processes

Editorial

Modeling, Control, and Optimization of Multi-Generation and Hybrid Energy Systems

Kody M. Powell * and Kasra Mohammadi

Department of Chemical Engineering, University of Utah, 50 S Central Campus Drive (Room 3290), Salt Lake City, UT 84112, USA; kasra.mohammadi@utah.edu
* Correspondence: kody.powell@utah.edu

Citation: Powell, K.M.; Mohammadi, K. Modeling, Control, and Optimization of Multi-Generation and Hybrid Energy Systems. *Processes* **2021**, *9*, 1125. https://doi.org/10.3390/pr9071125

Received: 9 June 2021
Accepted: 28 June 2021
Published: 29 June 2021

1. Introduction

As renewable energy technologies decrease in cost and become more prevalent, there is an increasing trend towards electrification of many energy systems. This is in effort to align end use of energy with the prevailing renewable electricity generation technologies: solar photovoltaic and wind energy, which are electricity-generation technologies. While this electrification effort will be beneficial in many ways, there remain significant challenges associated with the exclusive adoption of renewable energy technologies. One of these challenges is the intermittency of renewable energy sources. Another is the fact that not all end uses of energy are electrical. While they may perhaps need to be applied situationally, multi-generation and hybrid energy systems can greatly enhance the efficiency, reliability, and economics of renewable energy systems. For instance, solar thermal power plants can produce more than just electricity, and the ability to cogenerate multiple products, such as fresh water, can dramatically improve the overall system efficiency [1,2]. Similarly, hybrid solar thermal power generation systems, relying on a complimentary energy source, such as natural gas, have actually proven to increase the amount of solar energy harnessed and improve the reliability compared to a stand-alone solar thermal system [3,4]. Hybrid and multi-generation energy systems can enhance overall energy performance largely because they give a system more flexibility. This flexibility can be exploited via optimization techniques centered on maximizing efficiency, minimizing cost, or minimizing environmental impact.

This special issue of *Processes* highlights many different ways that novel multi-generation or hybrid energy systems can enhance overall energy system performance. The papers in this issue can be broadly divided into three categories: (1) multi-generation and district energy systems, (2) hybrid power generation applications, and (3) coordination at the grid or micro-grid level to better enable multiple sources of energy. With a hybrid or multi-generation system, automation and optimization are essential. This special issue focuses on modeling, control, and optimization of these systems and each contributed paper contains these elements. Using these tools of process systems engineering, the performance of hybrid energy systems can be enhanced from an economic, environmental, or reliability standpoint.

2. Multi-Generation and District Energy Systems

In their paper on combined cooling, heating, and power (CCHP) systems, Zheng et al. conducted multi-objective optimization on the design of a plant equipped with photovoltaics, wind, natural gas, thermal storage (both heat and cooling), and absorption cooling. The design of the system can be adapted in order to optimize different objective functions. Their study shows that this system is capable of reducing total investment costs, increasing environmental benefits, and increasing system reliability [5]. In terms of operational optimization of CCHP systems, Xu et al. proposed a staged optimization strategy designed to help with scheduling of the system. Their strategy includes a day-ahead economic scheduling stage, an intraday rolling optimization stage, and a real-time adjustment stage. Their strategy helps to account for potential forecasting errors and allows the system to be both economical and reliable [6]. Chen and Wang also focused on optimal system scheduling for integrated energy systems. Their multi-objective optimization algorithm helps to improve the economic dispatch of integrated energy systems [7]. From a modeling and energy/exergy analysis standpoint, Zhang et al. explored various hybrid configurations of absorption chillers, designed to recover waste heat and convert it to cooling energy. Their hybrid designs improved the peak coefficient of performance (COP) of the system by up to 15% [8]. Another method of process cooling is through lake water heat pump systems. Shahzad et al. completed a performance assessment of a closed loop system in Pakistan and found that an average COP as high as 3.46 could be achieved with this system [9]. Modeling of district heating networks can also provide valuable insight. Hanus et al. evaluated a combined heat and power (CHP)-driven steam heating network for an industrial complex. Their thermo-hydrodynamic model helps to identify bottlenecks in the process so that improvement opportunities can be identified [10]. For optimization of complex hybrid energy systems, Quah et al. proposed a novel methodology for process optimization. Rather than traditional methods that require a process model that is frequently pinged to determine optimal operation, they proposed using reinforcement learning and demonstrated that computational speeds can be dramatically enhanced compared to more conventional methods [11].

