batteries

Review

Energy Storage Systems: Technologies and High-Power Applications

Ahmed Aghmadi and Osama A. Mohammed *

Energy Systems Research Laboratory, Department of Electrical and Computer Engineering, Florida International University, Miami, FL 33174, USA; aaghm001@fiu.edu
* Correspondence: mohammed@fiu.edu

Abstract: Energy storage systems are essential in modern energy infrastructure, addressing efficiency, power quality, and reliability challenges in DC/AC power systems. Recognized for their indispensable role in ensuring grid stability and seamless integration with renewable energy sources. These storage systems prove crucial for aircraft, shipboard systems, and electric vehicles, addressing peak load demands economically while enhancing overall system reliability and efficiency. Recent advancements and research have focused on high-power storage technologies, including supercapacitors, superconducting magnetic energy storage, and flywheels, characterized by high-power density and rapid response, ideally suited for applications requiring rapid charging and discharging. Hybrid energy storage systems and multiple energy storage devices represent enhanced flexibility and resilience, making them increasingly attractive for diverse applications, including critical loads. This paper provides a comprehensive overview of recent technological advancements in high-power storage devices, including lithium-ion batteries, recognized for their high energy density. In addition, a summary of hybrid energy storage system applications in microgrids and scenarios involving critical and pulse loads is provided. The research further discusses power, energy, cost, life, and performance technologies.

Keywords: hybrid energy storage system; pulse load; flywheel; supercapacitor; battery; superconducting magnetic energy storage; grid service; transportation system

check for updates

Citation: Aghmadi, A.; Mohammed, O.A. Energy Storage Systems: Technologies and High-Power Applications. *Batteries* **2024**, *10*, 141. https://doi.org/10.3390/batteries10040141

Academic Editors: Yong Tian and Ottorino Veneri

Received: 8 March 2024
Revised: 9 April 2024
Accepted: 19 April 2024
Published: 20 April 2024

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Energy storage systems designed for microgrids have emerged as a practical and extensively discussed topic in the energy sector. These systems play a critical role in supporting the sustainable operation of microgrids by addressing the intermittency challenges associated with renewable energy sources [1–4]. Their capacity to store excess energy during periods of high generation, primarily from renewables, and release it during peak demand or low renewable output enhances the reliability and resilience of microgrids [5]. This dynamic functionality ensures a consistent power supply, mitigates fluctuations, and optimizes the utilization of locally generated green energy. As microgrids gain prominence as decentralized and resilient energy solutions, effectively incorporating energy storage systems becomes essential for achieving energy independence and meeting the changing demands of a more sustainable energy landscape [6]. Load conditions and power generation characteristics significantly influence power exchange dynamics within a DC microgrid. This power exchange can be broadly classified into two distinct categories: low-frequency and high-frequency components. Low-frequency components primarily encompass the natural variations in renewable energy sources (RESs) and daily energy consumption patterns. These variations are typically gradual and predictable, reflecting the inherent behavior of renewable sources and the regular energy demands of the system.

On the other hand, high-frequency components represent sudden and unpredictable fluctuations in power exchange. These fluctuations may arise due to increased power demand, pulsed loads, or significant variations in renewable energy output, particularly on cloudy days. Understanding and effectively managing both low- and high-frequency components of power exchange are essential for ensuring the stability and reliability of DC microgrids under varying operating conditions [7–10]. Thus, energy storage technologies can be categorized into two main groups: those with high energy capacity for extended discharge and those with high power capacity for rapid discharge. Established technologies such as pumped hydroenergy storage (PHES), compressed air energy storage (CAES), and electrochemical batteries fall into the high-energy storage category. These technologies have seen widespread deployment, ranging from a few kilowatts in residential settings to large-scale multimegawatt systems serving various grid purposes. These applications include energy management, backup and seasonal reserves, and load leveling. The distinction between high-energy and high-power storage solutions highlights their versatility in meeting diverse energy demands across different scales and applications. The effective deployment of these technologies enhances grid reliability and efficiency by addressing the varied energy needs of residential and utility-scale contexts [11–14]. The second category concerns high-power storage technologies. This category includes supercapacitors, superconducting magnetic energy storage (SMES), and flywheels, all renowned for their capacity to deliver intense power outputs over short durations. Their distinctive strength lies in their ability to undergo frequent and rapid charge and discharge cycles with remarkable efficiency. These high-power storage technologies have practical applications in power systems dealing with critical and pulse loads, transportation systems, and power grids. The ongoing endeavors in this domain mark a significant leap forward in refining the capabilities and adaptability of energy storage solutions. This shift in focus highlights the critical importance of addressing energy capacity and enhancing power output capabilities to meet the diverse and instantaneous energy requirements across various sectors [15–18].

Hybrid energy storage systems (HESSs) have emerged as a groundbreaking approach, standing at the forefront of energy storage innovation. These systems go beyond traditional categories by seamlessly integrating multiple storage technologies such as batteries, supercapacitors, and flywheels. The synergy achieved through this amalgamation optimizes critical metrics, including energy density, power density, efficiency, and cycle life, beginning a new era in energy storage capabilities.

What sets an HESS apart is its ability to combine different storage mediums, each contributing unique strengths strategically. Batteries, known for their high energy density and sustained power output, form a stable foundation for storing and releasing energy over extended periods. Supercapacitors complement this by excelling in delivering rapid bursts of energy with exceptional power density and swift response times, making them ideal for addressing sudden high-power demands. With their rotational inertia, flywheels provide an additional dimension by offering instantaneous power during brief yet critical energy spikes.

The dynamic integration of diverse storage technologies within hybrid energy storage systems (HESSs) represents a pivotal advancement for adaptive responses to modern applications' diverse and evolving energy requirements. In microgrids, where intermittent renewable energy sources pose challenges, the HESS is a linchpin in managing and optimizing energy flows. By seamlessly combining batteries and ultracapacitors, an HESS mitigates grid fluctuations, ensuring stability and reliability in localized and distributed energy systems. The collaborative operation of these storage components within microgrids contributes significantly to the effective utilization of renewable energy, addressing the inherent intermittency of sources like solar and wind.

An HESS's influence extends to transportation systems, particularly in optimizing energy utilization for electric vehicles (EVs). The strategic combination of ultracapacitors or Supercapacitor Energy Management Systems (SEMSs) with batteries allows the HESS to enhance the range and performance of EVs through efficient power delivery. The high power density of ultracapacitors plays a crucial role in delivering bursts of energy for acceleration or regenerative braking, complementing the sustained energy output provided by batteries. This collaboration ensures a harmonious response to the dynamic energy demands of transportation systems, contributing to the broader adoption of electric vehicles and fostering sustainable mobility solutions. On a macro scale, an HESS acts as a stabilizing force in large-scale power grids, addressing the challenges posed by the intermittent nature of renewable energy inputs. The synergistic operation of batteries and ultracapacitors allows the HESS to smooth out fluctuations in power generation, fortifying grid resilience and contributing to the overall stability of the electricity network. This macro-level impact is crucial in facilitating the integration of renewable energy sources into the mainstream power grid, where maintaining a balance between supply and demand is paramount for grid reliability. In essence, the HESS's dynamic adaptability across different scales and applications underscores its versatility and effectiveness in addressing the multifaceted challenges of modern energy systems. From microgrids to transportation networks and large-scale power grids, HESSs emerge as a robust solution, leveraging the synergies between energy storage devices to create a resilient and efficient energy landscape.

The versatility of an HESS extends to applications characterized by dynamic and diverse energy needs, where traditional energy storage systems fall short. Whether addressing rapid fluctuations in energy demand within microgrids or optimizing power delivery in transportation systems, the HESS emerges as a pivotal technology that transcends limitations.

As research and development propel the evolution of energy storage technologies, the HESS stands as a testament to relentless innovation. The intricate orchestration of batteries, supercapacitors, and flywheels within hybrid systems represents a dynamic synthesis responsive to the complicated demands of modern applications. The rise of hybrid energy storage systems is not merely an evolution but a paradigm shift toward more adaptable, efficient, and resilient energy solutions, marking a significant stride toward a sustainable and energy-efficient future [19–21].

While several previous studies have addressed the issue of energy storage systems, each offering distinctive perspectives, the current review focuses intensely on recent advances in high-power storage devices and hybrid energy storage systems (HESSs). Prior studies explored several elements of energy storage devices. However, their focus may have been something other than high-power storage systems or the integrated use of different storage technologies throughout an HESS. As a result, this study aimed to fill a significant vacuum in academic discussion by offering a detailed examination of these topics. This study is an asset for affecting strategic decision making and encouraging the greater utilization of new energy storage systems across several sectors by providing current insights and performing comparison research.

This review article explores recent advancements in energy storage technologies, including supercapacitors, superconducting magnetic energy storage (SMES), flywheels, lithium-ion batteries, and hybrid energy storage systems. Section 2 provides a comparative analysis of these devices, highlighting their respective features and capabilities. In Section 3, the focus shifts to the application of high-power storage technologies within grid systems, covering essential services such as voltage control, pulse load, and oscillation damping. Additionally, this section delves into the diverse applications of these technologies in transportation systems, critical loads, and pulse loads. A detailed examination of the advantages and limitations of high-power storage technologies for each application scenario is provided, facilitating a comprehensive understanding of their practical implications. Finally, Section 4 offers concluding remarks summarizing the essential findings and insights presented throughout the review.

2. Energy Storage Technologies

2.1. Lithium-Ion Battery

Lithium-ion batteries, crucial to modern electronics, the aerospace industry, and electric vehicles, are sophisticated electrochemical devices adept at converting chemical energy into electrical energy during discharge and, reversely, during charging [22]. Lithium batteries' attraction lies in lithium's unique characteristics as an exceptionally electropositive element and the lightest metal on the periodic table. Electrochemical cells are interconnected in series or parallel in a typical battery configuration. Each cell comprises a negative electrode (anode during discharge) and a positive electrode (cathode during discharge), with an electrolyte layer as a separator. Additionally, a separator acts as a barrier between the cathode and anode within each cell [23,24].

Battery performance and safety depend heavily on the electrolyte and separator selection. Solid-state electrolytes, one of the emerging technologies, offer faster charging and discharging times and increased safety [25]. Nevertheless, choosing materials that can provide high ion conduction is constrained when the electrolyte is polymer-based because of concerns about electrochemical stability. However, liquid electrolytes offer a more comprehensive range of alternatives since various solvents have distinct viscosity and dielectric constants that affect their performance in different ways [26,27].

