IJEES

International Journal of Electrical Engineering and Sustainability (IJEES)

https://ijees.org/index.php/ijees/index

Volume 1 | Number 1 | January-March 2023 | Pages 9-17

Editorial Article

Recent Advances in Energy Storage Technologies

Abdussalam Ali Ahmed [1]*, Abdulagader Alsharif [2], Nassar Yasser [3]

[1]Department of Mechanical Engineering, Faculty of Engineering, Bani Waleed University, Bani Waleed, Libya

[2]School of Electrical Engineering, Faculty of Engineering, Universiti Teknologi Malaysia (UTM) Johor Bahru, Malaysia

[3]Mechanical and Renewable Energy Engineering Department, Faculty of Engineering, Wadi Alshatti University, Libya

*Corresponding author: abdussalam.a.ahmed@gmail.com

Received: December 07, 2022 Accepted: January 18, 2023 Published: January 25, 2023

Keywords: Energy Storage Technologies; Thermal Energy Storage; Mechanical Energy Storage; Chemical Energy Storage; Electrochemical Energy Storage; Electrical Energy Storage.

Editorial on the Research Topic

Recent Advances in Energy Storage Technologies

The global adoption of renewable energy alternatives is rapidly increasing at an unprecedented pace in response to the mounting environmental crisis caused by CO2 emissions. Renewable energy systems possess immense potential to decarbonize the environment owing to their ability to generate energy without releasing greenhouse gases or other polluting emissions [1,2]. Nevertheless, renewable energy systems are reliant on natural resources such as sunlight, wind, water, and geothermal, which are inherently unpredictable and fluctuate based on weather patterns, seasons, and years. To account for these intermittencies, renewable energy can be stored using various techniques and subsequently utilized in a consistent and controlled manner as required [3-5]. Over the past century, numerous researchers from across the globe have made significant contributions to developing innovative methods of energy storage that are efficient enough to address the escalating energy demand and technological advancements.

According to a recent survey by the International Energy Agency (IEA), there is a promising increase in electricity generation from renewable sources, with a projected growth of more than 8% and an expected production level of 8,300 TWh in 2021. Moreover, to align with the objectives of the Paris Agreement, which aims to limit the average global temperature increase to below 2°C, the International Renewable Energy Agency (IRENA) has suggested that the share of renewable sources in global energy generation must reach 57% by 2030 [6]. The renewable energy sector has already achieved a remarkable milestone, accounting for 30% of the power generation mix in 2021, with solar photovoltaic and wind energy sources contributing significantly, contributing to approximately two-thirds of the overall growth of renewable energy production, with an estimated increase in renewable electricity generation of approximately 18% and 17%, respectively [7-12].

Numerous authors have investigated energy storage technologies (ESTs) in the literature due to their wide range of applications and diverse varieties. However, these reviews often exhibit limitations concerning the types of ESTs that are covered. Some assessments exclusively focus on electrical energy storage systems (EESSs), while disregarding the existence of thermal or chemical energy storage systems. There are only a few reviews in the literature that provide a comprehensive overview of all the major ESSs available. Previous research by [13-18] has presented an overview of various ESTs, followed by a detailed comparison based on technical and economic data, while other studies [19-25] offered a technological, economic, and environmental evaluation of mechanical, electrochemical, chemical, and thermal energy storage systems. Studies by [26-30] have demonstrated numerous EST categorizations, comparisons, applications, and recent advancements.

Thermal energy storage (TES) systems are designed specifically to store heat energy through a range of methods, such as cooling, heating, melting, condensing, or vaporizing a substance. The materials used in TES systems are stored in an insulated repository at either high or low temperatures, depending on the operating temperature range [31-36]. The energy recovered from these materials is subsequently employed for various residential and industrial applications, such as space heating or cooling, hot water production, or electricity generation, depending on the temperature range. TES systems are utilized for diverse purposes, such as industrial cooling below -18°C, building cooling between 0 and 12°C, heating buildings between 25 and 50°C, and industrial heat storage above 175°C [37-45]. TES systems are categorized into two groups based on the operating temperature of the energy storage material concerning the ambient temperature, namely, low-Temperature Energy Storage (LTES) systems and high-temperature energy storage (HTES) systems [46-51].

The mechanical energy storage (MES) system operates by transforming energy between mechanical and electrical forms [53,54]. During periods of low demand, electrical energy from the power source is converted and stored as mechanical energy in the form of potential or kinetic energy. This stored mechanical energy is then transformed back into electrical power during peak hours [55-60]. MES systems can be categorized into three different types: pumped hydro energy storage (PHES), gravity energy storage (GES), compressed air energy storage (CAES), and flywheel energy storage (FES). PHES, GES, and CAES systems store potential energy, while FES systems store kinetic energy. The key advantage of the MES system is its ability to rapidly convert and release stored mechanical energy [61,62].

