Guest Editorial
Distributed Energy Management Systems

ENERGY management system (EMS) is well known as the brain of power grid operation, for real-time monitoring, security assessment, dispatch schedule, and coordinated control of power grids. With the development of smart grids, a pressing need of transition from a traditional centralized EMS architecture to a distributed one is arising. This special section addresses the challenges and opportunities for the development of distributed EMS for smart grids.

The special section covers distributed energy management for smart transmission grids, active distribution grids, microgrids, networked microgrids, energy storage, and flexible demands, as well as cyber issue such as the architecture/infrastructure and cyber security of distributed EMS.

I. Distributed Energy Management for Smart Transmission Grids

The paper entitled "Distributed State Estimation of Hybrid AC/HVDC Grids by Network Decomposition" proposes a distributed state estimation method for hybrid AC/HVDC grids. Based on the Lagrangian relaxation and block-wise Gauss–Seidel solution technique, hybrid AC/HVDC grids can be naturally decomposed into AC and HVDC subsystems operated by different entities. A unified modeling framework for monopole/bipole converter configurations, parallel converters, converter-less DC buses, and wind farm connections is presented.

The paper entitled "Distributed Voltage Security Monitoring in Large Power Systems using Synchrophasors" proposes a real-time distributed voltage security monitoring framework for large power systems using synchrophasor measurements. At the substation level, two Q–V sensitivity-based voltage security indices are calculated from local synchrophasor measurements. These local sensitivities are collected at the control center level, where wide-area voltage security assessment is carried out to estimate the system proximity to voltage collapse as well as to identify voltage insecure subareas.

The paper entitled "Distributed MPC for Efficient Coordination of Storage and Renewable Energy Sources Across Control Areas" proposes a distributed model predictive control method to optimally coordinate control areas leveraging storage available in one area to balance variable resources in another area with less information exchange among the areas.

II. Distributed Energy Management for Active Distribution Grids

The paper entitled "State Forecasting and Operational Planning for Distribution Network Energy Management Systems" describes the application of AMI data for developing three energy management services in distribution networks with significant DERs, including demand forecasting, constraint management, and voltage profiles forecasting, in order to improve situational awareness and provide early warning of potential network issues.

The paper entitled "An Automated Impedance Estimation Method in Low-Voltage Distribution Network for Coordinated Voltage Regulation" proposes a novel method for automated internode line impedance estimation for coordinated voltage regulation based on practically available parameters at the terminal nodes. The distributed energy devices measure and transmit the terminal parameters to a host device, where the line impedances are estimates based on its impedance model and the collected parameters. The proposed method is verified via a simulation that assumes a realistic environment.

The paper entitled "A Fully Distributed Reactive Power Optimization and Control Method for Active Distribution Networks" presents a fully distributed reactive power optimization algorithm that can obtain the global optimum solution of non-convex problems for distribution networks without requiring a central coordinator. Second-order conic (SOC) relaxation is used to achieve exact convexification. A fully distributed SOCP solver with little interchange of boundary information between neighboring areas is formulated corresponding to the given division of areas based on the alternating direction method of multipliers algorithm.

III. Distributed Energy Management for Microgrids

The paper entitled "Robust Energy Management of Microgrid With Uncertain Renewable Generation and Load" develops a scenario-based robust energy management method accounting for the worst-case amount of renewable generation and load. The economic and robust model is formulated to maximize the total exchange cost while getting the minimum social efficiency cost at the same time. Uncertainty of renewable generation and load is described as an uncertain set produced by interval prediction.

The paper entitled "An Energy Scheduling Algorithm Supporting Power Quality Management in Commercial Building Microgrids" presents an energy scheduling algorithm for a small-scale microgrid serving small to medium size commercial buildings. The proposed algorithm is formulated as

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a mixed integer programming problem where power quality requirements are modeled in the constraints. The study results demonstrate the effectiveness of the algorithm in managing voltage and frequency deviations, as well as harmonic distortions.

The paper entitled "Multi-Agent Supervisory Control for Power Management in DC Microgrids" proposes multi-agent supervisory control for precise power management in isolated DC microgrids. Two power management algorithms are considered: 1) equal power sharing and 2) optimal power dispatch. Both algorithms offer the additional advantage of the ability to restore the average system voltage to its nominal value. The proposed algorithms are based on the average consensus theory along with voltage sensitivity analysis.

The paper entitled "A Time-Scale Adaptive Dispatch Method for Renewable Energy Power Supply Systems on Islands" develops a time-scale adaptive dispatch method for island microgrid with high penetration of renewables. The time-scale for dispatch is adjusted online according to the confidence interval of predicted forecast errors. Tests have validated the effectiveness of the presented method in offsetting the uncertainties in the system and improving the system reliability.