As for the cathode, various lithiated metal oxides, including LiCoO2, Li-Mn-O, LiFePO4, and lithium-layered metal oxide, can be utilized. Each cathode material possesses unique electrochemical properties, affecting energy density, power density, and safety as shown in Table 1. For instance, while lithium cobalt oxide offers high energy density, it raises concerns about thermal stability and safety. On the other hand, lithium iron phosphate exhibits lower energy density but provides enhanced safety and thermal stability. Therefore, carefully considering cathode materials is essential to balancing performance metrics and ensuring safe battery operation.

During the charging process, the cathode transforms into lithium ions, traversing the lithium salt electrolyte toward the anode, where they combine with external electrons. The electrolyte, comprising organic carbonates of lithium (e.g., LiPF6), facilitates this electrochemical process [24,28]. It is worth noting that electrolyte selection and formulation significantly affect battery performance, particularly in ion conductivity, viscosity, flammability, and thermal stability. Therefore, optimizing electrolyte properties enhances battery efficiency, safety, and lifespan.

Table 1. Comparison between three cathode materials [29].

Parameters	Li-Ion Manganese	Li-Ion Cobalt	Li-Ion Phosphate
Specific energy density (Wh/kg)	100–135	150–190	90–120
Internal resistance (mΩ)	25–75	150–300	25–50
Cycle life (80% discharge)	500–1000	500–1000	1000–2000
Fast charge time (Hours)	<1	2–4	<1
Cell voltage (nominal V)	3.8	3.6	3.3

Lithium-ion batteries are recognized for their high energy density, rapid response, extended cyclic life, and high efficiency. The discharge voltage curves, particularly in Li-Mn and Li–phosphate batteries, exhibit a notably flat profile, simplifying the application design as nearly 80% of stored energy falls within this region. These advantages have positioned lithium-ion batteries as prevalent choices in portable electronic devices and promising components in electric and hybrid vehicles. However, challenges in implementation include the substantial cost associated with large-scale utilization due to special packaging and internal overcharge protection circuits. Additionally, deploying batteries in power systems and managing grid-tied battery energy storage systems introduce complexities [26,30–33].

2.2. Pumped Hydroenergy Storage (PHES)

Pumped hydroenergy storage (PHES) is a proven and widely adopted technology in renewable energy storage. This system plays a pivotal role in mitigating the intermittency of renewable energy sources by storing excess electricity during periods of low demand and releasing it when demand is high, as shown in Figure 1. The process involves two water reservoirs positioned at different elevations. During surplus electricity generation, excess energy is utilized to pump water from the lower reservoir to the upper one. When electricity demand peaks, the stored water is released, flowing downhill through turbines to generate electricity.

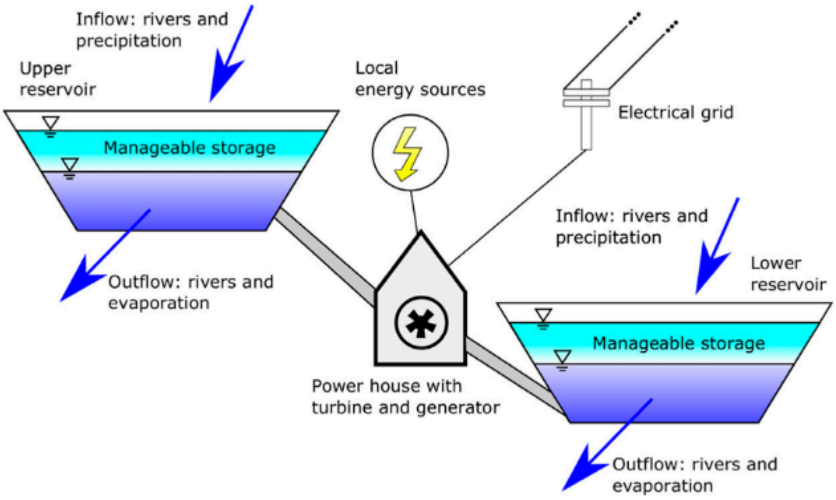

Figure 1. Structure of pumped hydroenergy storage [34], licensed under CC BY 4.0.

The amount of stored energy depends on the stored water volume and the level difference between both bodies. PHES serves as a valuable solution for grid stabilization and enhancing overall grid reliability [34–36].

2.3. Compressed Air Energy Storage (CAES)

Compressed air energy storage (CAES) is an advanced technology for efficient energy storage. Its operational mechanism involves air compression into underground caverns or storage tanks during periods of low electricity demand. Subsequently, the stored compressed air is released during peak demand periods, undergoing expansion, and driving turbines to generate electricity. The CAES process is structured around two essential stages: compression and expansion. Surplus electricity is judiciously employed in the compression phase to compress and store air. Conversely, the stored compressed air is methodically released during the expansion stage to generate electricity. It is pertinent to acknowledge that CAES exhibits a relatively lower energy efficiency, ranging between 40 and 70%. Despite this efficiency limitation, CAES plays an integral role in addressing energy demand fluctuations and contributes significantly to the overall stability of the electrical grid [37–39].

2.4. Supercapacitor Energy Storage

Supercapacitors, also known as ultracapacitors, play a pivotal role in energy storage systems owing to their exceptional attributes, including high power density, swift charging capabilities, extended cycle life, and broad operating temperature range. Their significance has surged notably, particularly within transportation and smart grid applications, where they effectively smooth out energy spikes. Nonetheless, it is crucial to recognize that the performance of supercapacitors can be influenced by diverse parameters like temperature, current, and voltage, resulting in fluctuations in their physical and chemical properties. Moreover, real-world conditions may lead to disparities among individual cells within supercapacitor modules, leading to diminished service performance and posing risks to system reliability and safety.

In contrast to rechargeable batteries, supercapacitors have a comparable chemical composition and operational method, allowing energy storage and conversion via ion diffusion and migration. However, supercapacitors have particular characteristics that make them essential in storage systems. They can store hundreds of times more energy than traditional capacitors because they operate as double-layer electrochemical capacitors as depicted in Figure 2. Furthermore, they suffer fewer losses and have a longer lifespan. Notably, supercapacitors can withstand several charge and discharge cycles, significantly beyond the lifespan of lead–acid batteries, which generally last only a few thousand cycles. Supercapacitors also excel at supplying higher currents than regular batteries [40–44].

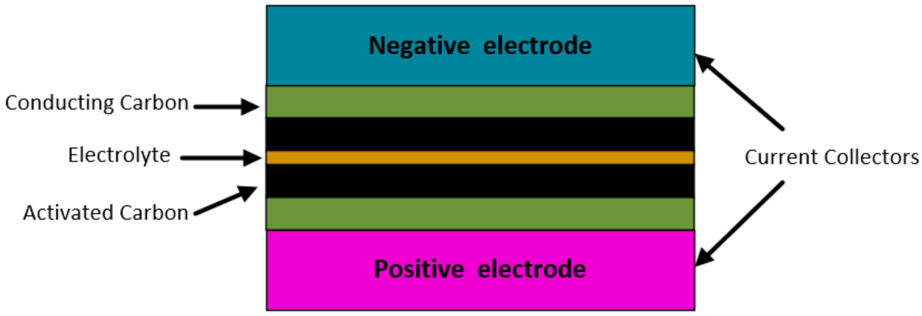

Figure 2. Structure of supercapacitor.

Understanding the complex dynamics of the electrode–electrolyte contact is critical. In situations with a rough interface and uniform electrolyte material, the dimensionless imaginary impedance of a supercapacitor, designated as L_m^*, is critical. The impedance, represented by Equation (1), is significantly impacted by two significant factors: the dimensionless angular frequency (ω^*) and the electrolyte-to-electrode conductivity ratio (γ).

The dimensionless imaginary impedance of a supercapacitor L_m^* can be found as follows:

$$L_m^* = \frac{(1+\gamma^2)}{(1+\gamma)^2\omega^*}\left\{\frac{\sinh(\omega^*)\cosh(\omega^*)+\sin(\omega^*)\cos(\omega^*)}{\cosh^2(\omega^*)-\cos^2(\omega^*)}\right\}+2\frac{\gamma}{(1+\gamma)^2\omega^*}\left\{\frac{\sinh(\omega^*)\cos(\omega^*)+\cosh(\omega^*)\sin(\omega^*)}{\cosh^2(\omega^*)-\cos^2(\omega^*)}\right\} \quad (1)$$

and ω^*, which is the dimensionless angular frequency, can be determined using the following equation:

$$\omega^* = \sqrt{\omega a C L^2(\kappa+\sigma)/2\kappa\sigma} \quad (2)$$

where C is the capacitance per interfacial area and the interfacial area per unit volume (a), and L is the thickness of the electrode [43].

Derived from Equation (1), the imaginary impedance of the supercapacitor is notably influenced by both the dimensionless angular frequency and the electrolyte-to-electrode conductivity ratio. In the context of a pure capacitor, the cell capacitance aligns with the inverse of the frequency multiplied by the imaginary component of the frequency response. Consequently, the cell capacitance can be expressed as a function of L_m^* as follows:

$$C = \frac{\kappa\sigma}{L_m^*\omega(\kappa+\sigma)L} \quad (3)$$

Supercapacitor technology is distinguished by its ability to store electrical energy directly, facilitating rapid and efficient charging and discharging processes. Unlike batteries, supercapacitors exhibit a notably low energy density. Consequently, integrating supercapacitors with high-energy-density storage devices, such as batteries, presents a practical solution for many applications. This hybrid combination proves particularly beneficial across diverse domains, from large-scale grid applications to electric vehicles.

Aqueous and organic electrolytes are the two main types of electrolytes that are frequently used in supercapacitor technology. Aqueous electrolytes provide several benefits, such as strong ionic conductivity and low cost. They are often made of salts dissolved in water, such as sulfuric acid (H_2SO_4) or potassium hydroxide (KOH). Nevertheless, they frequently show signs of electrochemical stability constraints, which limit the supercapacitors' operational voltage range and energy density. Aqueous electrolytes have a stability limit of 0.9 V, which limits the highest voltage at which supercapacitors may function. However, organic electrolytes, which use solvents like propylene carbonate (PC) or acetonitrile (CH3CN), offer better electrochemical stability, enabling higher voltages and higher energy densities. Supercapacitors may operate at higher voltages and store more energy per unit volume because of the stability that organic electrolytes provide up to 2.7 V. Despite their benefits, organic electrolytes are more expensive, have flammability-related safety issues, and need organic solvents, which poses environmental problems. The optimal operating voltage, energy density specifications, cost considerations, safety issues, and environmental impact all play a role in choosing between aqueous and organic electrolytes [42–47].