Previous study work [63-66] has shown that the first pumped hydro energy storage (PHES) plants were constructed in the Alpine regions of Switzerland, Austria, and Italy in the 1890s. The early PHES plants utilized separate pump impellers and turbine generators. However, a new design was introduced in the 1950s that incorporated a single reversible pump-turbine unit, which subsequently became the preferred design for PHES plants. The development of PHES was initially slow until the 1960s, but from the 1960s to the late 1980s, significant progress was observed, primarily due to the deployment of nuclear power plants, which were complemented by the flexibility of PHES. During the 1990s, global PHES growth slowed significantly, primarily due to the scarcity and saturation of suitable and cost-effective geographical locations, as well as a deceleration in nuclear development [67-71]. Since 2000, numerous PHES plants have been built across Europe, particularly in Germany and Austria. PHES was developed to address the challenges associated with fluctuating electricity demand at different times of the day, particularly for major thermal and nuclear power plants. Initially, PHES plants were constructed as a system tool to supply energy during peak demand and support baseload power plants in operating at high efficiency during periods of low demand.

Pumped Hydro Energy Storage (PHES) is the most widely implemented Mechanical Energy Storage (MES) system due to its significant energy capacity, prolonged storage period, and high efficiency [72-74]. A typical PHES system comprises two large reservoirs situated at different elevations, a water pumping unit that transfers water from the lower reservoir to the upper reservoir, and a turbine that generates electricity as water flows back down from the higher to the lower reservoir. During off-peak hours (charging process), electrical energy from the power source is converted into mechanical energy, which is then transformed into potential energy by pumping and storing water from the lower reservoir to the upper reservoir via the pump. During peak hours (discharging process), the stored water from the upper reservoir is released back into the lower reservoir, causing the turbines to rotate and generate electricity through generators [75-77]. By transferring water between two reservoirs at different elevations, PHES stores and generates energy in the form of potential energy. The quantity of water stored in the reservoirs and the elevation difference determine the amount of energy stored.

The gravity energy storage (GES) system has emerged as a promising alternative to pumped hydro energy storage (PHES) due to the geological limitations and water requirements associated with the latter [78-79]. The GES system stores energy by lifting a piston or any other object with the requisite mass using water and then dropping the piston to push the water back through hydroelectric generators when power is required. This storage concept, known as the gravity power module, was proposed by gravity power, LLC [80]. The powerhouse is composed of a pump, turbine, and motor/generator.

During the charging cycle, off-peak electricity powers the motor/generator, which drives the pump and converts electrical energy into mechanical energy.

Chemical energy storage (CES) systems are well-suited for the long-term storage of chemical energy, which is stored in the chemical bonds between atoms and molecules of materials. The stored chemical energy is released during chemical reactions, leading to changes in the composition of the materials as the original chemical bonds break and new ones form. Currently, chemical fuels are the primary source of energy for both the electricity generation and transportation sectors globally. Common chemical fuels include coal, gasoline, diesel fuel, natural gas, liquefied petroleum gas (LPG), propane, butane, ethanol, and hydrogen. These chemicals are first converted into mechanical energy and subsequently into electrical energy, which is then used to generate electricity. CES systems typically comprise hydrogen, synthetic natural gas, and solar fuel storage systems [80-82].

In this context, hydrogen is considered an exceptional energy carrier as it is a clean chemical energy carrier that is free of carbon emissions [83-85]. Its production can be accomplished by water electrolysis or direct sunlight-driven photocatalytic water splitting. A typical hydrogen energy system consists of three primary components. These include (i) a hydrogen generation unit, such as an electrolyze, that converts the electrical energy input into hydrogen, (ii) a hydrogen storage system, and (iii) a hydrogen energy conversions unit, such as a fuel cell (FC) or regenerative FC, which converts the stored chemical energy in hydrogen back into electrical energy. **Figure 1**, illustrates the fuel cell with additional components.

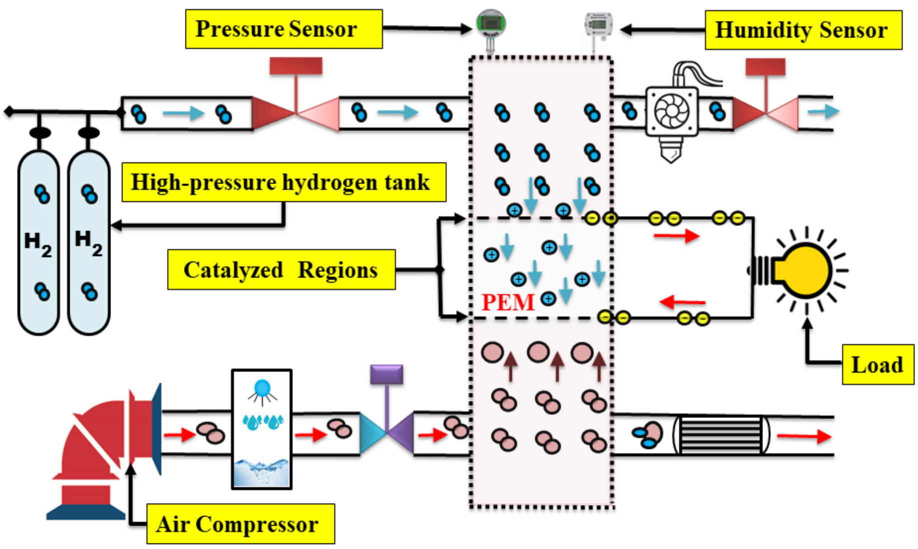

Figure 1. Fuel cells with additional components [42].