3. Hybrid Power Generation Applications

Modeling, control, and optimization are also important in power generation applications. In their study on concentrated solar power (CSP), Al-Kouz et al. used the System Advisor Model to evaluate a plant with thermal energy storage. Their results showed capacity factors of up to 41%, demonstrating that CSP plants with storage are getting more reliable [12]. Reliability of renewable power generation systems can also be enhanced with good control algorithms. Hamed et al. demonstrated that by applying nonlinear structural control to an offshore wind turbine system. They focused on vibration control, stability, and energy transfer by using advanced control techniques, yielding very positive results [13]. Advanced control and optimization techniques can help make important decisions about complex energy systems. Niegodajew et al. demonstrated this by applying the Nelder-Mead approach to a modern thermal power plant. Their results show that optimization can be achieved in combination with advanced software packages, such as IPSEpro and MATLAB, in order to make decisions such as setting bleed and outlet pressures on turbines [14]. Control and design decisions can also be integrated by using advanced tools such as economic linear optimal control. A study by Zhang et al. showed that this tool can be used in an integrated gasification and combined cycle (IGCC) plant to maximize plant revenue by shifting production times toward periods of high electricity prices [15].

4. Grid and Micro-Grid Applications

As process systems engineering tools have proven effective in power generation applications, they are also effective in grid regulation applications. For multiple plant coordination efforts, Xu et al. developed an event-triggered communication mechanism to be used for optimal frequency regulation of multiple power generation stations on the grid. This algorithm allows for multiple distributed systems to coordinate with minimal communication burden [16]. On a similar topic, Weng et al. also developed a hybrid-triggered mechanism for distributed secondary control of islanded microgrids [17]. Luo et al. developed a multi-timescale rolling optimal dispatch methodology, which they applied to grid-connected AC/DC hybrid microgrids. In their paper, they propose a three-timescale system that helps to coordinate grid operations with day-ahead, intraday, and real-time dispatching stages [18]. While hybrid power generation systems are connected electrically at the grid level, the grid interfaces with end uses of energy. Other forms of energy, such as thermal and mechanical, can also affect grid operations. Simmons et al. demonstrated this in their study on using proactive energy optimization of residential buildings. They use weather and market forecasts to incentivize home owners to store energy via batteries, schedule their appliances, and use their HVAC system as a thermal battery. Their work demonstrated cost reductions of up to 40% for homeowners [19]. Although there may be a substantial benefit for homeowners to change their energy behavior, the use of market signals at the grid level can also be a way to turn residential buildings into a grid asset. On a similar topic, Sheha et al. have demonstrated that a real-time market can be an effective means for coordinating demand-side behavior, allowing the grid to leverage distributed energy resources such as battery storage and home energy management systems [20,21].

5. Conclusions

This special issue includes many innovative designs as well as modeling, control, and optimization techniques for hybrid and multi-generation energy systems. Each of these works contains a novel contribution to science and engineering with the mission of improving the reliability, efficiency, environmental performance, or cost of these systems. They have demonstrated that hybridizing a system to give it more flexibility can indeed improve system performance and that the tools of process systems engineering are invaluable in realizing these benefits.

Funding: This work received no funding.

Conflicts of Interest: The authors of this editorial declare no conflict of interest.

