energies

Editorial

Emerging and Advanced Green Energy Technologies for Sustainable and Resilient Future Grid

Surender Reddy Salkuti

Department of Railroad and Electrical Engineering, Woosong University, Daejeon 34606, Korea; surender@wsu.ac.kr; Tel.: +82-10-9674-1985

Citation: Salkuti, S.R. Emerging and Advanced Green Energy Technologies for Sustainable and Resilient Future Grid. *Energies* **2022**, *15*, 6667. https://doi.org/10.3390/en15186667

Received: 6 September 2022
Accepted: 12 September 2022
Published: 13 September 2022

1. Introduction

Future grid refers to the next generation of the electrical grid, which will enable smart integration of conventional, renewable, and distributed power generation, energy storage, transmission and distribution, and demand management. Renewable energy is crucial in transitioning to a less carbon-intensive economy and a more sustainable energy system. The high penetration and uncertain power outputs of renewable energy poses a great challenge to the stable operation of energy systems. The deployment of the smart grid is revolutionary and also imperative around the world. It involves and deals with multidisciplinary fields such as energy sources, control systems, communications, computational, generation, transmission, distribution, customer, operations, markets, and service provider. Smart grids are emerging in both developed and developing countries, with the aim of achieving a reliable and secure electricity supply. Smart grids will eventually need standards, policy, and a regulatory framework for successful implementation.

This Special Issue invited original contributions on, but not limited to, themes and topics related to: renewable power and clean energy technologies; design and operation of sustainable energy systems; smart grid architectures and cyber and physical security; smart grid and green energy integration; operation and control of renewable energy sources; smart grid and smart cities modeling; forecasting techniques for renewable energy sources and loads; electric vehicle systems for smart grid; distributed generation and distributed storage; agent-based smart grid simulation; decision support approaches for smart grids; electricity market modeling and simulation for the integration of renewable sources; intelligent approaches for smart grid management; multi-agent applications for smart grids; smart grid energy management system; computational intelligence technologies for sustainable energy; machine learning, IoT, and big data applications for energy systems; and demand side management.

2. Special Issue Content

This Special Issue on "Emerging and Advanced Green Energy Technologies for Sustainable and Resilient Future Grid" includes 18 papers presenting various advanced technologies related to the future grid. The first paper, by Battula et al. [1], provides an in-depth review on energy management in microgrid; its components, control techniques, communication technologies in the use, architecture, auxiliary services, structure, and standards available for implementation and future scope in the area of energy management system (EMS). The prime aspects that are covered in this review are on the prospects, solutions, and opportunities of the objective functions of the EMS using efficient strategies. This article introduces the microgrid, its architecture composing of an AC microgrid, a DC microgrid, and a hybrid microgrid. The microgrid components composing of distributed generators, storage elements, loads and their composition, integration of electrical vehicles (EVs) and their applications, demand response, and electricity market pricing. The main focus of the review is on the different techniques adopted, which are classified as classical methods, meta-heuristic methods, and intelligent methods used to solve different objective functions considering cost, active power loss, voltage stability, and emission of greenhouse gasses with usage on non-renewable generators. The review further broadened with the structure of control such as centralized, decentralized, and distributed control with multiple distribution generation sources, integration of EVs, and utilization of demand response and their mode of operation which is either in islanded mode or grid connected mode. The areas such as customer confidentiality regulations, management of communication systems, and reliability studies with depth of discharge of the batteries, effect of the conventional grid on greenhouse gas emissions, and demand response, active and reactive losses along with resilience and customer management for effective and efficient operation of microgrids have scope to emphasize in future studies.

Soliman et al. [2] proposed a robust tracking (servomechanism) controller for linear time-invariant (LTI) islanded (autonomous, isolated) microgrid voltage control. The studied microgrid (MG) consists of many distributed energy resources (DERs) units, each using a voltage-sourced converter (VSC) for the interface. The optimal tracker design uses the ellipsoidal approximation to the invariant sets. The MG system is decomposed into different subsystems (DERs). Each subsystem is affected by the rest of the system that is considered as a disturbance to be rejected by the controller. The proposed tracker (state feedback integral control) rejects bounded external disturbances by minimizing the invariant ellipsoids of the MG dynamics.