2.5. Flywheel

Flywheel energy storage systems (FESSs) are formidable solutions in energy storage, boasting a range of advantages that position them as a competitive alternative. Among these advantages are the notably high energy density, low maintenance requirements, and rapid response capabilities inherent to FESS technology. One of the key strengths lies in the environmental sustainability of FESSs, as they adeptly harness the kinematic energy of rotational mass to absorb and release energy efficiently, contributing to an extended operational lifespan.

The operational principle of an FESS involves storing kinetic energy as an electromechanical system. This is achieved by rotating mass on magnetic bearings, effectively minimizing friction even at elevated speeds. The magnetic bearings play a crucial role in facilitating the smooth rotation of the flywheel, ensuring that energy is stored and released with minimal losses. This design contributes to the high efficiency of FESS, reaching approximately 90% at rated power. The combination of a prolonged cycling life and elevated power and energy densities positions FESS as a compelling technology for various applications.

Despite these commendable characteristics, an FESS encounters challenges in the form of standing losses. The self-discharge rates, reaching approximately 20% of the stored capacity per hour, represent an area of concern that necessitates further attention. Efforts to address standing losses are crucial for optimizing the FESS's overall efficiency and performance, particularly in scenarios where extended periods of energy storage without discharge are prevalent.

Flywheel energy storage systems offer robust advantages, making them an attractive option in the diverse landscape of energy storage technologies. The focus on environmental sustainability, high efficiency, and energy density positions FESS as a promising solution for applications ranging from grid stabilization to uninterruptible power supply. While challenges such as standing losses persist, ongoing research and innovation can enhance their performance further and address limitations, solidifying the role of FESSs in the future of energy storage [48,49].

The quantity of kinetic energy (E) stored in a rotating object depends on both its mass and velocity, as expressed by the following equation:

$$E = \frac{1}{2} R \omega^2 \tag{4}$$

where R represents the moment of inertia, and ω is the rotational velocity.

To guarantee the reliability and stability of the flywheel energy storage system (FESS), precise control of the flywheel speed within a specific range is imperative. Consequently, the accessible energy of the flywheel is determined within the defined parameters of maximum and minimum speeds.

$$E_p = \frac{1}{2} R \left(\omega_{\max}^2 - \omega_{\min}^2 \right) \tag{5}$$

While the flywheel has a significant power density, its energy density is very low. As a result, it is best suited for grid applications that need frequency management and short-term power quality services. Additionally, flywheel energy storage can be used in a hybrid design with high-energy storage devices such as batteries or fuel cells [48–52].

2.6. Superconducting Magnetic Energy Storage

Superconducting magnetic energy storage (SMES) systems leverage the properties of superconductors to store energy in a magnetic field. These systems use superconducting coils to generate and store a magnetic field, and when electricity is needed, the stored magnetic energy is converted back into electrical energy. SMES systems are known for their rapid response times and high efficiency, making them suitable for applications requiring quick and precise energy delivery, such as through grid frequency regulation. The stored energy E of an SMES coil with inductance L and current I can be expressed as follows:

$$E = \frac{1}{2}LI^2 \quad (6)$$

The schematic representation below—Figure 3—illustrates the integral components of a typical SMES system, encompassing a cryogenic system, superconducting coil, protective system, and control system. The superconducting coil serves as the central component, functioning as the core of the SMES system by storing energy. Maintaining its superconducting state is facilitated by the cryogenic refrigerator system, ensuring zero losses and resistance in the coil. The coil is typically crafted from superconducting materials like mercury or niobium–titanium. The protective system safeguards against irregularities within the SMES unit, while the control system establishes the connection between grid power requirements and SMES coil power flows.

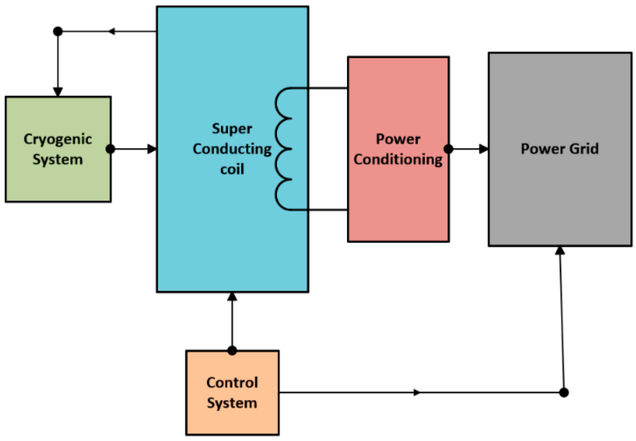

Figure 3. Structure of SEMS.

Advancements in superconducting materials and cryogenic systems have opened up new possibilities for superconducting magnetic energy storage (SMES) in various applications. The combination of improved superconducting coils and advanced power conditioning systems enables SMES to respond swiftly, typically within milliseconds, with the capacity to handle power ratings extending to several megawatts [53–57].

2.7. Comparative Analysis of Various Energy Storage Technologies

The various energy storage technologies exhibit distinct characteristics based on a comparative analysis on critical variables, as shown in Table 2. Power density, a crucial factor in assessing the rate of energy release or absorption, varies across these options. Supercapacitors stand out with a remarkable power density exceeding 100,000 W/kg, indicating their ability for rapid charge and discharge. Lithium-ion batteries and SEMS follow, with power densities ranging from 1500 to 10,000 W/kg and 1000 to 4000 W/kg, respectively. The flywheel lags slightly behind, with a range of 1000 to 2000 W/kg.

Energy density is another vital parameter, representing the amount of energy stored per unit mass. Lithium-ion batteries and flywheels showcase high energy density, ranging from 200 to 500 Wh/kg and 20 to 80 Wh/kg, respectively. Supercapacitors and SEMS, however, exhibit lower energy density, with values spanning from 2.5 to 15 Wh/kg and 0.2 to 2.5 Wh/kg, respectively.

Table 2. Comparison between energy storage technologies.

Energy Storage Technologies	Power Density (W/kg)	Energy Density (Wh/kg)	Efficiency (%)	Lifetime (Cycles)	Advantages	Drawbacks	Energy Capital ($/kWh)
Li-ion battery	1500–10,000	200–500	85–95	500–1000	High energy density, widely used	Limited cycle life, potential safety concerns	600–2500
Flywheel	1000–2000	20–80	90	10 k–100 k	Rapid response, long cycle life	Limited energy density, high upfront cost	2000–5000
Supercapacitor	>100,000	2.5–15	95–98	>125 k	High power density, fast charge/discharge	Lower energy density compared to batteries	100–400
Superconducting magnetic (SEMS)	1000–4000	0.2–2.5	95–99	>125 k	Extremely high power density, fast response	High initial cost, complexity, cryogenic cooling	200–500

Efficiency, denoting the ratio of useful energy output to the input, is relatively high across all technologies. Supercapacitors and SEMS lead with efficiency levels between 95% and 99%, while lithium-ion batteries and flywheels maintain efficiency within the range of 85% to 95% and 90%, respectively.

Lifetime, indicating the number of charge–discharge cycles a storage system can undergo, is notably extended for flywheels and SEMS, ranging from 10,000 to 100,000 cycles and exceeding 125,000 cycles, respectively. Lithium-ion batteries and supercapacitors, however, have more limited lifetimes, ranging from 500 to 1000 cycles and over 125,000 cycles, respectively.

Considering drawbacks, each technology has its challenges. Lithium-ion batteries face limited cycle life and potential safety concerns. Flywheels encounter limitations in energy density and higher upfront costs. Supercapacitors trade off energy density compared to traditional batteries. SEMS poses challenges with high initial costs, complexity, and the need for cryogenic cooling [58].

It is evident from examining the critical factors of different energy storage systems that each choice has compromises and factors to consider. Supercapacitors have an excellent power density that allows for rapid charging and discharging; moreover, their energy density is lower than those of flywheels and lithium-ion batteries. On the other hand, superconducting magnetic energy storage (SEMS) systems have higher power densities and efficiency but are more complicated and have lower energy densities due to issues such as high startup costs and cryogenic cooling requirements.

3. Energy Storage System Applications

3.1. Hybrid Energy Storage Systems

A hybrid energy storage system (HESS) plays a pivotal role in enhancing the performance of power systems, especially in applications characterized by diverse power dynamics. The intricate design of an HESS involves the strategic combination of two or more complementary energy storage devices. Managing "high-frequency components" is crucial, demanding high power density and swift dynamic response. An ultracapacitor or SEMS is an optimal choice due to their unique efficiency and extended cycle lifetime. Concurrently, the second storage component is designed to address the challenges of slow power fluctuations, emphasizing high energy density. In this context, a battery energy storage system (BESS) is a practical addition, offering the capacity to efficiently compensate for gradual power variations. Hybrid energy storage systems (HESSs) leverage the synergies between energy storage devices with complementary characteristics, such as batteries and ultracapacitors. This integration allows HESSs to attain high power and energy densities, creating a robust system capable of successfully mitigating short and high-power fluctuations within systems (i.e., microgrids). The collaborative operation of these storage components ensures a harmonious response to the dynamic energy demands of the microgrid, contributing to its overall stability and efficiency. For instance, research studies [7,8,59,60] have shown that an HESS can reduce the DC bus fluctuations in a DC standalone microgrid by incorporating a Li-ion battery with supercapacitor in case of pulse loads or variable pulse loads by allocating the high transient demand to the supercapacitor and average demand to the battery. In another study [61], a hybrid energy storage system (HESS) with an effective adaptive energy management technique (EMS) was used to counteract power fluctuations. The authors concluded through a simulation and experiment validation that the fluctuation in DC link voltage was reduced, and the battery and supercapacitor's coordinated function lessened the battery's stress. In [62], a dual model predictive control (D-MPC) technique for a hybrid energy storage system (HESS) coupled with superconducting magnetic energy storage (SMES) and a battery in naval DC microgrids was used to meet pulsed power demands.

The indispensability of a hybrid energy storage system becomes particularly apparent in applications characterized by specific load profiles. Models where multiple loads exhibit a standard profile, requiring relatively high pulse power but a lower average, highlight the significance of an HESS. The high level of short-term current behavior inherent in these scenarios necessitates components with higher power ratings, as failure to meet these requirements could disrupt the entire grid. In such applications, the flexibility and adaptability of an HESS prove instrumental in maintaining grid integrity and ensuring reliable performance, making it an indispensable asset for the evolving landscape of DC microgrids. Several research studies have been conducted to analyze the impact of HESSs on power systems [61–71].

