Supply System of a Civic Building with Thermal Energy Storage Units" presents the co-simulation of a real heating application from a civil building for health services integrating thermal ES (TES) units. The co-simulation framework is constructed between Apros and MATLAB/Simulink. The thermal network under investigation consists of multiple thermal-hydraulic components and actuators. The dynamic model of the network was developed in Apros using available library models. The process control system includes several loops and logic operational orders and was implemented in MATLAB/Simulink. Heat supply and demand profiles based on historical data were included for 1 week of simulation time. These heat flows have their own dynamics, which in turn affect the operation of the thermal network. The co-simulation framework was applied to analyse the effectiveness of incorporating TES units operated by the process control system into the facility's heating system to provide it with load shifting capabilities. It is shown that a time-schedule control approach based on the heat load profiles of the building allows the TES units to shift the heat demand from low-demand to high-demand periods. Consequently, a reduced utilisation of the heat generation units is achieved during peak-demand hours.

Mazaheri, et al., in their paper "Harnessing Power System Flexibility under Multiple Uncertainties" present a Mixed-Integer Linear Programming (MILP) direct-optimization co-planning model to model power system flexibility. By integrating Battery Energy Storage System (BESS) modules in the network, a novel Renewable Energy Sources (RES)-BESS-based grid-scale system flexibility metric is presented to optimally measure as well as improve system flexibility. And the MILP stochastic co-planning direct-optimization formulation is used to solve the proposed model by converting two-stage optimization into one-stage with an efficient linearization method in which the model is converged faster. Then, a new repetitive offline fast solution method is defined to reach the desired amount of system flexibility by defining an engineering price/benefit trade-off to finally find the best investment plan. Meanwhile, multiple uncertainties associated with wind farms generation as well as demanded loads and a practical module-type (BESS) structure for each node are defined. Simulation results on the modified IEEE 73-bus test system including wind farms generation prove the efficiency of the proposed algorithm as the impacts of energy storage system modules on the grid-scale system flexibility, investment plans, and power system economics.

6 | TOPIC E: STATE ESTIMATION AND MODEL IDENTIFICATION/ CALIBRATION OF IES

Xu et al., in their paper "A Real-Time State Estimation Framework for Integrated Energy System Considering Measurement Delay" propose real-time state estimation framework for the gas–electricity coupled system. Considering the characteristics of the gas pipelines and coupling elements, the dynamic model of the natural gas system is established. Then, a modified unscented Kalman filter (UKF) based estimation method is designed based on unified time processing and delay noise synthesising. In the modelling of gas–electricity coupled IES, the pipeline characteristics are analysed for the effects of the different transmission media within the gas and electricity network. At the same time, the analysis of the coupled gas–electricity network of CHP plants is not neglected. The measurements in the gas network are harmonised to the time scale of the measures in the electricity system and corrected for delays based on Pearson correlation coefficients for SCADA measurements in both the gas network and the electricity. The modified UKF algorithm is employed for the gas–electricity coupled IES to enhance estimation stability, effectively avoiding the curse of dimensionality from traditional Kalman filter algorithms. The IEEE 39-bus electrical system and the 20-node Belgian gas system are coupled to form the test system, and the case study shows the advantages of the proposed method in efficiency and accuracy compared with the existing methods.

7 | SUMMARY/CONCLUSION

All of the papers selected for this special issue demonstrate and advance the state of the art of situational awareness solutions to integrated energy systems. We provide innovative avenues on various aspects of this essential topic and towards the secure, reliable, economical, and sustainable operation of IES.

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