Malik et al. [3] designed and fabricated a novel thermal energy storage system using phase change material. The concept of utilizing phase change materials (PCMs) has attracted wide attention in recent years. This is due to their ability to extract thermal energy when used in collaboration with photovoltaic (PV), thus improving the photoelectric conversion efficiency. The aim of this study was to design and study a latent heat thermal energy storage system which can store solar energy for a reasonable amount of time. This stored energy is environmentally friendly and can be used for any indoor heating purpose such as cooking, water, and room heating applications in the absence of sunlight. The experimental results of the designed system show that the system is capable of storing enough energy during sunshine hours that can later be used for any heating application in the absence of sunlight. In the current study, potash alum was identified as a phase change material combined with renewable energy sources that can be efficiently and effectively used in storing thermal energy at comparatively lower temperatures that can later be used in daily life heating requirements. A parabolic dish which acts of a heat collector is used to track and reflects solar radiation at a single point on a receiver tank.

Swain et al. [4] presented a smart city energy model along with a comprehensive state-of-the-art overview of blockchain-powered energy systems with an objective to transform traditional cities into smart communities. It aims to increase the energy efficiency and network security of smart grids with the help of nature-inspired algorithms and blockchain technology. This work also identifies some of the major issues associated with the energy grids and provides solution to overcome these challenges. Focusing mainly on the intelligent management of energy systems, it introduced wireless sensor networks, microgrid, prosumers, and blockchain technology in this energy model to generate and consume clean energy on a decentralized trading system. The smart grid network consists of several wireless sensor nodes that come with various challenges such as limited computational capabilities, huge consumption of energy by the sensors in longer communication distances resulting in decreased network lifespan, and increased communication costs. This led to the introduction of nature-inspired algorithms such as particle swarm optimization (PSO) and genetic algorithm which provided optimal solutions for these challenges. This work presents the properties and mechanisms of biological systems and deployed PSO and genetic algorithm for energy-efficient selection of cluster head in a group of sensor nodes and achieved optimal routing in the communication system, respectively, for faster transmission of data in less processing time. In order to improve energy distribution capability in the smart community and maintain security of the systems, the blockchain-based smart microgrid technology is deployed using a decentralized application to enable peer-to-peer energy trading. This is done by implementing Web3 technologies and Ethereum smart contract to maintain energy records in a decentralized, transparent, and cost-effective way.

Kim et al. [5] proposed a photovoltaic (PV) string-level isolated DC–DC power optimizer with wide voltage range. A hybrid control scheme in which pulse frequency modulation (PFM) control and pulse width modulation (PWM) control are combined with a variable switching frequency is employed to regulate the wide PV voltage range. By adjusting the switching frequency during the PWM control process, the circulating current period can be eliminated and the turn-on period of the bidirectional switch of the dual-bridge LLC (DBLLC) resonant converter is reduced compared to that with a conventional PWM control scheme with a fixed switching frequency, resulting in better switching and conduction loss. Soft start-up control under a no-load condition is proposed to charge the DC-link electrolytic capacitor from 0 V. A laboratory prototype of a 6.25 kW DBLLC resonant converter with a transformer, including integrated resonant inductance, is built and tested in order to verify the performance and theoretical claims.