During the charging process, excess power is utilized to produce hydrogen from water via electrolysis, which is subsequently stored in a storage tank. When power availability is limited during peak hours, electricity is generated from the stored hydrogen using fuel cells during the discharging cycle. Electrolysis, a process that employs an electrolyser, is used to split water into hydrogen and oxygen. The oxygen is then released into the atmosphere, while hydrogen is stored in the storage tank [80-83]. Moreover, a fuel cell consists of four main components: an anode, a cathode, an electrolyte, and an external circuit. At the anode, hydrogen is oxidized to protons (positively charged hydrogen ions) and electrons to drive the fuel cell. The positively charged hydrogen ions from the anode are conveyed to the oxygen electrode via the electrolyte. The reaction of oxygen, hydrogen ions, and electrons at the cathode produces water and heat. During this process, electrons flow from the anode to the cathode through an external circuit, resulting in current flow and, ultimately, electricity production [86].

Electrochemical energy storage (EcES) systems are the most commonly used energy storage systems, primarily operating via three major processes. EcES is primarily classified into two categories: (a) battery energy storage (BES) systems, in which charge is stored within the electrodes, and (b) flow battery energy storage (FBES) systems, in which charge is first stored within the fuel and then externally supplied to the surface of the electrodes. In addition to these two traditional energy storage technologies, extensive research is being conducted into the electrochemical storage capabilities to address the increasing demand for lightweight, compact, and flexible electronic devices. In this direction, Battery energy storage (BES) systems are electrochemical devices that convert chemical energy into electrical energy. They comprise multiple cells, each of which encompasses three fundamental components, namely two electrodes - an anode and a cathode - and an electrolyte. BES systems are broadly classified into primary and secondary batteries. While primary batteries are designed for single use and cannot be recharged once the chemical is depleted, secondary batteries are intended to be rechargeable. Depending on the electrode and electrolyte material, secondary batteries are classified as lead-acid (LA), lithium-ion, nickel-cadmium (Ni-Cd), sodium sulphur (NaS), sodium-ion (Na-ion), and metal-air batteries. Lead-acid (LA) batteries, which were invented in 1859, are the oldest and most widely used electrochemical energy storage devices. These batteries consist of two electrodes, a metallic sponge lead anode and a lead dioxide cathode, immersed in an electrolyte composed of 37% sulfuric acid and 63% water. The two electrodes are separated by a porous separator that prevents direct electron flow from the anode to the cathode [85-87]. During the discharge cycle, both electrodes are covered with lead sulfate, and the electrolyte is reduced to water. Upon charging, both electrodes return to their initial state. LA batteries are classified into two types, namely flooded lead-acid (FLA) and valve-regulated lead-acid (VRLA), both of which operate on the same principle. However, VRLA batteries are constructed differently and are generally sealed with a pressure-regulating valve to prevent air from entering the cells.

Electrical energy storage (EES) systems store energy in an electric field without converting it into other forms of energy. EES systems can be broadly classified into two categories: electrostatic energy storage systems and magnetic energy storage systems. Examples of electrostatic energy storage systems include capacitors and supercapacitors while superconducting magnetic energy storage (SMES) represents a type of magnetic energy storage system. A capacitor, when charged, stores electrical energy by utilizing an electrostatic field [45,48]. It is composed of two closely spaced metal plates separated by a dielectric layer made of non-conductive material. During operation, when a voltage source is applied across the metal plates, one plate is charged with electricity, while the opposite sign induces the other plate. A capacitor's energy storage capacity is dependent on the size and spacing between the conducting plates. Due to their low energy density, capacitors can only handle high currents for brief periods.

Supercapacitors, also referred to as electric double-layer capacitors (EDLCs) or ultracapacitors consist of two conducting electrodes, an electrolyte, and a separator. They store energy in the form of an electrostatic field that arises from a continuous direct current (DC) voltage supplied between two electrodes separated by a thin insulator or dielectric material [15,54,71]. The two electrodes, composed of activated carbon, provide a larger surface area, resulting in higher energy density. A porous membrane separates the two electrodes, enabling charged ions to move freely while preventing electronic contact between them. When the electrodes are charged by an applied DC voltage, ions in the electrolyte diffuse into the pores of the electrode with an opposite charge.