3.2. Energy Storage for Transportation Systems

Developing energy storage technologies is critical in the global search for sustainable and efficient transportation options. The widespread lithium-ion battery, which has driven the growth of electric vehicles (EVs) and hybrids, is a key participant in this environment. Energy storage for transportation purposes may be broadly classified into high power/rapid discharge and high energy/extended discharge. High-power devices deliver brief, quick discharges for vehicle starting and accelerating. While they cannot offer continuous discharge for electrified transportation, they may significantly increase fuel efficiency for today's hybrid electric cars. Hybrid energy storage systems can be an alternative to such transportation systems. They are merging many technologies, such as lithium-ion batteries, supercapacitors, and flywheels. This technique seeks to maximize the twin objectives of energy and power density, establishing a balance between long-range and high-performance demands. The use of lithium-ion batteries offers long-term energy for movement, while supercapacitors excel at supplying quick bursts of power during acceleration and regenerative braking. An example to prove this approach was introduced in [72], in which the author presented a hybrid energy storage system (HESS) paradigm for electric cars (EVs) that addresses issues such as long charging times, frequent discharging, and battery life degradation. A bidirectional converter with a battery–SC combination is part of the HESS used. The supercapacitor responds to the regenerative braking action by absorbing the transients and reducing the battery's peak current. Supercapacitors help absorb discharge/charge current by reducing the strain on battery current when used with batteries. The idea of high-power storage hybridization may be used for several industrial, railroad, and airplane applications in addition to the transportation system, with the comparable benefits and advantages previously mentioned [19,73–78].

3.3. Critical Loads

To ensure reliable power supply for commercial, public, and residential users, uninterruptible power supplies (UPSs) have been the go-to solution, traditionally relying on lead–acid batteries for energy storage. However, the prevalence of very short power failures and disturbances, often lasting less than 1 s, necessitates oversized battery banks, incurring additional costs for unused energy reserves. Telecommunication centers and critical facilities, mandated to have standby gensets, require short-duration energy storage to mitigate brief power disturbances and facilitate a seamless transition to startup and synchronize the standby gensets for an extended power supply. In addressing these challenges, flywheel energy storage systems emerged as a viable alternative, offering immediate power availability during outages, dips, or surges in voltage and/or current. Compared to batteries, flywheel systems present a lower cost per power unit, reduced operating costs due to lower maintenance and replacement expenses, and enhanced environmental friendliness. The compact design of flywheel UPS technology, leveraging high power density, further distinguishes it as a favorable option.

Flywheel energy storage systems operate on the principle of storing kinetic energy in a rapidly spinning mass. During regular operation, the flywheel spins and stores energy. In the event of a power disruption, the stored kinetic energy is rapidly converted back into electricity, providing an instantaneous and reliable power source. This contrasts with traditional lead-acid batteries, which require charging time before delivering power.

The economic advantages of flywheel systems become apparent when considering their lower cost per power unit than batteries. Additionally, their reduced operating costs stem from lower maintenance and replacement expenses, as flywheels do not suffer from the degradation that batteries experience over time. The environmental benefits of flywheel technology contribute to its appeal, aligning with the growing emphasis on sustainable and eco-friendly energy solutions.

The compact design of flywheel UPS technology, leveraging high power density, allows for more efficient use of space compared to traditional battery-based systems. This makes flywheel systems particularly suitable for environments with premium space, such as densely populated urban areas or critical facilities with limited physical footprint [79–81].

Similarly, supercapacitors are an effective solution for short-term failures with their high power density and low cost per unit power. These systems, ranging from 20 kW to several milliwatts in size, can function as bridging power supplies to more permanent backup sources, such as gensets or fuel cells. Supercapacitor UPSs, known for their compactness, entail minimal maintenance and standby power costs, making them a pragmatic choice for applications requiring swift responses to short-term power disruptions [82–86].

3.4. Pulse Load

In communication, shipboard, and spacecraft power systems, the strategic application of high-power energy storage plays a key role, particularly when addressing the unique challenges of pulsed loads. These applications share a distinctive profile characterized by relatively low average power consumption but with intermittent, high, and instantaneous power requirements. Pulsed loads in these scenarios exhibit varying durations from hundreds of milliseconds to seconds, with power levels that dynamically adjust based on specific use cases.

Pulsed power loads (PPLs) are aptly described as fluctuating load demands that transition from the minimum power (P_{min}) to the maximum power (P_{max}) over a defined period (T), with a specific duty cycle (D), as shown in Figure 4. This fluctuating nature necessitates innovative solutions to efficiently manage these dynamic loads' power requirements. For N pulses, the instantaneous power demand $P_D(t)$ may be computed as

$$P_D(t) = P_{min} + \sum_{K=0}^{N-1} (P_{max} - P_{min})[\delta(t - KT) - \delta(T - (K + D)T)] \tag{7}$$

where δ is a unit step function at $t = 0$.

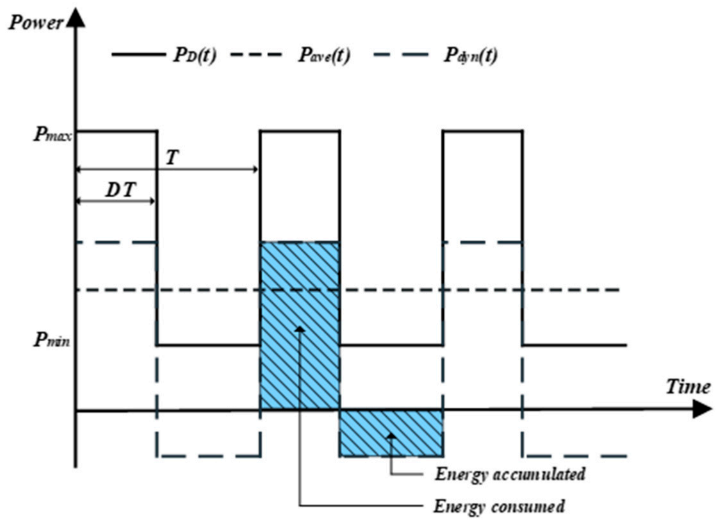

Figure 4. Pulse load structure.

As shown in Figure 1, the computed instantaneous value of the PPL demand may be described using two components of the power profiles: average power P_{ave} and dynamic power P_{dyn};

$$P_{ave} = \frac{1}{T}\int_0^T P_D(t)dt = D(P_{max} - P_{min}) + P_{min} \quad (8)$$

$$P_{dyn} = P_D(t) - P_{ave} = -D(P_{max} - P_{min}) + \sum_{K=0}^{N-1}(P_{max} - P_{min}) * (\delta(t - KT) - \delta(T - (K + D)T)) \quad (9)$$

Integrating supercapacitors or flywheels becomes a strategic option in response to the challenges posed by pulsed loads. This approach proves essential when a single energy source struggles to handle a pulse load's high instantaneous power demands, potential power outages, and thermal concerns. When combined with appropriate power electronic infrastructure and management methodologies, supercapacitors and flywheels emerge as power-dense storage systems with a low cost per unit power, significantly enhancing overall system performance.

The configuration of incorporating supercapacitors or flywheels into the power system is designed to manage dynamic power requirements effectively. In this approach, while meeting typical pulse load demands, the long-term primary energy supply is complemented by supercapacitors or flywheels' rapid response and high-power capabilities. This dynamic interplay offers notable benefits, including reducing system weight and volume. Integrating these energy storage components minimizes voltage disturbances, frequency variations, and heat-related issues, ensuring enhanced reliability and efficiency in power system operations.

Supercapacitors, with their ability to deliver rapid bursts of energy and high-power density, prove instrumental in handling the instantaneous power requirements of pulsed loads. Their efficiency and longevity make them well suited for applications where frequent and rapid charging and discharging cycles are essential. Similarly, flywheels leverage kinetic energy storage, responding instantly to fluctuating power demands. Their rotational inertia allows for seamless energy discharge during pulsed load scenarios, making them an ideal complement to the primary energy source.

When implemented with careful consideration of power electronic infrastructure and management methodologies, the integration of supercapacitors or flywheels into power systems ensures a harmonious balance between instantaneous power demands and sustained energy supply. This innovative configuration addresses the specific challenges posed by pulsed loads and sets the stage for more efficient, reliable, and adaptable power systems in communication, shipboard, and spacecraft applications [7,8,87].

3.5. Power Grid

3.5.1. Frequency Regulation

Maintaining the ideal frequency of 60 Hz is crucial for power systems, and high-power energy storage devices offer effective solutions for frequency control [12]. These devices, reaching traditional options like compressed air energy storage (CAES) and pumped hydroenergy storage (PHES) systems in efficiency and responsiveness, have become economically viable with advancements in frequency control techniques [88]. Large flywheel systems and advanced power monitoring software have been proven to be particularly successful for frequency regulation services. Additionally, studies have highlighted the suitability of high-power energy storage technologies such as supercapacitors, batteries, and superconducting magnetic energy storage (SMES) for frequency control, especially in primary control scenarios [49].

Effective frequency management is essential in maintaining grid stability to keep the system frequency within allowable bounds. These regulators operate as primary, secondary, and tertiary controllers, with primary control balancing the system frequency over five minutes, secondary control supervising and sustaining frequency based on primary control, and tertiary control serving as a backup for the secondary controller. This coordinated strategy, ensuring a harmonious balance between generation and load, significantly contributes to the overall stability of the power system [89–91].

3.5.2. Voltage Control

Power grid stability depends on voltage regulation, ensuring that transmission system voltages remain within predetermined bounds. Voltage instability can result from variations in renewable energy sources, such as wind and solar power, in heavily utilized systems. Batteries and other sophisticated storage systems are high-power technologies that work well with dynamic reactive power supplies to facilitate voltage management. These technologies' quick response times allow them to inject or absorb power quickly, controlling voltage levels within predetermined bounds. Storage devices can minimize the impact on stored actual energy by continually providing reactive power at the grid frequency by utilizing four-quadrant power converters. High-power storage technologies, which function as dynamic voltage regulators, are essential for maintaining grid integrity, guaranteeing that the power system runs smoothly, and averting unfavorable circumstances like overvoltage or undervoltage. These storage devices are essential for voltage stability in power networks with high integration with renewable energy [92,93].

3.5.3. Grid Resilience

High-power storage systems provide a dependable backup for power outages or variations in renewable energy output, guaranteeing a continuous supply of electricity to vital loads. These technologies can immediately supply electricity during unanticipated situations, eliminating grid interruptions. High-power storage solutions minimize downtime, improve overall power supply dependability, and strengthen grid resilience by serving as a backup power source. This becomes especially important when there must be a consistent and reliable power source, such as in emergencies or essential infrastructure [89].