Yoo et al. [6] presented a demonstration and validation of primary frequency control (PFC) and secondary frequency control (SFC) with a vehicle-to-grid (V2G)-capable Nissan leaf EV using a commercially available supervisory control and data acquisition (SCADA) and MATLAB/Simulink, based on droop characteristics designed for PFC and the dispatch of area control error (ACE) signals for SFC at a V2G testing facility of the National Research Council (NRC), Canada. The simulation models derived, implemented, and described in this work are based on time-domain dynamic analysis using the phasor modeling technique. Then, model-based simulations of PFC and SFC with an intelligent optimal control algorithm, including a coordinated control of the state of charge (SOC) and charging schedule for five aggregated EVs with different departure times and SOC management profiles, are presented to validate the effectiveness of frequency control using the integrated fleet of V2G-capable EVs and to verify its relevant technical issues.

Veeramsetty et al. [7] uses a stochastic gradient descent optimizer to update the parameters in the regression models. Simple linear regression and polynomial regression models were used to predict the active power load. A new approach, i.e., predict the active power load based on load at last three hours and load at one day before was used with various regression models and dimensionality reduction technique was used to reduce the complexity of the model so that overfitting problem was removed. Data analytic tools were used to process the data before feeding it to the model.

Musengimana et al. [8] proposed a method that uses the DC-link voltage error deviation to generate the additional reactive current reference. The obtained compensating reactive current is added to the reactive current reference from the point of common coupling (PCC) voltage control loop. By updating the reactive current reference with respect to the DC-link voltage, the instability issues induced by the control loops coupling are overcome. Further, the proposed control strategy also benefits from easy implementation and good robustness against AC voltage control (AVC), DC bus voltage control (DVC), and phase-locked loop (PLL) bandwidth variation, as well as the grid strength variation. The performance of the proposed method is evaluated by using the small-signal stability analysis based on the derived small-signal model. The comparative evaluation of the proposed control method with the conventional control method is also performed in this work.

Devarapalli et al. [9] proposed an approach to measure the true power factor (TPF) using a four-term minimal sidelobe cosine-windowed enhanced dual-spectrum line interpolated Fast Fourier Transform (FFT). The proposed method was used to measure the TPF with a National Instruments cRIO-9082 real-time (RT) system, and four different low-power consumer electronic appliances (LPCEAs) in a smart home were considered. The RT results exhibited that the TPF uniquely identified each usage pattern of the LPCEAs and could use them to improve the TPF by suggesting an alternative usage pattern to the consumer. A positive response behavior on the part of the consumer that is in their interest can improve the power quality in a demand-side management application.

Benbouhenni et al. [10] designed the third-order sliding mode (TOSM) command to control and minimize the ripples of current, reactive power, torque, and active power of asynchronous generators (ASGs)-based variable-speed contra-rotating wind power (CRWP) systems. A TOSM technique to overcome the undulations power problem is designed for the direct field-oriented control (DFOC) technique of variable-speed CRWP systems. A DFOC control strategy with TOSM controllers is employed to enable avoidance of the power undulations and improve the response time. The system states can be ensured to improve in variation parameters. The principle of the proposed TOSM controllers is detailed in the work. Validation of the designed technology is carried out by digital simulations using MATLAB software.

Gunda et al. [11] explored an extended Kalman filter (EKF) algorithm to predict primary side currents of the transformer, using the nonlinear state-space transformer model. A residual signal is derived from the difference of measured and estimated currents on the primary side winding of the transformer. When the transformer is under normal conditions, the residual signal becomes zero based on the EKF estimation. If the transformer is in a faulty condition, large residual currents are generated. The residual signal amplitude is compared with the threshold value in order to classify the magnetic inrush current and internal fault current. In this work, the diagonal elements of the covariance matrix are utilized to analyze the severity of the fault occurrence in the transformer. The simulation results are presented to evaluate the EKF for different conditions of the transformer.

Bayati et al. [12] proposed an analytical expression of the current of a DC microgrid (MG) cluster under fault conditions. First, the analytical model of the fault current of the AC/DC converter between the grid and DC MG is presented. Second, the analytical model of a bidirectional interlink DC/DC converter of the interconnection line between two adjacent DC microgrids in a clustered DC MG is derived in detail. Then, a DC fault clearing strategy is proposed based on using a DC fault current limiter (FCL) in series with a DC circuit breaker. Finally, the performance of the proposed method is evaluated based on time-domain simulation studies on a test DC MG cluster in MATLAB/Simulink environment. The simulation results are also compared with the results of the proposed analytical model. The obtained results verify the analytical expression of the fault current and prove the effectiveness of the proposed DC fault current limiting and clearing strategy.