The paper entitled "Energy Management System for Stand-alone Wind-Powered-Desalination Microgrid" proposes an EMS design for stand-alone wind-powered desalination microgrid to achieve the goal of maximizing utilization of wind energy and minimizing utilization of diesel generator on the basis of stable system operation. The coordinated control of the distributed generation and energy storage system is researched with two operation modes. A real-time rolling horizon energy management method is presented based on hour-ahead wind speed forecasts.

IV. Distributed Energy Management for Networked Microgrids

The paper entitled "Interactive Control of Coupled Microgrids for Guaranteed System-wide Small Signal Stability" proposes a three-level hierarchical control framework for microgrid interconnections to achieve effective load sharing and guaranteed system-wide small signal stability. A model reference control based scheme is implemented for primary-level power sharing. At the secondary level, an interactive droop management scheme is proposed to manage the reference model droop gains based on a distributed stability criterion. At the tertiary level, an AC power flow based supervisory control strategy is utilized.

The paper entitled "Decentralized Energy Management System for Networked Microgrids in Grid-connected and Islanded Modes" proposes a decentralized EMS for the coordinated operation of networked microgrids in a distribution system. In the grid-connected mode, a decentralized bi-level algorithm is applied to coordinate the operation. In the islanded mode, each MG is to maintain a reliable power supply to its customers. Two-stage stochastic programs are formulated to take the uncertainties of DG outputs and load into account.

V. Distributed Energy Management for Energy Storages

The paper entitled "Distributed Online Modified Greedy Algorithm for Networked Storage Operation under Uncertainty" proposes an efficient modified greedy algorithm to solve the optimal control problem of storage networks online in a stochastic environment with performance guarantee. A sub-optimality bound for the algorithm is derived, and a semidefinite program is constructed to minimize the bound. A task-based distributed implementation of the online algorithm relying only on local information and neighborhood communication is then developed based on the alternating direction method of multipliers.

The paper entitled "Distributed Control of Micro-Storage Devices With Mean Field Games" proposes a fully distributed control strategy for the management of micro-storage devices that perform energy arbitrage. The problem with large storage populations is approximated as a differential game with infinite players (mean field game). The optimal feedback strategy for each player and the resulting price of energy are solved through the resolution of coupled partial differential equations. Once this price is calculated, it is communicated to the devices which are able to independently determine their optimal charge profile.

VI. Distributed Energy Management for Flexible Demands

The paper entitled "Dynamic Pricing and Distributed Energy Management for Demand Response" proposes a Stackelberg game-based method to study the problem of dynamic pricing of electricity in a retail market. A complete characterization of the tradeoffs between consumer surplus and retail profit is obtained. It is shown that the benefits of renewable integration all go to the retailer when the capacity of renewable is relatively small. As the capacity increases beyond a certain threshold, the benefit from renewables that goes to consumers increases.

The paper entitled "Non-linear and Randomized Pricing for Distributed Management of Flexible Loads" develops a novel, fully price-based approach where the flexibility restriction on flexible loads is replaced by a soft, non-linear price signal. This signal is customized to the operating properties of the different flexible load types by penalizing the square of the demand and the duration of cycle delay of loads with continuously adjustable power levels and deferrable cycles respectively. For the latter type, randomization of the non-linear prices brings additional benefits, especially in low operating diversity cases.

The paper entitled "Hierarchical Charge Control of Large Populations of EVs" proposes a novel hierarchical charge control framework based on Bender's decomposition for large populations of EVs. On the upper level, the cooperative dispatch scheme between the generation and the EV aggregators is obtained. On the lower level, the feasibility of the scheme is checked with EV constraints considered. In addition, the distributed approximate Benders cuts are also proposed, which help to protect user privacy and a three-level framework is developed based on the decentralized control.

VII. Architecture/Infrastructure and Cyber Security of Distributed EMS

The paper entitled "Distributed Software Infrastructure for General Purpose Services in Smart Grid" presents a design of an event-driven middleware to mainly provide a P2P distributed software infrastructure to allow the access of new multiple and authorized actors to smart grid's information in order to provide new services. The features of the proposed middleware are 1) event-based; 2) reliable; 3) secure from malicious ICT attacks; and 4) to enable hardware independent interoperability between heterogeneous technologies.

The paper entitled "Railway Energy Management System: Centralized-decentralized Automation Architecture" develops a new railway energy management system (REMS) to integrate on-board, wayside, and coordination services. This paper presents the proposed REMS architecture, which is based on a hybrid centralized-decentralized concept and developed according to a smart grid architecture model framework.

The paper entitled "Preventing Time-Delay Switch Attack on Load Frequency Control in Distributed Power Systems" presents a novel, simple, and effective method to thwart time-delay-switch attacks on the sensing loop. The method works by augmenting the controller with a time delay estimator, which can track time delays introduced by an adversary using a modified model reference control with an indirect supervisor and a modified least mean square minimization technique.

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