3.5.4. Oscillation Damping

Controlling oscillations caused by disturbances or variations in demand is essential to grid stability. Technologies for high-power storage actively contribute to oscillation damping, which is a critical part of this process. These technologies contribute to grid stability by lowering the possibility of amplification that might cause disruptions through the injection or absorption of electricity as needed. Effective oscillation control is essential for optimal performance in power grids with a large percentage of renewable energy since intermittent sources bring extra dynamics. High-power storage systems have a dynamic impact on the flow of power within the grid, which improves the grid's capacity to absorb and reduce oscillations and maintain overall stability and dependability. This support becomes crucial to keeping a steady and uninterrupted power supply and avoiding power outages [94].

Synchronous machines maintain consistent rotor angular positions in stable, disturbance-free grids. On the other hand, power oscillations might result from changes in power in renewable resources or from the loss of a primary transmission line. These oscillations can potentially cause undamped electromechanical oscillations and rotor angular instability. If not adequately mitigated, such disturbances, particularly those occurring across poor transmission connections, may cause partial or complete power outages. Counteracting these disturbances can be achieved by injecting or absorbing actual oscillatory power at frequencies between 0.5 and 1 Hz. For this application, high-power energy storage devices with sophisticated power electronics interfaces—such as SMES, supercapacitors, flywheels, and high-power batteries—have become competitive options. These storage devices can sense disturbances, react at full power in 20 ms, and inject or absorb oscillatory power for a maximum of 20 cycles. As a result, they offer practical solutions for mitigating power oscillations and ensuring grid stability [12,95].

3.6. Military Applications of High-Power Energy Storage Systems (ESSs)

High-power energy storage systems (ESSs) have emerged as revolutionary assets in military operations, where the demand for reliable, portable, and adaptable power solutions is paramount. These advanced energy storage systems play a multifaceted role, enhancing the operational capabilities of military forces across a spectrum of applications. In this comprehensive exploration, we delve into the intricacies of high-power ESSs in military contexts, uncovering the diverse applications, technological advancements, and strategic implications that underscore their importance on the modern battlefield. Military operations often unfold in remote or hostile environments where traditional power infrastructure is unavailable or impractical. A high-power ESS addresses this challenge by offering a swift and mobile power source that can be rapidly deployed to support communication systems, electronic equipment, and other mission-critical devices. These energy storage systems' compact and portable nature becomes a linchpin in sustaining connectivity, information flow, and overall mission success [96–98].

The rapid response capabilities of high-power ESSs play a pivotal role in addressing military operations' dynamic and unpredictable nature. Electronic warfare systems, known for their sudden spikes in power demand, benefit immensely from an ESS's agility. Whether adapting to abrupt changes in energy requirements or ensuring a stealthy and silent power source, a high-power ESS empowers military forces to maintain a tactical advantage without compromising operational efficiency.

Durability and resilience are non-negotiable attributes in military applications, and high-power ESSs rise to the occasion. These systems are designed to withstand harsh environmental conditions, extreme temperatures, and physical stresses, ensuring operational continuity in challenging terrains and adverse weather conditions. From arid deserts to freezing arctic landscapes, high-power ESSs remain steadfast, providing a reliable power supply that is integral to the success of military missions.

The versatility of high-power ESSs extends to a diverse range of military applications. In addition to supporting communication systems and electronic warfare, these systems power surveillance systems, unmanned aerial vehicles (UAVs), command and control centers, and field hospitals. The adaptability of high-power ESSs makes them a universal solution, contributing to the overall effectiveness of military operations across various domains. Technological advancements further amplify the impact of high-power ESSs in military settings. The integration of smart and predictive capabilities enhances the efficiency of energy deployment. Predictive analytics allow military forces to anticipate energy needs, optimize the use of stored power, and ensure a continuous supply during critical operations. This predictive approach conserves energy and contributes to strategic planning and resource management.

Moreover, the development of energy-harvesting technologies complements the capabilities of high-power ESSs in military applications. Harvesting energy from ambient sources, such as solar or kinetic energy, provides an additional layer of sustainability. This capability is particularly valuable in prolonged missions or scenarios where recharging traditional power sources is impractical.

The cybersecurity aspect of high-power ESSs in military operations is of paramount importance. As military systems increasingly rely on interconnected electronic devices, safeguarding the integrity and security of power storage and distribution becomes crucial. Encryption, secure communication protocols, and robust cyber defenses ensure that high-power ESSs remain a dependable and secure asset in military applications. The strategic implications of incorporating high-power ESSs into military operations are profound. These systems' rapid deployment and adaptability contribute to increased agility and flexibility on the battlefield. Military forces equipped with high-power ESSs can precisely execute complex maneuvers, responding dynamically to changing circumstances. This enhanced flexibility improves the chances of mission success and contributes to personnel safety.

Furthermore, the reduced logistical burden associated with high-power ESSs enhances the overall operational efficiency of military forces. Traditional power solutions often require extensive fuel supply lines, presenting logistical challenges and vulnerabilities. With its self-contained energy storage and rapid deployment capabilities, high-power ESS mitigates these challenges, allowing military forces to operate with increased autonomy and reduced dependence on external resources [96–103].

3.7. Industrial Peak Shaving

Industries with a high power demand face many operational and economic challenges, particularly during peak demand periods when the strain on the electrical grid is at its zenith. In response to these challenges, high-power energy storage systems (ESSs) have emerged as strategic solutions by applying industrial peak shaving. This innovative approach addresses the immediate concerns of industries and contributes to broader goals of cost savings, grid stability, and overall operational efficiency. Industrial peak shaving is a sophisticated strategy that reduces electricity consumption precisely when the demand on the electrical grid reaches its highest point. High-power ESSs support this strategy by efficiently storing surplus energy during off-peak hours, which is characterized by lower electricity demand. This stored energy is subsequently released during peak demand times, alleviating the need for industries to draw excessive power directly from the grid during these critical periods. The economic benefits of industrial peak shaving facilitated by high-power ESSs are substantial. By avoiding electricity consumption during peak hours, industries can take advantage of lower electricity rates during off-peak times, resulting in significant cost savings. This financial advantage is particularly relevant for industries with high power demands, where electricity costs can constitute a substantial portion of operational expenses [104–106].

One key advantage of high-power ESSs for industrial peak shaving is their remarkable rapid response capabilities. Industrial facilities are dynamic environments where the energy demand can experience sudden fluctuations due to production processes or operational shifts. An ESS's ability to adapt swiftly by releasing stored energy ensures that industries can effectively manage their power consumption in real time. This responsiveness minimizes the impact of demand spikes on operational costs and contributes to the stability of the broader electrical grid.

In addition to the economic benefits, deploying high-power ESSs in industrial settings significantly contributes to grid stability. By strategically managing energy consumption and reducing the overall demand during peak hours, industries equipped with ESSs play a crucial role in stabilizing the electrical grid. This proactive approach helps prevent voltage fluctuations or disruptions, fostering a more reliable and resilient energy infrastructure [107].

Furthermore, the integration of high-power ESSs aligns with broader sustainability goals. Reducing peak demand from the grid translates into a decreased reliance on conventional power sources during critical periods. This lowers the environmental impact of high-power consumption and aligns with the growing global emphasis on sustainable and responsible energy practices. As industries continue to navigate the evolving landscape of energy management, the role of high-power ESSs in industrial peak shaving is poised to grow exponentially. The versatility and adaptability of these energy storage systems offer industries dynamic and cost-effective solutions for optimizing energy usage, reducing peak demand from the grid, and enhancing overall grid stability. The strategic incorporation of high-power ESSs into industrial operations reflects a forward-thinking approach, ensuring industries' sustainability, efficiency, and competitiveness in an increasingly complex and dynamic energy landscape [108–110].

Thorough analyses and performance evaluations are essential before implementing energy storage technologies in practical applications. Hybrid energy storage systems (HESSs) show promise in managing power dynamics, yet integration challenges, maintenance needs, and system optimization pose deployment obstacles. Transportation concerns, including weight, cost, and lifetime of hybrid systems, particularly for EVs and hybrids, require attention. Despite energy storage devices' critical role in critical load scenarios, ensuring dependability and smooth integration into existing infrastructure remains challenging. High-power energy storage systems offer reliable military power, but logistical issues like maintenance and equipment compatibility persist.

Moreover, sustainability demands careful consideration of environmental impacts from resource extraction, manufacturing, and disposal. While high-power energy storage aids industrial peak shaving for grid stability and economic benefits, scalability, efficiency, and their broader influence on the energy ecosystem raise concerns. Effective and sustainable deployment across sectors demands careful consideration of technical, financial, environmental, and societal factors.

4. Conclusions

This comprehensive study presents the critical roles of high-power storage technologies in promoting sustainable energy solutions, focusing on microgrid resilience, grid stability, and frequency control. This paper discussed the profound impact of Li-ion batteries, supercapacitors, superconducting magnetic energy storage (SMES), and flywheels on these critical domains by distinguishing between high-energy and high-power storage categories and providing valuable insights into their respective capabilities and diverse applications. In addition, the beneficial integration of several storage technologies into hybrid systems has emerged as a practical approach to maximizing performance metrics across distinct applications, providing detailed insights into critical decision-making criteria for choosing specific storage solutions. In an energy environment characterized by fast transitions and more renewable integration, the research emphasizes the crucial role of high-power storage technologies in improving grid dependability and promoting sustainability. Furthermore, this work enhances our understanding of the minor differences between high-energy and high-power storage. It emphasizes their combined influence on advancing sustainable energy solutions as the energy storage sector evolves with ongoing technical advancements and strategic implementations. Research and development efforts continue to investigate new substances and composites that will improve the energy density, power density, and cycle life of storage systems. This will encourage more innovation in the continually developing field of energy storage technologies.

Funding: This research received no external funding.