Dubey et al. [13] proposed a multiobjective model capable of finding a set of trade-off solutions for the joint optimization problem, considering the cost of reserve and curtailment of power from renewable sources. Managing a hybrid power system is a challenging task due to its stochastic nature mixed with the objective function and complex practical constraints associated with it. This work focuses on profit-based multiobjective scheduling with the objectives are profit maximization by selling electricity generated through various sources and minimizing emissions by conventional (thermal) sources. The generation sources include solar photovoltaic (PV), wind, and conventional plants. The optimization problem addressed has practical constraints, including power balance, generation limits, and ramp limits. The conflicting objectives: profit and emission, are aggregated using the fuzzy-min ranking method. Thermal sources are modeled as quadratic polynomial; solar PV units use probabilistic modeling, and wind power uses Weibull distribution for wind velocity variation. The PV and wind power costs use overestimation and overestimation to balance renewable power generation uncertainty. A novel metaheuristic Equilibrium Optimizer (EO) algorithm is used for computing the optimal schedule and impact of renewable energy integration on profit and emission for different optimization objectives.

Javed et al. [14] analyzed an effective scheduling of a battery energy storage system (BESS) and the effects of PV systems for a campus microgrid to minimize the energy operating costs for a prosumer microgrid with the implementation of actual load data. The suggested system utilized solar energy, a BESS, and diesel generators in several scenarios and their consequences were investigated. The optimal scheduling was implemented in MATLAB and formed as a mixed-integer linear programming (MILP) problem. The time-of-use (TOU) pricing-based demand response (DR) was investigated here as part of a financial and economic analysis, and the energy storage system (ESS) was used as a flexible DR framework that could be charged or discharged wisely at various times to meet the budget target without compromising its durability. Without the distributed generation (DG) or ESS, the utility grid supplied all the campus microgrids required energy, leading to higher operational expenses.

Pothireddy et al. [15] addressed the complication of solutions, merits, and demerits that may be encountered in today's power system and encompasses DR and its impacts in reducing the installation cost, the capital cost of DGs, and total electricity tariff. To achieve this, an objective function was formulated and an optimal sizing method has been proposed by considering the impact of DR for finding the optimal size of DGs, i.e., wind turbine, PV, and diesel generator. Further, the proposed algorithm clusters the load into interruptible loads (ILs) and non-interruptible loads (NILs) and assigns a priority to the non-essential loads with the order of scheduled times by using time of use pricing (TOU) pricing. In addition, this work suggests a limit on the amount of load shift to avoid the issues like rebound effect, increase in marginal price, and operational cost of the MG due to load recovery. The future extension of this work is studying the impact of DR programs in optimal sizing of DGs by considering the uncertainty in renewable energy sources. Finding the elasticity and cross elasticity matrix of load with respect to price changes can be performed.

Romero-Ramirez et al. [16] introduced a methodology for the detection and quantification of stationary frequency components in the electrical signals of a smart building, and fusing the spectral kurtosis (SK) with the fast Fourier transform (FFT). The use of the proposed methodology presents some advantages against the conventional approaches, for instance, the ease of its implementation since the mathematics behind this methodology are simple. This situation results in a technique that is efficient and demands a low computational burden. Moreover, it is possible to perform a time tracking of a specific stationary frequency component (SFC) without problems, such as the mode mixing introduced by time-frequency transforms, such as wavelet transform (WT) and empirical mode decomposition (EMD), this way it is possible to perform a quantification of how every SFC contributes to detriment the quality of the power grid. Although SK is a widely explored technique, its use is more extended in the identification of transient events. Additionally, the combination of SK and FFT represents a novel solution for the time tracking and quantification of SFC. The proposed methodology aims to be a helpful tool to perform an estimation of the types of loads that appear in the grid and how they impact the quality of the supply. This way it is possible to propose actions in order to mitigate the undesired effects associated with a specific type of load.

