smart cities

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Editorial

Next Generation of Smart Grid Technologies

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1. Introduction

The emergence of smart cities demands a fundamental transformation in how energy is managed, positioning smart grid technologies as a key driver in urban progress. Through the integration of various energy resources (renewable energy sources, energy storage systems, green hydrogen, electric vehicles, etc.), grid-edge power electronics, advanced control systems, and information and communication technologies with conventional power grids, smart grids facilitate efficient, dependable, and eco-friendly energy use in city settings. This Special Issue examines the impactful role of smart grid technologies in defining the future of smart cities.

This Special Issue is devoted to publishing new research articles exploring innovative applications and advancements in smart grid technologies specifically tailored to smart city environments. It encompasses a diverse range of topics, including:

- Microgrid integration and distributed energy resources—examining the seamless integration of renewable energy sources and distributed energy resources like rooftop solar, energy storage systems, and electric vehicles into the urban grid, maximizing local energy generation and reducing reliance on centralized power plants, or integration of microgrid clusters, energy communities, and multi-energy microgrids (combining different energy vectors like electricity, hydrogen, heating/cooling, etc.) into smart cities.
- Demand-side management (DSM) and energy efficiency—exploring strategies to optimize energy consumption in buildings, industries, and transportation systems based on real-time data and dynamic pricing mechanisms.
- Cybersecurity and data privacy—addressing the growing challenge of cyberattacks on smart grids and implementing robust security measures to protect critical infrastructure and user data.
- Data analytics and artificial intelligence (AI)—utilizing data analytics and AI algorithms to optimize grid operations, predict demand fluctuations, and enable real-time decision-making for efficient energy management.

In this Special Issue, we encourage researchers involved in smart grid technologies for smart cities to discuss key topics in the field and submit innovative papers that make significant contributions to existing literature in the field of smart grid technologies for smart cities. We expect these papers to be widely read and highly influential within the field.

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The subject areas may include, but are not limited to, the following:

- Smart microgrids for smart cities;
- Smart grids in buildings (residential, commercial, and industrial) and transport;
- Design, planification and operation of smart grids for smart cities;
- Intelligent energy storage for smart cities;
- Demand forecasting and weather forecasting;
- Efficient demand-side management;
- Intelligent control and energy management systems of smart grids;
- Digital twins of smart cities for smart cities;
- Grid stability, reliability, and resilience of smart cities;
- Market operations in smart microgrids for smart cities;
- Microgrid clusters;
- Multi-energy microgrids;
- Energy communities;
- Power converters;
- Control and communication devices;
- Information and communication technologies;
- Cybersecurity and data privacy;
- Data analytics and artificial intelligence.

2. Short Presentation of the Papers

Pandey et al. (contribution 1) claimed that a virtual power plant (VPP) is a potential alternative that aggregates the distributed energy resources (DERs) and addresses the prosumer's power availability, quality, and reliability requirements. The paper reported the optimized scheduling of an interconnected VPP in a multi-area framework established through a tie-line connection comprising multiple renewable resources. The scheduling was initially performed on a day-ahead (hourly basis) interval, followed by an hour-ahead interval (intra-hour and real time), i.e., a 15 min and 5 min time interval for the developed VPP in a multi-area context. The target objective functions for the selected problem were two-fold, i.e., net profit and emission, for which maximization was performed for the former and reduction for the latter, respectively. Since renewables are involved in the energy mix and the developed problem was complex in nature, the proposed multi-area-based VPP was tested with an advanced nature-inspired metaheuristic technique. Moreover, the proposed formulation was extended to a multi-objective context, and multiple scheduling strategies were performed to reduce the generated emissions and capitalize on the cumulative profit associated with the system by improving the profit margin simultaneously. Furthermore, a comprehensive numeric evaluation was performed with different optimization intervals, which revealed the rapid convergence in minimal computational time to reach the desired solution.