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

Abbreviations

HESS	Hybrid Energy Storage System
ESS	Energy Storage System
RES	Renewable Energy Resource
BESS	Battery Energy Storage System
SEMS	Superconducting Energy Storage
SC	Supercapacitor
FESS	Flywheel Energy Storage System
PHES	Pumped Hydroenergy Storage
CAES	Compressed Air Energy Storage
PC	Propylene Carbonate
Li-Ion	Lithium-Ion
PPL	Pulse Power Load
UPS	Uninterruptible Power Supply
EV	Electric Vehicle
UAV	Unmanned Aerial Vehicle
D-MPC	Dual-Model Predictive Control
DC	Direct Current
EMS	Energy Management System

References

1. Faisal, M.; Hannan, M.A.; Ker, P.J.; Hussain, A.; Mansor, M.B.; Blaabjerg, F. Review of Energy Storage System Technologies in Microgrid Applications: Issues and Challenges. *IEEE Access* **2018**, *6*, 35143–35164. [CrossRef]
2. Katsanevakis, M.; Stewart, R.A.; Lu, J. Aggregated applications and benefits of energy storage systems with application-specific control methods: A review. *Renew. Sustain. Energy Rev.* **2017**, *75*, 719–741. [CrossRef]
3. Ali, Z.M.; Calasan, M.; Aleem, S.H.E.A.; Jurado, F.; Gandoman, F.H. Applications of Energy Storage Systems in Enhancing Energy Management and Access in Microgrids: A Review. *Energies* **2023**, *16*, 5930. [CrossRef]
4. Aghmadi, A.; Hussein, H.; Polara, K.H.; Mohammed, O. A Comprehensive Review of Architecture, Communication, and Cybersecurity in Networked Microgrid Systems. *Inventions* **2023**, *8*, 84. [CrossRef]
5. Kandari, R.; Neeraj, N.; Micallef, A. Review on Recent Strategies for Integrating Energy Storage Systems in Microgrids. *Energies* **2022**, *16*, 317. [CrossRef]
6. Zhou, X.; Guo, T.; Ma, Y. An overview on microgrid technology. In Proceedings of the 2015 IEEE International Conference on Mechatronics and Automation (ICMA), Beijing, China, 2–5 August 2015; pp. 76–81. [CrossRef]
7. Aghmadi, A.; Ali, O.; Mohammed, O.A. Enhancing DC Microgrid Stability under Pulsed Load Conditions through Hybrid Energy Storage Control Strategy. In Proceedings of the 2023 IEEE Industry Applications Society Annual Meeting (IAS), Nashville, TN, USA, 29 October–2 November 2023; pp. 1–6. [CrossRef]
8. Aghmadi, A.; Ali, O.; Hussein, H.; Mohammed, O.A. Dynamic Pulsed Load Mitigation in PV-Battery-Supercapacitor Systems: A Hybrid PI-NN Controller Approach. In Proceedings of the 2023 IEEE Design Methodologies Conference (DMC), Bath, UK, 14–15 July 2021; pp. 1–6. [CrossRef]
9. Mendis, N.; Muttaqi, K.M.; Perera, S. Management of Low- and High-Frequency Power Components in Demand-Generation Fluctuations of a DFIG-Based Wind-Dominated RAPS System Using Hybrid Energy Storage. *IEEE Trans. Ind. Appl.* **2013**, *50*, 2258–2268. [CrossRef]
10. Wasim, M.S.; Habib, S.; Amjad, M.; Bhatti, A.R.; Ahmed, E.M.; Qureshi, M.A. Battery-Ultracapacitor Hybrid Energy Storage System to Increase Battery Life Under Pulse Loads. *IEEE Access* **2022**, *10*, 62173–62182. [CrossRef]
11. Sherrill, S.A.; Banerjee, P.; Rubloff, G.W.; Lee, S.B. High to ultra-high power electrical energy storage. *Phys. Chem. Chem. Phys.* **2011**, *13*, 20714–20723. [CrossRef] [PubMed]
12. Farhadi, M.; Mohammed, O. Energy Storage Technologies for High-Power Applications. *IEEE Trans. Ind. Appl.* **2015**, *52*, 1953–1961. [CrossRef]
13. Fu, Q.; Fu, C.; Fu, P.; Deng, Y. Energy Storage Technology Used in Smart Grid. *J. Physics Conf. Ser.* **2021**, *2083*, 032067. [CrossRef]
14. Ise, T.; Kita, M.; Taguchi, A. A Hybrid Energy Storage with a SMES and Secondary Battery. *IEEE Trans. Appl. Supercond.* **2005**, *15*, 1915–1918. [CrossRef]
15. Östergård, R. Flywheel Energy Storage a Conceptual Study. 2011. Available online: http://www.teknat.uu.se/student (accessed on 6 March 2024).
16. Ribeiro, P.; Johnson, B.; Crow, M.; Arsoy, A.; Liu, Y. Energy storage systems for advanced power applications. *Proc. IEEE* **2001**, *89*, 1744–1756. [CrossRef]
17. Hadjipaschalis, I.; Poullikkas, A.; Efthimiou, V. Overview of current and future energy storage technologies for electric power applications. *Renew. Sustain. Energy Rev.* **2009**, *13*, 1513–1522. [CrossRef]

18. Wei, P.; Abid, M.; Adun, H.; Awoh, D.K.; Cai, D.; Zaini, J.H.; Bamisile, O. Progress in Energy Storage Technologies and Methods for Renewable Energy Systems Application. *Appl. Sci.* **2023**, *13*, 5626. [CrossRef]
19. Wang, B.; Fan, H.; Li, Z.; Feng, G.; Han, Y. An Ultra-Local Model-Based Control Method With the Bus Voltage Supervisor for Hybrid Energy Storage System in Electric Vehicles. *IEEE J. Emerg. Sel. Top. Power Electron.* **2023**, *12*, 461–471. [CrossRef]
20. Yuming, C.; Peng, J.; Gaojun, M.; Yao, W.; Tiantian, L. Optimal Capacity Configuration of Hybrid Energy Storage System Considering Smoothing Wind Power Fluctuations and Economy. *IEEE Access* **2022**, *10*, 101229–101236. [CrossRef]
21. Li, J.; Yao, F.; Yang, Q.; Wei, Z.; He, H. Variable Voltage Control of a Hybrid Energy Storage System for Firm Frequency Response in the U.K. *IEEE Trans. Ind. Electron.* **2022**, *69*, 13394–13404. [CrossRef]
22. Parsa, S.M.; Norozpour, F.; Shoeibi, S.; Shahsavar, A.; Aberoumand, S.; Afrand, M.; Said, Z.; Karimi, N. Lithium-ion battery thermal management via advanced cooling parameters: State-of-the-art review on application of machine learning with exergy, economic and environmental analysis. *J. Taiwan Inst. Chem. Eng.* **2023**, *148*, 104854. [CrossRef]
23. Xu, J.; Cai, X.; Cai, S.; Shao, Y.; Hu, C.; Lu, S.; Ding, S. High-Energy Lithium-Ion Batteries: Recent Progress and a Promising Future in Applications. *Energy Environ. Mater.* **2023**, *6*, e12450. [CrossRef]
24. Rouholamini, M.; Wang, C.; Nehrir, H.; Hu, X.; Hu, Z.; Aki, H.; Zhao, B.; Miao, Z.; Strunz, K. A Review of Modeling, Management, and Applications of Grid-Connected Li-Ion Battery Storage Systems. *IEEE Trans. Smart Grid* **2022**, *13*, 4505–4524. [CrossRef]
25. Bindra, A. Electric Vehicle Batteries Eye Solid-State Technology: Prototypes Promise Lower Cost, Faster Charging, and Greater Safety. *IEEE Power Electron. Mag.* **2020**, *7*, 16–19. [CrossRef]
26. Mekonnen, Y.; Sundararajan, A.; Sarwat, A.I. A review of cathode and anode materials for lithium-ion batteries. In Proceedings of the SoutheastCon 2016, Norfolk, VA, USA, 30 March–3 April 2016; IEEE: New York, NY, USA, 2016; pp. 1–6.
27. Zhuang, W.; Lu, S.; Lu, H. Progress in Materials for Lithium-ion Power Batteries. In Proceedings of the International Conference on Intelligent Green Building and Smart Grid (IGBSG), Taipei, Taiwan, 23–25 April 2014; IEEE: New York, NY, USA, 2014; pp. 1–2.
28. Xiaopeng, C.; Weixiang, S.; Tu, V.T.; Zhenwei, C.; Ajay, K. An overview of lithium-ion batteries for electric vehicles. In Proceedings of the 2012 10th International Power & Energy Conference (IPEC), Ho Chi Minh, Vietnam, 12–14 December 2012; IEEE: New York, NY, USA, 2012; pp. 230–235.
29. Diouf, B.; Pode, R. Potential of lithium-ion batteries in renewable energy. *Renew. Energy* **2015**, *76*, 375–380. [CrossRef]
30. Saini, V.K.; Seervi, A.; Kumar, R.; Sujil, A.; Mahmud, M.A.; Al-Sumaiti, A.S. Cloud Energy Storage Based Embedded Battery Technology Architecture for Residential Users Cost Minimization. *IEEE Access* **2022**, *10*, 43685–43702. [CrossRef]
31. Wu, C.; Lu, S.; Xue, F.; Jiang, L.; Chen, M. Optimal Sizing of Onboard Energy Storage Devices for Electrified Railway Systems. *IEEE Trans. Transp. Electrification* **2020**, *6*, 1301–1311. [CrossRef]
32. Maletić, F.; Deur, J.; Erceg, I. A Multitimescale Kalman Filter-Based Estimator of Li-Ion Battery Parameters Including Adaptive Coupling of State-of-Charge and Capacity Estimation. *IEEE Trans. Control. Syst. Technol.* **2022**, *31*, 692–706. [CrossRef]
33. Yao, W.; Wang, K.; Sun, J. Study of Li-ion Battery Exchange Stations in Future Power System. In Proceedings of the 2022 9th International Conference on Power Electronics Systems and Applications (PESA), Hong Kong, 20–22 September 2022; pp. 1–5.
34. Görtz, J.; Aouad, M.; Wieprecht, S.; Terheiden, K. Assessment of pumped hydropower energy storage potential along rivers and shorelines. *Renew. Sustain. Energy Rev.* **2022**, *165*, 112027. [CrossRef]
35. Kocaman, A.S.; Modi, V. Value of pumped hydro storage in a hybrid energy generation and allocation system. *Appl. Energy* **2017**, *205*, 1202–1215. [CrossRef]
36. Ichimura, S. Utilization of cross-regional interconnector and pumped hydro energy storage for further introduction of solar PV in Japan. *Glob. Energy Interconnect.* **2020**, *3*, 68–75. [CrossRef]
37. Olabi, A.; Wilberforce, T.; Ramadan, M.; Abdelkareem, M.A.; Alami, A.H. Compressed air energy storage systems: Components and operating parameters—A review. *J. Energy Storage* **2020**, *34*, 102000. [CrossRef]
38. Bazdar, E.; Sameti, M.; Nasiri, F.; Haghighat, F. Compressed air energy storage in integrated energy systems: A review. *Renew. Sustain. Energy Rev.* **2022**, *167*, 112701. [CrossRef]
39. Nozari, M.H.; Yaghoubi, M.; Jafarpur, K.; Mansoori, G.A. Development of dynamic energy storage hub concept: A comprehensive literature review of multi storage systems. *J. Energy Storage* **2022**, *48*, 103972. [CrossRef]
40. Subramanian, S.; Johny, M.A.; Neelanchery, M.M.; Ansari, S. Self-Discharge and Voltage Recovery in Graphene Supercapacitors. *IEEE Trans. Power Electron.* **2018**, *33*, 10410–10418. [CrossRef]
41. German, R.; Hammar, A.; Lallemand, R.; Sari, A.; Venet, P. Novel Experimental Identification Method for a Supercapacitor Multipore Model in Order to Monitor the State of Health. *IEEE Trans. Power Electron.* **2015**, *31*, 548–559. [CrossRef]
42. Prasad, R.; Kothari, K.; Mehta, U. Flexible Fractional Supercapacitor Model Analyzed in Time Domain. *IEEE Access* **2019**, *7*, 122626–122633. [CrossRef]
43. Srinivasan, V.; Weidner, J.W. Mathematical Modeling of Electrochemical Capacitors. *J. Electrochem. Soc.* **1999**, *146*, 1650–1658. [CrossRef]
44. Abu Sayem, M.; A Hannan, M.; Ansari, M.N.M.; Al-Shetwi, A.Q.; Muttaqi, K.M. Effect of activation temperature on the performance of Chitosan-based activated carbon for super-capacitor application. In Proceedings of the 2022 IEEE Industry Applications Society Annual Meeting (IAS), Nashville, TN, USA, 29 October–2 November 2023; pp. 1–8.
45. Zhou, Y.; Huang, Z.; Li, H.; Peng, J.; Liu, W.; Liao, H. A Generalized Extended State Observer for Supercapacitor State of Energy Estimation With Online Identified Model. *IEEE Access* **2018**, *6*, 27706–27716. [CrossRef]