Lee et al. [17] defined the life-cycle cost for an ESS in detail based on a life assessment model and used for scheduling. The life-cycle cost is affected by four factors: temperature, average state-of-charge (SOC), depth-of-discharge (DOD), and time. In the case of the DOD stress model, the life-cycle cost is expressed as a function of the cycle depth, whose exact value can be determined based on fatigue analysis techniques such as the Rainflow counting algorithm. The optimal scheduling of the ESS is constructed considering the life-cycle cost using a tool based on reinforcement learning. Since the life assessment cannot apply the analytical technique due to the temperature characteristics and time-dependent characteristics of the ESS SOC, the reinforcement learning that derives optimal scheduling is used. The results show that the SOC curve changes with respect to weight. As the weight of life-cycle cost increases, the ESS output and charge/discharge frequency decrease.

Menniti et al. [18] illustrated the main enabling technologies, smart meter, ESS, DC Nanogrid (DCNG) and Energy Community Management (ECM) platform that must be used to support the growth of renewable energy communities (RECs). The innovative settlement of the Advanced End-User (AEU) is introduced, defined as an active and proactive end-user equipped with the above-mentioned enabling technologies. Additionally, some use cases and the associated performance indexes have been identified and defined, respectively. The numerical results performed both, considering the operation of a single

AEU and four AEUs operating as an REC, are illustrated, and discussing when flexibility service requests are sent or not, highlighting how it is possible to both maximize the self-consumption and satisfy the flexibility service request in the case of an REC consisting of AEUs as members.

3. Closing Remarks and Future Challenges

The papers in this Special Issue reveal an exciting research area, namely the "Future Grid" that is continuing to grow. This Special Issue addresses the emerging and advanced green energy technologies for a sustainable and resilient future grid, and provides a platform to enhance interdisciplinary research and share the most recent ideas. Various high-priority areas of smart grid technologies are addressed including information and communication technology integration, transmission enhancement applications, distribution and management, advanced metering infrastructure, charging infrastructure, sharing of energy storage, demand flexibility to the grid, and trading of renewable energy. Therefore, I believe that the published papers will have practical importance for the development of the future grid. Finally, I would like to thank all our authors, reviewers, and editorial staff who have contributed for the publication of this Special Issue. I am sure all readers of this Special Issue of *Energies* will find the scientific articles interesting and beneficial to their research work.

Funding: This research work was funded by "WOOSONG UNIVERSITY's Academic Research Funding-2022".

Conflicts of Interest: The author declares no conflict of interest.