Rodriguez et al. (contribution 2) mentioned that OT (operational technology) protocols such as DNP3/TCP, commonly used in the electrical utility sector, have become a focal point for security researchers. The authors studied the applicability of attacks previously published from theoretical and practical points of view. From the theoretical point of view, previous work strongly focuses on transcribing protocol details (e.g., list fields at the link, transport, and application layer) without providing the rationale behind protocol features or how the features are used. This has led to confusion about the impact of many theoretical DNP3 attacks. After a detailed analysis of which protocol features are used and how, a review of the configuration capabilities for several IEDs (Intelligent Electrical Devices), and some testing with real devices, the authors concluded that similar results to several complex theoretical attacks can be achieved with considerably less effort. From a

more practical point of view, there is existing work on DNP3 man-in-the-middle attacks; however, research still needs to discuss how to overcome a primary hardening effect: IEDs can be configured to allow for communication with specific IP addresses (allow list). For purely scientific purposes, we implemented a DNP3 man-in-the-middle attack capable of overcoming the IP allow-list restriction. The authors tested the attack using real IEDs and network equipment ruggedized for electrical environments. Even though the man-in-the-middle attack can be successful in a lab environment, the authors also explained the defense-in-depth mechanisms provided by industry in real life that mitigate the attack. These mechanisms are based on standard specifications, capabilities of the OT hardware, and regulations applicable to some electrical utilities.

Okasha et al. (contribution 3) stated that Intentional controlled islanding (ICI) is a crucial strategy to avert power system collapse and blackouts caused by severe disturbances. This paper introduced an innovative IoT-based ICI strategy that identifies the optimal location for system segmentation during emergencies. Initially, the algorithm transmits essential data from phasor measurement units (PMUs) to the IoT cloud. Subsequently, it calculates the coherency index among all pairs of generators. Leveraging IoT technology increases system accessibility, enabling the real-time detection of changes in network topology post-disturbance and allowing the coherency index to adapt accordingly. A novel algorithm is then employed to group coherent generators based on relative coherency index values, eliminating the need to transfer data points elsewhere. The "where to island" subproblem is formulated as a mixed integer linear programming (MILP) model that aims to boost system transient stability by minimizing power flow interruptions in disconnected lines. The model incorporates constraints on generators' coherency, island connectivity, and node exclusivity. The subsequent layer determines the optimal generation/load actions for each island to prevent system collapse post-separation. Signals from the IoT cloud are relayed to the circuit breakers at the terminals of the optimal cut-set to establish stable isolated islands. Additionally, controllable loads and generation controllers receive signals from the cloud to execute load and/or generation adjustments. The proposed system's performance is assessed on the IEEE 39-bus system through time-domain simulations on DIgSILENT PowerFactory connected to the ThingSpeak cloud platform. The simulation results demonstrate the effectiveness of the proposed ICI strategy in boosting power system stability.

Ieva et al. (contribution 4) justified that digital-twin platforms are increasingly adopted in energy infrastructure management for smart grids. Novel opportunities arise from emerging artificial intelligence technologies to increase user trust by enhancing predictive and prescriptive analytics capabilities and by improving user interaction paradigms. This paper presented a novel data-driven and knowledge-based energy digital-twin framework and architecture. Data integration and mining based on machine learning are integrated into a knowledge graph, annotating asset status data, prediction outcomes, and background domain knowledge in order to support a retrieval-augmented generation approach, which enhances a conversational virtual assistant based on a large language model to provide user decision support in asset management and maintenance. Components of the proposed architecture have been mapped to commercial-off-the-shelf tools to implement a prototype framework, exploited in a case study on the management of a section of the high-voltage energy infrastructure in central Italy.

Richter et al. (contribution 5) claimed that in line with several European directives, residents are strongly encouraged to invest in renewable power plants and flexible consumption systems, enabling them to share energy within their Renewable Energy Community at lower procurement costs. This, along with the ability for residents to switch between such communities on a daily basis, leads to dynamic portfolios, resulting in non-

stationary and discontinuous electrical load time series. Given the poor predictability and insufficient examination of such characteristics, as well as the critical importance of electrical load forecasting in energy management systems, the authors proposed a novel forecasting framework using Federated Learning to leverage information from multiple distributed communities, enabling the learning of domain-invariant features. To achieve this, we initially utilized synthetic electrical load time series at the district level and aggregated them to profiles of Renewable Energy Communities with dynamic portfolios. Subsequently, the authors developed a forecasting model that accounts for the composition of residents of a Renewable Energy Community, adapts data pre-processing in accordance with the time series process, and details a federated learning algorithm that incorporates weight averaging and data sharing. Following the training of various experimental setups, the authors evaluated their effectiveness by applying different tests for white noise in the forecast error signal. The findings suggest that our proposed framework is capable of effectively forecasting non-stationary as well as discontinuous time series, extracting domain-invariant features, and is applicable to new, unseen data through the integration of knowledge from multiple sources.

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