The electricity grid has become an indispensable part of modern society. It supplies electricity to millions of people every day and powers various industries and businesses. However, the grid faces numerous challenges, including the integration of renewable energy sources and the need for increased flexibility and reliability. One solution to these challenges is the use of energy storage systems (ESS) on the grid. Energy Storage Technologies (ESTs) are increasingly being used to enhance the stability and reliability of power grids. ESTs can help mitigate the variability of renewable energy sources, improve power quality, and provide backup power during outages [55-62]. Renewable energy integration: ESTs can be used to store excess energy generated by renewable sources such as wind and solar. This stored energy can be used during times of low generation, such as when the wind is not blowing or the sun is not shining.

ESTs can be used to reduce peak demand on the grid. By storing energy during periods of low demand and releasing it during periods of high demand, ESTs can help balance the grid and avoid the need for expensive peaker plants. ESTs can help maintain grid stability by providing frequency regulation services. By charging and discharging the batteries as needed, ESTs can help balance the grid frequency and prevent blackouts. ESTs can be used to create Microgrids, which are small-scale power systems that can operate independently from the main grid. Microgrids can be used to provide backup power during outages, improve grid reliability, and reduce energy costs. Voltage support: ESTs can help improve power quality by providing voltage support [87]. By storing energy during times of high voltage and releasing it during times of low voltage, ESTs can help maintain a stable voltage on the grid. To sum up, ESTs have the potential to revolutionize the way we generate and consume electricity. As the cost of ESTs continues to decline and new technologies emerge, we can expect to see even more applications of ESTs on power grids in the future.

Author Contributions: All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Acknowledgments: We would like to take this opportunity to express our sincere gratitude to the Bani Waleed University and Universiti Teknologi Malaysia (UTM) for their invaluable technical support during our research.

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

References

1. Abomazid, A. M., El-Taweel, N. A., & Farag, H. E. Z. (2022). Optimal energy management of hydrogen energy facility using integrated battery energy storage and solar photovoltaic systems. *IEEE Transactions on Sustainable Energy*, *13*(3), 1457–1468.
2. Alami, A. H. (2020). Recent innovations and applications of mechanical energy storage technologies. In *Mechanical Energy Storage for Renewable and Sustainable Energy Resources* (pp. 93–98). Cham: Springer International Publishing.
3. Amunátegui, B., Ibáñez, A., Sierra, M., & Pérez, M. (2018). Electrochemical energy storage for renewable energy integration: zinc-air flow batteries. *Journal of Applied Electrochemistry*, *48*(6), 627–637.
4. Thiyagarajan, S. R., Emadi, H., Hussain, A., Patange, P., & Watson, M (2022). A comprehensive review of the mechanisms and efficiency of underground hydrogen storage. Journal of Energy Storage, 51(104490), 104490.
5. Khaleel, M. M., Adzman, M. R., & Zali, S. M (2021). An integrated hydrogen fuel cell to distribution network system: Challenging and opportunity for D-STATCOM. *Energies*, 14(21), 7073.
6. IEA 2021. Global Energy Review 2020 https://www.iea.org/reports/ global- energy- review- 2021 (Accessed 17 January 2023.
7. Arroyo, J. M., Baringo, L., Baringo, A., Bolanos, R., Alguacil, N., & Cobos, N. G. (2020). On the use of a convex model for bulk storage in MIP-based power system operation and planning. *IEEE Transactions on Power Systems: A Publication of the Power Engineering Society*, *35*(6), 4964–4967.
8. Balsamo, F., De Falco, P., Mottola, F., & Pagano, M. (2020). Power flow approach for modeling shipboard power system in presence of energy storage and energy management systems. *IEEE Transactions on Energy Conversion*, *35*(4), 1944–1953. Bharatee, A., K. Ray, P., & Ghosh, A. (2022). A power management scheme for grid-connected PV integrated with hybrid energy storage system. *Journal of Modern Power Systems and Clean Energy*, *10*(4), 954–963.
9. Alsharif, A., Tan, C. W., Ayop, R., Ali Ahmed, A., Mohamed Khaleel, M., & Abobaker, A. K. (2022). Power management and sizing optimization for hybrid grid-dependent system considering photovoltaic wind battery electric vehicle. *2022 IEEE 2nd International Maghreb Meeting of the Conference on Sciences and Techniques of Automatic Control and Computer Engineering (MI-STA)*. IEEE.
10. Koohi-Fayegh, S., & Rosen, M. A. (2020). A review of energy storage types, applications and recent developments. Journal of Energy Storage, 27(101047).
11. Akinyele D., Rayudu R., (2014). Review of energy storage technologies for sustainable power networks, Sustain. Energy Technol. Assess. 8, 74–91.
12. Khaleel, M. M. (2023). Intelligent Control Techniques for Microgrid Systems. *Brilliance: Research of Artificial Intelligence*, 3(1), 56–67.
13. Díaz-González, F., Bullich-Massagué, E., Vitale, C., Gil-Sánchez, M., Aragüés-Peñalba, M., & Girbau-Llistuella, F. (2019). Services of energy storage technologies in renewable-based power systems. In *Smart Cities* (pp. 53–64).