46. Bellache, K.; Camara, M.B.; Dakyo, B. Supercapacitors Characterization and Modeling Using Combined Electro-Thermal Stress Approach Batteries. *IEEE Trans. Ind. Appl.* **2018**, *55*, 1817–1827. [CrossRef]
47. Krishnan, G.; Das, S.; Agarwal, V. An Online Identification Algorithm to Determine the Parameters of the Fractional-Order Model of a Supercapacitor. *IEEE Trans. Ind. Appl.* **2019**, *56*, 763–770. [CrossRef]
48. Olabi, A.G.; Wilberforce, T.; Abdelkareem, M.A.; Ramadan, M. Critical Review of Flywheel Energy Storage System. *Energies* **2021**, *14*, 2159. [CrossRef]
49. Vasconcelos, H.; Moreira, C.; Madureira, A.; Lopes, J.P.; Miranda, V. Advanced Control Solutions for Operating Isolated Power Systems: Examining the Portuguese islands. *IEEE Electrification Mag.* **2015**, *3*, 25–35. [CrossRef]
50. Zhai, D.; Yao, L.; Liao, S.; Xu, J.; Mao, B.; Xie, B. Modeling and Control of Flywheel Energy Storage System. In Proceedings of the 2023 6th International Conference on Electronics Technology (ICET), Chengdu, China, 12–15 May 2023; pp. 1289–1293.
51. Zhao, P.; Wang, M.; Wang, J.; Dai, Y. A preliminary dynamic behaviors analysis of a hybrid energy storage system based on adiabatic compressed air energy storage and flywheel energy storage system for wind power application. *Energy* **2015**, *84*, 825–839. [CrossRef]
52. Gao, H.; Li, W.; Cai, H. Distributed control of a flywheel energy storage system subject to unreliable communication network. *Energy Rep.* **2022**, *8*, 11729–11739. [CrossRef]
53. Zhang, T.L.; Zhou, Q.; Mu, S.; Li, H.; Li, Y.J.; Wang, J. Voltage-Based Segmented Control of Superconducting Magnetic Energy Storage for Transient Power Fluctuation Suppression in Island DC Microgrid. *IEEE Trans. Appl. Supercond.* **2021**, *31*, 1–5. [CrossRef]
54. Bhardwaj, A.; Nguyen, L.N.; Schillig, J.B.; Cheetham, P.; Kim, C.H.; Nguyen, D.N.; Pamidi, S. Superconducting Magnetic Energy Storage for Pulsed Power Magnet Applications. *IEEE Trans. Appl. Supercond.* **2023**, *33*, 1–6. [CrossRef]
55. Vyas, G.; Dondapati, R.S. Feasibility of Supercritical Hydrogen for cooling Superconducting Magnetic Energy Storage (SMES) Devices. In Proceedings of the 2021 International Conference on Simulation, Automation & Smart Manufacturing (SASM), Mathura, India, 20–21 August 2021; pp. 1–3.
56. Sun, Q.; Lv, H.; Wang, S.; Gao, S.; Wei, K. Optimized State of Charge Estimation of Lithium-Ion Battery in SMES/Battery Hybrid Energy Storage System for Electric Vehicles. *IEEE Trans. Appl. Supercond.* **2021**, *31*, 1–6. [CrossRef]
57. Hernando, C.; Munilla, J.; García-Tabarés, L.; Pedraz, G. Optimization of High Power SMES for Naval Applications. *IEEE Trans. Appl. Supercond.* **2023**, *33*, 1–5. [CrossRef]
58. Viswanathan, V.; Mongird, K.; Franks, R.; Li, X.; Sprenkle, V.; Baxter, R. 2022 Grid Energy Storage Technology Cost and Performance Assessment. 2022. Available online: https://www.energy.gov/eere/analysis/2022-grid-energy-storage-technology-cost-and-performance-assessment (accessed on 6 March 2024).
59. Dong, Z.; Cong, X.; Xiao, Z.; Zheng, X.; Tai, N. A Study of Hybrid Energy Storage System to Suppress Power Fluctuations of Pulse Load in Shipboard Power System. In Proceedings of the 2020 International Conference on Smart Grids and Energy Systems (SGES), Perth, Australia, 23–26 November 2020; pp. 437–441.
60. Steurer, M.; Andrus, M.; Langston, J.; Qi, L.; Suryanarayanan, S.; Woodruff, S.; Ribeiro, P.F. Investigating the Impact of Pulsed Power Charging Demands on Shipboard Power Quality. In Proceedings of the 2007 IEEE electric ship technologies symposium, Arlington, VA, USA, 21–23 May 2007.
61. Mitra, S.K.; Karanki, S.B. An SOC Based Adaptive Energy Management System for Hybrid Energy Storage System Integration to DC Grid. *IEEE Trans. Ind. Appl.* **2022**, *59*, 1152–1161. [CrossRef]
62. Zheng, Z.; Chen, X.; Hu, W.; Wang, Y.; Zong, Y.; Huang, C.; Ni, F. Dual Model Predictive Controlled Hybrid Energy Storage System for Naval DC Microgrids. *IEEE Trans. Transp. Electrification* **2022**, *9*, 156–168. [CrossRef]
63. Fang, J.; Tang, Y.; Li, H.; Li, X. A Battery/Ultracapacitor Hybrid Energy Storage System for Implementing the Power Management of Virtual Synchronous Generators. *IEEE Trans. Power Electron.* **2017**, *33*, 2820–2824. [CrossRef]
64. Roy, P.; He, J.; Liao, Y. Cost Minimization of Battery-Supercapacitor Hybrid Energy Storage for Hourly Dispatching Wind-Solar Hybrid Power System. *IEEE Access* **2020**, *8*, 210099–210115. [CrossRef]
65. Ravada, B.R.; Tummuru, N.R. Control of a Supercapacitor-Battery-PV Based Stand-Alone DC-Microgrid. *IEEE Trans. Energy Convers.* **2020**, *35*, 1268–1277. [CrossRef]
66. Abadi, S.A.G.K.; Habibi, S.I.; Khalili, T.; Bidram, A. A Model Predictive Control Strategy for Performance Improvement of Hybrid Energy Storage Systems in DC Microgrids. *IEEE Access* **2022**, *10*, 25400–25421. [CrossRef]
67. Liu, X.; Suo, Y.; Zhang, Z.; Song, X.; Zhou, J. A New Model Predictive Current Control Strategy for Hybrid Energy Storage System Considering the SOC of the Supercapacitor. *IEEE J. Emerg. Sel. Top. Power Electron.* **2022**, *11*, 325–338. [CrossRef]
68. Behera, M.K.; Saikia, L.C. A Novel Resilient Control of Grid-Integrated Solar PV-Hybrid Energy Storage Microgrid for Power Smoothing and Pulse Power Load Accommodation. *IEEE Trans. Power Electron.* **2022**, *38*, 3965–3980. [CrossRef]
69. Behera, P.K.; Pattnaik, M. Coordinated Power Management of a Laboratory Scale Wind Energy Assisted LVDC Microgrid With Hybrid Energy Storage System. *IEEE Trans. Consum. Electron.* **2023**, *69*, 467–477. [CrossRef]
70. Luo, Y.; Fang, S.; Kong, L.; Niu, T.; Liao, R. Dynamic power management of Shipboard Hybrid Energy Storage System under Uncertain Navigation Conditions. *IEEE Trans. Transp. Electrification* **2023**. [CrossRef]
71. Li, J.; Han, Y.; Zhou, S.; Li, Z.; Fan, H.; Wang, B. Improved Linear Active Disturbance Rejection Control with Dynamic Event-triggered Mechanism for Hybrid Energy Storage System. *IEEE Trans. Transp. Electrification* **2023**. [CrossRef]