References

1. Mohammadi, K.; Saghafifar, M.; Ellingwood, K.; Powell, K. Hybrid concentrated solar power (CSP)-desalination systems: A review. *Desalination* **2019**, *468*, 114083. [CrossRef]
2. Mohammadi, K.; Khanmohammadi, S.; Khorasanizadeh, H.; Powell, K. A comprehensive review of solar only and hybrid solar driven multigeneration systems: Classifications, benefits, design and prospective. *Appl. Energy* **2020**, *268*, 114940. [CrossRef]
3. Rashid, K.; Safdarnejad, S.M.; Powell, K.M. Process intensification of solar thermal power using hybridization, flexible heat integration, and real-time optimization. *Chem. Eng. Process. Process. Intensif.* **2019**, *139*, 155–171. [CrossRef]
4. Rashid, K.; Ellingwood, K.; Safdarnejad, S.M.; Powell, K.M. Designing Flexibility into a Hybrid Solar Thermal Power Plant by Real-Time, Adaptive Heat Integration. *Comput. Aided Chem. Eng.* **2019**, *2019*, 457–462. [CrossRef]
5. Zheng, L.; Wang, X.; Jiang, B. Multi-Objective Optimal Configuration of the CCHP System. *Processes* **2020**, *8*, 351. [CrossRef]
6. Xu, Y.; Luo, Z.; Zhu, Z.; Zhang, Z.; Qin, J.; Wang, H.; Gao, Z.; Yang, Z. A Three-Stage Coordinated Optimization Scheduling Strategy for a CCHP Microgrid Energy Management System. *Processes* **2020**, *8*, 245. [CrossRef]
7. Chen, S.; Wang, S. An Optimization Method for an Integrated Energy System Scheduling Process Based on NSGA-II Improved by Tent Mapping Chaotic Algorithms. *Processes* **2020**, *8*, 426. [CrossRef]
8. Zhang, X.; Cai, L.; Chen, T. Energetic and Exergetic Investigations of Hybrid Configurations in an Absorption Refrigeration Chiller by Aspen Plus. *Processes* **2019**, *7*, 609. [CrossRef]
9. Shahzad, M.K.; Rehan, M.A.; Ali, M.; Mustafa, A.; Abbas, Z.; Mujtaba, M.; Akram, M.I.; Yousaf, M.R. Cooling Performance Assessment of a Slinky Closed Loop Lake Water Heat Pump System under the Climate Conditions of Pakistan. *Processes* **2019**, *7*, 553. [CrossRef]
10. Hanus, K.; Variny, M.; Illés, P. Assessment and Prediction of Complex Industrial Steam Network Operation by Combined Thermo-Hydrodynamic Modeling. *Processes* **2020**, *8*, 622. [CrossRef]
11. Quah, T.; Machalek, D.; Powell, K.M. Comparing Reinforcement Learning Methods for Real-Time Optimization of a Chemical Process. *Processes* **2020**, *8*, 1497. [CrossRef]
12. Al-Kouz, W.; Almuhtady, A.; Abu-Libdeh, N.; Nayfeh, J.; Boretti, A. A 140 MW Solar Thermal Plant in Jordan. *Processes* **2020**, *8*, 668. [CrossRef]
13. Hamed, Y.S.; Aly, A.A.; Saleh, B.; Alogla, A.F.; Aljuaid, A.M.; Alharthi, M.M. Nonlinear Structural Control Analysis of an Offshore Wind Turbine Tower System. *Processes* **2019**, *8*, 22. [CrossRef]
14. Niegodajew, P.; Marek, M.; Elsner, W.; Kowalczyk, Ł. Power Plant Optimisation—Effective Use of the Nelder-Mead Approach. *Processes* **2020**, *8*, 357. [CrossRef]
15. Zhang, J.; Fracaro, S.G.; Chmielewski, D.J. Integrated Process Design and Control for Smart Grid Coordinated IGCC Power Plants Using Economic Linear Optimal Control. *Processes* **2020**, *8*, 288. [CrossRef]
16. Xu, S.; Sun, H.; Zhao, B.; Yi, J.; Weng, S.; Chen, J.; Dou, C. Distributed Optimal Frequency Regulation for Multiple Distributed Power Generations with an Event-Triggered Communication Mechanism. *Processes* **2020**, *8*, 169. [CrossRef]

17. Weng, S.; Xue, Y.; Luo, J.; Li, Y. Distributed Secondary Control for Islanded Microgrids Cluster Based on Hybrid-Triggered Mechanisms. *Processes* **2020**, *8*, 370. [CrossRef]
18. Luo, Z.; Zhu, Z.; Zhang, Z.; Qin, J.; Wang, H.; Gao, Z.; Yang, Z. Multi-Time-Scale Rolling Optimal Dispatch for Grid-Connected AC/DC Hybrid Microgrids. *Processes* **2019**, *7*, 961. [CrossRef]
19. Simmons, C.R.; Arment, J.R.; Powell, K.M.; Hedengren, J.D. Proactive Energy Optimization in Residential Buildings with Weather and Market Forecasts. *Processes* **2019**, *7*, 929. [CrossRef]
20. Sheha, M.; Powell, K. Using Real-Time Electricity Prices to Leverage Electrical Energy Storage and Flexible Loads in a Smart Grid Environment Utilizing Machine Learning Techniques. *Processes* **2019**, *7*, 870. [CrossRef]
21. Sheha, M.N.; Powell, K.M. Dynamic Real-Time Optimization of Air-Conditioning Systems in Residential Houses with a Battery Energy Storage under Different Electricity Pricing Structures. *Comput. Aided Chem. Eng.* **2018**, *44*, 2527–2532. [CrossRef]