14. Doroudchi, E., Khajeh, H., & Laaksonen, H. (2022). Increasing self-sufficiency of energy community by common thermal energy storage. *IEEE Access: Practical Innovations, Open Solutions*, *10*, 85106–85113. doi:10.1109/access.2022.3195242
15. Fan, F., Kockar, I., Xu, H., & Li, J. (2022). Dynamic optimal power flow based scheduling framework for battery energy storage system. *CSEE Journal of Power and Energy Systems*, *8*(1), 271–280.
16. M. Guney, Y. Tepe, Classification and assessment of energy storage systems, Renew. Sustain. Energy Rev. 75 1187–1197.
17. Khaleel, M. M., Abulifa, S. A., & Abulifa, A. A. (2023). Artificial intelligent techniques for identifying the cause of disturbances in the power grid. Brilliance: *Research of Artificial Intelligence*, 3(1), 19–31.
18. Byers, C., & Botterud, A. (2020). Additional capacity value from synergy of variable renewable energy and energy storage. *IEEE Transactions on Sustainable Energy*, *11*(2), 1106–1109. doi:10.1109/tste.2019.2940421
19. Chen, J., & Song, X. (2015). Economics of energy storage technology in active distribution networks. *Journal of Modern Power Systems and Clean Energy*, *3*(4), 583–588. doi:10.1007/s40565-015-0148-5
20. Cheng, C.-C., Gao, J.-T., & Lo, K.-Y. (2020). Hot-swappable grid-connected multilevel converter for battery energy storage system. *IEEE Transactions on Circuits and Systems. II, Express Briefs: A Publication of the IEEE Circuits and Systems Society*, *67*(10), 2109–2113. doi:10.1109/tcsii.2019.2951707
21. Khaleel, M. M., Alsharif, A., & Imbayah, I. I. K. (2022). Renewable energy technologies: Recent advances and future predictions. *African Journal of Advanced Pure and Applied Sciences (AJAPAS)*., Vol. 1, Issue 3, pp. 58-64.
22. Gautam A., Saini R., (2020). A review on technical, applications and economic aspect of packed bed solar thermal energy storage systems, J. Energy Storage. 27,101046.
23. Khaleel, M. M., Mohamed Ghandoori, T., Ali Ahmed, A., Alsharif, A., Ahmed Alnagrat, A. J., & Ali Abulifa, A. (2022). Impact of mechanical storage system technologies: A powerful combination to empowered the electrical grids application. *2022 IEEE 2nd International Maghreb Meeting of the Conference on Sciences and Techniques of Automatic Control and Computer Engineering (MI-STA), 628–636. IEEE.*
24. Gao, H., Chen, M., Hong, J., Song, Y., & Yan, Y. (2021). Investigation on battery thermal management based on phase change energy storage technology. *Warme- Und Stoffubertragung [Heat and Mass Transfer]*.
25. Gao, H., Liu, Y., Hong, J., Song, Y., & Yan, Y. (2021). Investigation on battery thermal management based on phase change energy storage technology. In *Advances in Heat Transfer and Thermal Engineering* (pp. 553–562).
26. Gao, T., Jiang, L., Liu, K., Xiong, D., Lin, Z., Bu, W., & Chen, Y. (2021). Field exploration and analysis of power grid side battery energy storage system. *IEEE Access: Practical Innovations, Open Solutions*, *9*, 63213–63218.
27. Khaleel, M. M., Ahmed, A. A., & Alsharif, A. (2023). Energy Management System Strategies in Microgrids: A Review. *The North African Journal of Scientific Publishing (NAJSP)*, 1(1), 1–8.
28. T. Gür, Review of electrical energy storage technologies, materials and systems: challenges and prospects for large-scale grid storage, Energy Environ. Sci. 10 (2018) 2696–2767.
29. Garcia-Pereira, H., Blanco, M., Martinez-Lucas, G., Perez-Diaz, J. I., & Sarasua, J.-I. (2022). Comparison and influence of flywheels energy storage system control schemes in the frequency regulation of isolated power systems. *IEEE Access: Practical Innovations, Open Solutions*, *10*, 37892–37911.
30. Gulzar, M. M., Iqbal, A., Sibtain, D., & Khalid, M. (2023). An innovative converterless solar PV control strategy for a grid connected hybrid PV/wind/fuel-cell system coupled with battery energy storage. *IEEE Access: Practical Innovations, Open Solutions*, *11*, 23245–23259.
31. Khaleel, M. M., Abulifa, S. A., Abdaldeam, I. M., Abulifa, A. A., Amer, M., & Ghandoori, T. M. (2023). A current assessment of the renewable energy industry. *African Journal of Advanced Pure and Applied Sciences (AJAPAS)*, 2(1), 122–127.
32. Guo, Z., Wei, W., Chen, L., Dong, Z. Y., & Mei, S. (2021). Impact of energy storage on renewable energy utilization: A geometric description. *IEEE Transactions on Sustainable Energy*, *12*(2), 874–885.
33. Guo, Z., Wei, W., Chen, L., Shahidehpour, M., & Mei, S. (2021). Economic value of energy storages in unit commitment with renewables and its implication on storage sizing. *IEEE Transactions on Sustainable Energy*, *12*(4), 2219–2229.
34. Huang, W., Zhang, X., Li, K., Zhang, N., Strbac, G., & Kang, C. (2022). Resilience oriented planning of urban multi-energy systems with generalized energy storage sources. *IEEE Transactions on Power Systems: A Publication of the Power Engineering Society*, *37*(4), 2906–2918.
35. Jo, H.-C., Byeon, G., Kim, J.-Y., & Kim, S.-K. (2021). Optimal scheduling for a zero net energy community microgrid with customer-owned energy storage systems. *IEEE Transactions on Power Systems: A Publication of the Power Engineering Society*, *36*(3), 2273–2280. doi:10.1109/tpwrs.2020.3036077
36. Kang, W., Chen, M., Guan, Y., Tang, L., Vasquez, J. C., & Guerrero, J. M. (2022). Distributed event-triggered optimal control method for heterogeneous energy storage systems in smart grid. *IEEE Transactions on Sustainable Energy*, *13*(4), 1944–1956. doi:10.1109/tste.2022.3176741