72. Pasupuleti, S.S.; Tummuru, N.R.; Misra, H. Power Management of Hybrid Energy Storage System Based Wireless Charging System With Regenerative Braking Capability. *IEEE Trans. Ind. Appl.* **2023**, *59*, 3785–3794. [CrossRef]
73. Huang, Y.; Hu, H.; Ge, Y.; Liao, H.; Luo, J.; Gao, S.; He, Z. Joint Sizing Optimization Method of PVs, Hybrid Energy Storage Systems, and Power Flow Controllers for Flexible Traction Substations in Electric Railways. *IEEE Trans. Sustain. Energy* **2023**, *15*, 1210–1223. [CrossRef]
74. Lee, Y.-L.; Lin, C.-H.; Chang, C.-H.; Liu, H.-D.; Chen, C.-C. A Novel A Novel Hybrid Energy Storage System with an Adaptive Digital Filter−Based Energy Management Strategy for Electric Vehicles. *IEEE Trans. Transp. Electrification* **2023**. [CrossRef]
75. Lai, J.; Chen, M.; Dai, X.; Liu, L.; Zhao, N. Power Flow Optimization and Control Strategy for Energy Router in Dual Mode Traction Power Supply System. *IEEE Trans. Intell. Transp. Syst.* **2023**, *24*, 12284–12293. [CrossRef]
76. Mehraban, A.; Farjah, E.; Ghanbari, T.; Garbuio, L. Integrated optimal energy management and sizing of hybrid battery/flywheel energy storage for electric vehicles. *IEEE Trans. Ind. Informatics* **2023**, *19*, 10967–10976. [CrossRef]
77. Gao, P.; Li, Y.; Yao, W.; Zheng, X.; Zhang, C. Optimization of Hybrid Energy Storage System Sizing With Considering Energy Management Strategy for High-Power Pulsed Load in Aircraft. *IEEE Trans. Veh. Technol.* **2023**, *72*, 4525–4537. [CrossRef]
78. Han, Y.; Li, J.; Wang, B. Event-Triggered Active Disturbance Rejection Control for Hybrid Energy Storage System in Electric Vehicle. *IEEE Trans. Transp. Electrification* **2022**, *9*, 75–86. [CrossRef]
79. Lahyani, A.; Venet, P.; Guermazi, A.; Troudi, A. Battery/Supercapacitors Combination in Uninterruptible Power Supply (UPS). *IEEE Trans. Power Electron.* **2013**, *28*, 1509–1522. [CrossRef]
80. Tao, H.; Duarte, J.L.; Hendrix, M.A.M. Line-Interactive UPS Using a Fuel Cell as the Primary Source. *IEEE Trans. Ind. Electron.* **2008**, *55*, 3012–3021. [CrossRef]
81. Binduhewa, P.J. Uninterruptible power supply for short-time power back-up using ultracapacitors. In Proceedings of the 2011 IEEE 6th International Conference on Industrial and Information Systems (ICIIS), Kendy, Sri Lanka, 16–19 August 2011; IEEE: New York, NY, USA, 2011; pp. 551–556.
82. Aamir, M.; Kalwar, K.A.; Mekhilef, S. Review: Uninterruptible Power Supply (UPS) system. *Renew. Sustain. Energy Rev.* **2016**, *58*, 1395–1410. [CrossRef]
83. Hamidi, S.A.; Ionel, D.M.; Nasiri, A. 3 Batteries and Ultracapacitors for Electric Power Systems with Renewable Energy Sources. In *Renewable Energy Devices and Systems with Simulations in MATLAB® and ANSYS®*; Taylor & Francis Group: Abingdon, UK, 2017.
84. Nadeem, F.; Hussain, S.M.S.; Tiwari, P.K.; Goswami, A.K.; Ustun, T.S. Comparative review of energy storage systems, their roles, and impacts on future power systems. *IEEE Access* **2019**, *7*, 4555–4585. [CrossRef]
85. Amiryar, M.E.; Pullen, K.R. A Review of Flywheel Energy Storage System Technologies and Their Applications. *Appl. Sci.* **2017**, *7*, 286. [CrossRef]
86. Fan, X.; Liu, X.; Hu, W.; Zhong, C.; Lu, J. Advances in the development of power supplies for the Internet of Everything. *InfoMat* **2019**, *1*, 130–139. [CrossRef]
87. Falahi, M.; Butler-Purry, K.L.; Ehsani, M. Reactive Power Coordination of Shipboard Power Systems in Presence of Pulsed Loads. *IEEE Trans. Power Syst.* **2013**, *28*, 3675–3682. [CrossRef]
88. Grid Energy Storage, U.S. Department of Energy Report. 2013. Available online: https://energy.gov/oe/downloads/grid-energy-storage-december-2013 (accessed on 2 March 2024).
89. Tan, K.M.; Babu, T.S.; Ramachandaramurthy, V.K.; Kasinathan, P.; Solanki, S.G.; Raveendran, S.K. Empowering smart grid: A comprehensive review of energy storage technology and application with renewable energy integration. *J. Energy Storage* **2021**, *39*, 102591. [CrossRef]
90. Guerrero, J.M.; Loh, P.C.; Lee, T.-L.; Chandorkar, M. Advanced Control Architectures for Intelligent Microgrids—Part II: Power Quality, Energy Storage, and AC/DC Microgrids. *IEEE Trans. Ind. Electron.* **2012**, *60*, 1263–1270. [CrossRef]
91. Guerrero, J.M.; Vasquez, J.C.; Matas, J.; de Vicuna, L.G.; Castilla, M. Hierarchical Control of Droop-Controlled AC and DC Microgrids—A General Approach Toward Standardization. *IEEE Trans. Ind. Electron.* **2011**, *58*, 158–172. [CrossRef]
92. Mohd, A.; Ortjohann, E.; Schmelter, A.; Hamsic, N.; Morton, D. Challenges in integrating distributed Energy storage systems into future smart grid. In Proceedings of the 2008 IEEE International Symposium on Industrial Electronics (ISIE 2008), Cambridge, UK, 30 June–2 July 2008; pp. 1627–1632.
93. Eyer, J.; Corey, G. SANDIA REPORT Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide A Study for the DOE Energy Storage Systems Program. Available online: http://www.ntis.gov/help/ordermethods.asp?loc=7-4-0#online (accessed on 6 March 2024).
94. Sihler, C.; Miri, A. A Stabilizer for Oscillating Torques in Synchronous Machines. *IEEE Trans. Ind. Appl.* **2005**, *41*, 748–755. [CrossRef]
95. Neely, J.C.; Byrne, R.H.; Elliott, R.T.; Silva-Monroy, C.A.; Schoenwald, D.A.; Trudnowski, D.J.; Donnelly, M.K. Damping of inter-area oscillations using energy storage. In Proceedings of the IEEE Power & Energy Society General Meeting, Vancouver, BC, Canada, 21–25 July 2013; IEEE: New York, NY, USA, 2013; pp. 1–5.
96. Lucchese, F.C.; Canha, L.N.; Brignol, W.S.; Rangel, C.A.S.; Hammerschmitt, B.K.; Castro, C.C. A Review on Energy Storage Systems and Military Applications. In Proceedings of the 2020 55th International Universities Power Engineering Conference (UPEC), Torino, Italy, 1–4 September 2020; IEEE: New York, NY, USA, 2020; pp. 1–5.
97. Catenaro, E.; Rizzo, D.M.; Onori, S. Framework for energy storage selection to design the next generation of electrified military vehicles. *Energy* **2021**, *231*, 120695. [CrossRef]

98. Zhu, B.; Lu, J.; Zhang, X.; Ma, T.; Dai, Y. A Novel Hybrid Energy Storage System for Large Shipborne Electromagnetic Railgun. *IEEE Trans. Plasma Sci.* **2021**, *49*, 2420–2427. [CrossRef]
99. Mamun, A.-A.; Liu, Z.; Rizzo, D.M.; Onori, S. An Integrated Design and Control Optimization Framework for Hybrid Military Vehicle Using Lithium-Ion Battery and Supercapacitor as Energy Storage Devices. *IEEE Trans. Transp. Electrif.* **2018**, *5*, 239–251. [CrossRef]
100. Frankforter, K.J.; Tejedor-Tejedor, M.I.; Anderson, M.A.; Jahns, T.M. Investigation of Hybrid Battery/Ultracapacitor Electrode Customization for Energy Storage Applications with Different Energy and Power Requirements Using HPPC Cycling. *IEEE Trans. Ind. Appl.* **2019**, *56*, 1714–1728. [CrossRef]
101. He, L.; Jiang, X.; Tang, C.; Liu, Y.; Wu, Y.; Weilin, L. Energy Management Strategy of Composite Energy Storage System With Airborne High-power Pulse Load. In Proceedings of the 2022 IEEE 17th Conference on Industrial Electronics and Applications (ICIEA), Chengdu, China, 16–19 December 2023; pp. 219–224.
102. Wang, W.; Liu, H.; Lin, W.; Chen, Y.; Yang, J.-A. Investigation on Works and Military Applications of Artificial Intelligence. *IEEE Access* **2020**, *8*, 131614–131625. [CrossRef]
103. Rahman, A.; Kim, J.; Hossain, S. Recent advances of energy storage technologies for grid: A comprehensive review. *Energy Storage* **2021**, *4*, e322. [CrossRef]
104. Martins, R.; Hesse, H.C.; Jungbauer, J.; Vorbuchner, T.; Musilek, P. Optimal Component Sizing for Peak Shaving in Battery Energy Storage System for Industrial Applications. *Energies* **2018**, *11*, 2048. [CrossRef]
105. Bereczki, B.; Hartmann, B.; Kertesz, S. Industrial Application of Battery Energy Storage Systems: Peak shaving. In Proceedings of the 2019 7th International Youth Conference on Energy (IYCE), Bled, Slovenia, 3–6 July 2019; pp. 1–5.
106. Abbas, A.; Halbe, S.; Chowdhury, B. Comparison of Peak Demand Shaving Potential of Demand Response and Distributed Energy Storage in Residential Buildings. In Proceedings of the SoutheastCon 2019, Huntsville, Alabama, 11–14 April 2019; pp. 1–6.
107. Barzkar, A.; Hosseini, S.M.H. A novel peak load shaving algorithm via real-time battery scheduling for residential distributed energy storage systems. *Int. J. Energy Res.* **2018**, *42*, 2400–2416. [CrossRef]
108. Engels, J.; Claessens, B.; Deconinck, G. Optimal Combination of Frequency Control and Peak Shaving With Battery Storage Systems. *IEEE Trans. Smart Grid* **2019**, *11*, 3270–3279. [CrossRef]
109. Li, X.; Cao, X.; Li, C.; Yang, B.; Cong, M.; Chen, D. A Coordinated Peak Shaving Strategy Using Neural Network for Discretely Adjustable Energy-Intensive Load and Battery Energy Storage. *IEEE Access* **2019**, *8*, 5331–5338. [CrossRef]
110. Kein, H.C.; Huoy, L.B.; Yun, S.L.; Jianhui, W.; Li, W. The State-of-the-Arts of Peak Shaving Technologies: A Review. In Proceedings of the International Conference on Smart Grid and Clean Energy Technologies (ICSGCE), Kuching, Malaysia, 4–7 October 2020; pp. 162–166.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.