References

1. Battula, A.R.; Vuddanti, S.; Salkuti, S.R. Review of Energy Management System Approaches in Microgrids. *Energies* **2021**, *14*, 5459. [CrossRef]
2. Soliman, H.M.; Bayoumi, E.; Al-Hinai, A.; Soliman, M. Robust Decentralized Tracking Voltage Control for Islanded Microgrids by Invariant Ellipsoids. *Energies* **2020**, *13*, 5756. [CrossRef]
3. Malik, M.S.; Iftikhar, N.; Wadood, A.; Khan, M.O.; Asghar, M.U.; Khan, S.; Khurshaid, T.; Kim, K.-C.; Rehman, Z.; Rizvi, S.T.u.I. Design and Fabrication of Solar Thermal Energy Storage System Using Potash Alum as a PCM. *Energies* **2020**, *13*, 6169. [CrossRef]
4. Swain, A.; Salkuti, S.R.; Swain, K. An Optimized and Decentralized Energy Provision System for Smart Cities. *Energies* **2021**, *14*, 1451. [CrossRef]
5. Kim, H.; Yu, G.; Kim, J.; Choi, S. PV String-Level Isolated DC–DC Power Optimizer with Wide Voltage Range. *Energies* **2021**, *14*, 1889. [CrossRef]
6. Yoo, Y.; Al-Shawesh, Y.; Tchagang, A. Coordinated Control Strategy and Validation of Vehicle-to-Grid for Frequency Control. *Energies* **2021**, *14*, 2530. [CrossRef]
7. Veeramsetty, V.; Mohnot, A.; Singal, G.; Salkuti, S.R. Short Term Active Power Load Prediction on A 33/11 kV Substation Using Regression Models. *Energies* **2021**, *14*, 2981. [CrossRef]
8. Musengimana, A.; Li, H.; Zheng, X.; Yu, Y. Small-Signal Model and Stability Control for Grid-Connected PV Inverter to a Weak Grid. *Energies* **2021**, *14*, 3907. [CrossRef]
9. Devarapalli, H.P.; Dhanikonda, V.S.S.S.S.; Gunturi, S.B. Demand-Side Management for Improvement of the Power Quality in Smart Homes Using Non-Intrusive Identification of Appliance Usage Patterns with the True Power Factor. *Energies* **2021**, *14*, 4837. [CrossRef]
10. Benbouhenni, H.; Bizon, N. Third-Order Sliding Mode Applied to the Direct Field-Oriented Control of the Asynchronous Generator for Variable-Speed Contra-Rotating Wind Turbine Generation Systems. *Energies* **2021**, *14*, 5877. [CrossRef]
11. Gunda, S.K.; Dhanikonda, V.S.S.S.S. Discrimination of Transformer Inrush Currents and Internal Fault Currents Using Extended Kalman Filter Algorithm (EKF). *Energies* **2021**, *14*, 6020. [CrossRef]
12. Bayati, N.; Baghaee, H.R.; Savaghebi, M.; Hajizadeh, A.; Soltani, M.N.; Lin, Z. DC Fault Current Analyzing, Limiting, and Clearing in DC Microgrid Clusters. *Energies* **2021**, *14*, 6337. [CrossRef]
13. Dubey, S.M.; Dubey, H.M.; Pandit, M.; Salkuti, S.R. Multiobjective Scheduling of Hybrid Renewable Energy System Using Equilibrium Optimization. *Energies* **2021**, *14*, 6376. [CrossRef]
14. Javed, H.; Muqeet, H.A.; Shehzad, M.; Jamil, M.; Khan, A.A.; Guerrero, J.M. Optimal Energy Management of a Campus Microgrid Considering Financial and Economic Analysis with Demand Response Strategies. *Energies* **2021**, *14*, 8501. [CrossRef]
15. Pothireddy, K.M.R.; Vuddanti, S.; Salkuti, S.R. Impact of Demand Response on Optimal Sizing of Distributed Generation and Customer Tariff. *Energies* **2022**, *15*, 190. [CrossRef]

16. Romero-Ramirez, L.A.; Elvira-Ortiz, D.A.; Romero-Troncoso, R.d.J.; Osornio-Rios, R.A.; Zorita-Lamadrid, A.L.; Gonzalez-Gonzalez, S.L.; Morinigo-Sotelo, D. Spectral Kurtosis Based Methodology for the Identification of Stationary Load Signatures in Electrical Signals from a Sustainable Building. *Energies* **2022**, *15*, 2373. [CrossRef]
17. Lee, W.; Chae, M.; Won, D. Optimal Scheduling of Energy Storage System Considering Life-Cycle Degradation Cost Using Reinforcement Learning. *Energies* **2022**, *15*, 2795. [CrossRef]
18. Menniti, D.; Pinnarelli, A.; Sorrentino, N.; Vizza, P.; Barone, G.; Brusco, G.; Mendicino, S.; Mendicino, L.; Polizzi, G. Enabling Technologies for Energy Communities: Some Experimental Use Cases. *Energies* **2022**, *15*, 6374. [CrossRef]