37. Khaleel, M. M., Ahmed, A. A., & Alsharif, A. (2023a). Artificial Intelligence in Engineering. *Brilliance: Research of Artificial Intelligence*,2023, 3(1), 32–42.
38. Kermani, M., Shirdare, E., Parise, G., Bongiorno, M., & Martirano, L. (2022). A comprehensive technoeconomic solution for demand control in ports: Energy storage systems integration. *IEEE Transactions on Industry Applications*, *58*(2), 1592–1601.
39. Kumar, S., Krishnasamy, V., Kaur, R., & Kandasamy, N. K. (2022). Virtual energy storage-based energy management algorithm for optimally sized DC nanogrid. *IEEE Systems Journal*, *16*(1), 231–239.
40. Li, X., China Electric Power Research Institute, Wang, S., & China Electric Power Research Institute. (2019). A review on energy management, operation control and application methods for grid battery energy storage systems. *CSEE Journal of Power and Energy Systems*, *7*(5), 1026–1040.
41. Li, X., Ma, R., Yan, N., Wang, S., & Hui, D. (2021). Research on optimal scheduling method of hybrid energy storage system considering health state of echelon-use lithium-ion battery. *IEEE Transactions on Applied Superconductivity: A Publication of the IEEE Superconductivity Committee*, *31*(8), 1–4.
42. Khaleel, M. M., Adzman, M. R., & Zali, S. M. An integrated of hydrogen fuel cell to distribution network system: Challenging and opportunity for D-STATCOM. *Energies*, 2021, 14(21), 7073.
43. Mitra, J., & Nguyen, N. (2022). Grid-scale virtual energy storage to advance renewable energy penetration. *IEEE Transactions on Industry Applications*, *58*(6), 7952–7965.
44. Mitra, S. K., & Karanki, S. B. (2023). An SOC based adaptive energy management system for hybrid energy storage system integration to DC grid. *IEEE Transactions on Industry Applications*, *59*(1), 1152–1161.
45. Mohammadi, M., Noorollahi, Y., & Mohammadi-Ivatloo, B. (2018). Impacts of energy storage technologies and renewable energy sources on energy hub systems. In *Operation, Planning, and Analysis of Energy Storage Systems in Smart Energy Hubs* (pp. 23–52).
46. Nahhas, T., Py, X., & Olives, R. (2020). Life cycle assessment of air-rock packed bed storage system and its comparison with other available storage technologies for concentrating solar power plants. *Waste and Biomass Valorization*, *11*(5), 2357–2365.
47. Nonjola, P. T., Mutangwa, N., & Luo, H. (2016). Membrane separators for electrochemical energy storage technologies. In *Nanomaterials in Advanced Batteries and Supercapacitors* (pp. 417–462).
48. Khaleel, M., El-Naily, N., Alzargi, H., Amer, M., Ghandoori, T., & Abulifa, A. (20023). Recent Progress in Synchronization Approaches to Mitigation Voltage Sag Using HESS D-FACTS. *2022 International Conference on Emerging Trends in Engineering and Medical Sciences (ICETEMS),* 186–190. IEEE.
49. Wang, F., Lin, Z., Xu, B., & Fiebig, W. (2022). An electric-hydrostatic energy storage system for hydraulic hybrid wheel loader. *IEEE Transactions on Vehicular Technology*, *71*(7), 7044–7056.
50. Wang, H., & Du, Z. (2016). Dynamic analysis for the energy storage flywheel system. *Journal of Mechanical Science and Technology*, *30*(11), 4825–4831. doi:10.1007/s12206-016-1001-0
51. Wang, S., Wei, T., & Qi, Z. (2008). Supercapacitor energy storage technology and its application in renewable energy power generation system. In *Proceedings of ISES World Congress 2007 (Vol. I – Vol. V)* (pp. 2805–2809).
52. Wei, W., Wang, Z., Liu, F., Shafie-khah, M., & Catalao, J. P. S. (2021). Cost-efficient deployment of storage unit in residential energy systems. *IEEE Transactions on Power Systems: A Publication of the Power Engineering Society*, *36*(1), 525–528. doi:10.1109/tpwrs.2020.3025433
53. Alasali, F., Saidi, A. S., El-Naily, N., Alsmadi, O., Khaleel, M., & Ghirani, I. (2023). Assessment of the impact of a 10-MW grid-tied solar system on the Libyan grid in terms of the power-protection system stability. *Clean Energy*, 7(2), 389–407.
54. Liu, L., Huo, M., Guo, L., Zhang, Z., & Liu, Y. (2021). Energy storage technology development under the demand-side response: Taking the charging pile energy storage system as a case study. In *Advances in Intelligent Systems and Computing* (pp. 60–64).
55. Luin, U., & Valant, M. (2022). Electrolysis energy efficiency of highly concentrated FeCl2 solutions for power-to-solid energy storage technology. *Journal of Solid State Electrochemistry: Current Research and Development in Science and Technology*, *26*(4), 929–938.
56. Magdy, G., Bakeer, A., & Alhasheem, M. (2021). Superconducting energy storage technology-based synthetic inertia system control to enhance frequency dynamic performance in microgrids with high renewable penetration. *Protection and Control of Modern Power Systems*, *6*(1).
57. Maletin, Y. A., Stryzhakova, N. G., Zelinskyi, S. O., & Chernukhin, S. I. (2021). Energy storage technologies based on electrochemical double layer capacitors: A review. *Theoretical and Experimental Chemistry*, *57*(5), 311–324.
58. Khaleel, M. M., Ahmed, A. A., & Alsharif, A. (2023). Energy Management System Strategies in Microgrids: A Review. *The North African Journal of Scientific Publishing (NAJSP)*, 1(1), 1–8.

59. Shuai, H., Li, F., Pulgar-Painemal, H., & Xue, Y. (2021). Branching dueling Q-network-based online scheduling of a microgrid with distributed energy storage systems. *IEEE Transactions on Smart Grid*, *12*(6), 5479–5482. doi:10.1109/tsg.2021.3103405
60. Yao, L., Yang, B., Cui, H., Zhuang, J., Ye, J., & Xue, J. (2016). Challenges and progresses of energy storage technology and its application in power systems. *Journal of Modern Power Systems and Clean Energy*, *4*(4), 519–528. doi:10.1007/s40565-016-0248-x
61. Zhang, C., Dong, Z., & Yang, L. (2021). A feasibility pump based solution algorithm for two-stage robust optimization with integer recourses of energy storage systems. *IEEE Transactions on Sustainable Energy*, *12*(3), 1834–1837. doi:10.1109/tste.2021.3053143
62. Zhang, Y., Deng, Y., Zheng, Z., Yao, Y., & Liu, Y. (2023). Optimizing the operation strategy of a combined cooling, heating and power system based on energy storage technology. *Scientific Reports*, *13*(1), 2928.
63. Zohuri, B. (2018). Energy storage technologies and their role in renewable integration. In *Hybrid Energy Systems* (pp. 213–255).
64. Zohuri, B. (2019). Energy storage technologies and their role in renewable integration. In *Small Modular Reactors as Renewable Energy Sources* (pp. 247–290). Cham: Springer International Publishing.
65. Alsharif, A., Ahmed, A. A., Khaleel, M. M., & Altayib, M. A. (2023). Ancillary services and energy management for electric Vehicle: Mini-review. *The North African Journal of Scientific Publishing (NAJSP)*, 1(1), 9–12.
66. Li, X., Wang, L., Yan, N., & Ma, R. (2021). Cooperative dispatch of distributed energy storage in distribution network with PV generation systems. *IEEE Transactions on Applied Superconductivity: A Publication of the IEEE Superconductivity Committee*, *31*(8), 1–4.
67. Liu, J., Wang, Y., Wu, Y., Li, Y., & Wang, X. (2020). Research and implementation of new-type supercapacitor and battery hybrid energy storage system. *Journal of Power Electronics*, *20*(6), 1395–1404. doi:10.1007/s43236-020-00130-7
68. Nunna, H. S. V. S. K., Sesetti, A., Rathore, A. K., & Doolla, S. (2020). Multiagent-based energy trading platform for energy storage systems in distribution systems with interconnected microgrids. *IEEE Transactions on Industry Applications*, *56*(3), 3207–3217.
69. Parameshwaran, R., & Kalaiselvam, S. (2013). Thermal Energy Storage Technologies. In *Nearly Zero Energy Building Refurbishment* (pp. 483–536). London: Springer London.
70. Pati, S. S., Sahoo, P., Behera, S., Barisal, A. K., & Mishra, D. K. (2021). Frequency regulation of a multi-area renewable power system incorporating with energy storage technologies. In *Advances in Systems, Control and Automations* (pp. 83–91).
71. Ahmed, A. A., Alsharif, A., Triwiyanto, T., Khaleel, M., Tan, C. W., & Ayop, R. (2022). Using of neural network-based controller to obtain the effect of hub motors weight on electric vehicle ride comfort. *2022 IEEE 2nd International Maghreb Meeting of the Conference on Sciences and Techniques of Automatic Control and Computer Engineering (MI-STA)*, 189–192. IEEE.
72. Pulazza, G., Zhang, N., Kang, C., & Nucci, C. A. (2021). Transmission planning with battery-based energy storage transportation for power systems with high penetration of renewable energy. *IEEE Transactions on Power Systems: A Publication of the Power Engineering Society*, *36*(6), 4928–4940.
73. Ramavat, S. R., Jaiswal, S. P., Goel, N., & Shrivastava, V. (2018). Battery energy storage technology integrated for power system reliability improvement. In *Lecture Notes in Electrical Engineering* (pp. 131–140).
74. Ren, X., Sugai, T., Tokuchi, A., & Jiang, W. (2022). Solid-state Marx generator using hybrid energy storage. *IEEE Transactions on Plasma Science. IEEE Nuclear and Plasma Sciences Society*, *50*(12), 4905–4911.
75. Salimijazi, F., Parra, E., & Barstow, B. (2019). Electrical energy storage with engineered biological systems. *Journal of Biological Engineering*, *13*(1), 38. doi:10.1186/s13036-019-0162-7
76. Sayed, E. T., Olabi, A. G., Alami, A. H., Radwan, A., Mdallal, A., Rezk, A., & Abdelkareem, M. A. (2023). Renewable energy and energy storage systems. *Energies*, *16*(3), 1415.
77. Sharaf, I. M. (2021). A novel Pythagorean fuzzy MULTIMOORA applied to the evaluation of energy storage technologies. In *Pythagorean Fuzzy Sets* (pp. 273–312).
78. Sharma, S., Verma, A., Xu, Y., & Panigrahi, B. K. (2021). Robustly coordinated bi-level energy management of a multi-energy building under multiple uncertainties. *IEEE Transactions on Sustainable Energy*, *12*(1), 3–13.
79. Khaleel, M. M., Adzman, M. R., Zali, S. M., Graisa, M. M., & Ahmed, A. A. (2021). A review of fuel cell to distribution network interface using D-FACTS: Technical challenges and interconnection trends. *International Journal of Electrical and Electronic Engineering & Telecommunications*, 10(5), 319–332.
80. Sioshansi, R., Denholm, P., Arteaga, J., Awara, S., Bhattacharjee, S., Botterud, A., … Zhang, Z. (2022). Energy-storage modeling: State-of-the-art and future research directions. *IEEE Transactions on Power Systems: A Publication of the Power Engineering Society*, *37*(2), 860–875. doi:10.1109/tpwrs.2021.3104768

81. Tsioumas, E., Jabbour, N., Koseoglou, M., Papagiannis, D., & Mademlis, C. (2021). Enhanced sizing methodology for the renewable energy sources and the battery storage system in a nearly zero energy building. *IEEE Transactions on Power Electronics*, *36*(9), 10142–10156.
82. Valinejad, J., Marzband, M., Korkali, M., Xu, Y., & Saad Al-Sumaiti, A. (2020). Coalition formation of microgrids with distributed energy resources and energy storage in energy market. *Journal of Modern Power Systems and Clean Energy*, *8*(5), 906–918.
83. Worku, A. K., Ayele, D. W., Habtu, N. G., Admasu, B. T., Alemayehu, G., Taye, B. Z., & Yemata, T. A. (2022). Energy storage technologies; Recent advances, challenges, and prospectives. In *Energy Systems in Electrical Engineering* (pp. 125–150).
84. Alsharif, A., Tan, C. W., Ayop, R., Smin, A. A., Ahmed, A. A., Kuwil, F. H., & Khaleel, M. M. (2023). Impact of electric Vehicle on residential power distribution considering energy management strategy and stochastic Monte Carlo algorithm. *Energies*, 16(3), 1358.
85. Xu, Z., Han, G., Liu, L., Martinez-Garcia, M., & Wang, Z. (2021). Multi-energy scheduling of an industrial integrated energy system by reinforcement learning-based differential evolution. *IEEE Transactions on Green Communications and Networking*, *5*(3), 1077–1090.
86. Yang, Hejun, Hao, Z., Ma, Y., & Zhang, D. (2020). An inverse proportion technique based scheduling strategy of energy storage system considering electrical load demand difference. *CSEE Journal of Power and Energy Systems*, *8*(5), 1487–1496.
87. Yang, Hongming, Shen, W., Yu, Q., Liu, J., Jiang, Y., Ackom, E., & Dong, Z. Y. (2020). Coordinated demand response of rail transit load and energy storage system in considering driving comfort. *CSEE Journal of Power and Energy Systems*, *6*(4), 749–759.