SUPERCAPACITORS APPLICATION IN SMART ENVIRONMENTS

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In line with the smart city concept, supercapacitors offer potential for creating greener, sustainable, and efficient power systems across various industries. By utilizing distributed energy sources such as photovoltaic cells and fuel cells in urban smart environments, power sources shift towards a DC-based model. Since urban settings incorporate many distributed power sources connected to distribution lines, energy storage becomes a crucial aspect of the system. Both battery energy storage systems and supercapacitor energy storage systems, as well as hybrid combinations, can be implemented on different scales, making them an ideal fit for smart cities. Sensor networks and Internet of Things (IoT) devices and applications play an essential role in smart city development. Given that batteries offer a limited solution, supercapacitors provide a high-energy storage option for applications requiring high-voltage and high-current drives. Recent research highlights supercapacitors' suitability for a wide range of applications, including IoT, consumer products, white goods, office automation, long-term battery backup, and energy harvesting.

Keywords: supercapacitors, smart environment, large-scale integration, energy efficiency.

Given the contemporary emphasis on energy harvesting from renewable sources, current research endeavors are directed toward exploring various methodologies for storing such energy in an electrically available format. Supercapacitors emerge as highly efficient energy storage devices, distinguished by their numerous advantages, thus witnessing continuous integration into systems and devices necessitating robust power supply, in contrast to conventional batteries [1 – 6]. Their burgeoning application across diverse sectors stems from their superior performance and promising market prospects, encompassing industrial control, power management, transportation, consumer electronics, national defense, telecommunications, medical apparatus, electric and hybrid vehicles, among others.

In the context of burgeoning intelligent electronic devices, there is a growing focus on flexible energy storage solutions within research realms. Industry demands storage systems that are not only flexible and optimized but also possess commendable electrochemical properties [1, 4 – 6]. Supercapacitors, with their notable attributes such as longevity of charge-discharge cycles, compactness, environmental compatibility, find suitability across varied applications, increasingly tasked with storing and releasing substantial energy in short intervals. Noteworthy applications within the industry include automotive sector, global hybrid transportation systems, grid stabilization initiatives, utility vehicles, and rail-based power infrastructures [7].

The role of supercapacitors as energy reservoirs is pivotal, particularly in stationary applications within the energy sector, owing to their remarkable power characteristics. Furthermore, their minimal maintenance requirements and resilience to extreme conditions render them well-suited for applications related to renewable energy [8, 9]. In addition, supercapacitors offer significant advantages to railway electrification endeavors and aerospace endeavors, aligning with the objectives of transitioning toward more-electric power supply frameworks [9, 10]. Moreover, various industrial systems increasingly integrate supercapacitors, spanning from small vehicles such as forklifts, shovel trucks, agricultural machinery, excavators, mining shovels, and harbor cranes to industrial lasers [1, 9]. In the domain of consumer electronics, supercapacitors find utility in real-time clock or memory backup systems, power failure mitigation, and storage applications, often supplanting traditional batteries, besides serving as high-load assistants to primary electrical energy storage systems [9].

Application of the supercapacitors

From a user perspective, electricity is often regarded as the most environmentally friendly form of energy. However, the ecological advantage of electricity is contingent upon its source. It is most environmentally advantageous when derived predominantly from renewable sources such as solar, wind, wave, and to a significant extent, hydropower. Despite its benefits, hydropower can also pose ecological challenges, particularly regarding disturbances to water regimes, including surface waters. Nevertheless, even when electricity is generated from non-renewable sources like fossil fuels or nuclear reactions, addressing the negative effects of by-products may be more efficiently managed at centralized facilities compared to the distributed impacts associated with transportation systems reliant on such energy sources.

The adoption of electric energy in transportation necessitates high-specific-energy and high-specific-power devices, surpassing conventional electric systems. The development of supercapacitors has significantly enhanced the feasibility of this application. In scenarios where energy is sourced from solar or wind power, effective energy storage solutions are required to address intermittency issues. Supercapacitors offer advantages over standard batteries due to their ability to withstand a significantly greater number of charge-discharge cycles.

Supercapacitors find diverse applications across various domains, owing to their unique characteristics and capabilities. In pursuit of enhancing lifespan and minimizing maintenance expenses, ongoing research endeavors encompass the utilization of secondary (rechargeable) batteries alongside the practice of energy harvesting (EH), which involves harnessing ambient energy sources. This convergence contributes to Wireless Sensor Nodes (WSNs) achieving self-powered functionality. Given the intrinsic degradation of secondary batteries over time, extending their lifespan alone proves insufficient for prolonged multi-year environmental parameter monitoring. Consequently, capacitors with exceptionally high capacitance—referred to as supercapacitors—emerge as viable alternatives for node power supply. These devices operate as reversible electrochemical systems and are increasingly favored for sensor node empowerment.

Supercapacitors boast attributes such as high-power density, rapid charging capability, extensive charge-discharge cycles, temperature resilience, low equivalent series resistance, and minimal leakage current, aligning favorably with the operational requirements of most wireless sensor nodes. However, their lower energy density relative to batteries results in comparatively rapid discharge and necessitates frequent recharging [1]. Hence, a consistent or intermittent energy source within the natural environment becomes imperative. Such sources may include solar panels, piezoelectric vibration transducers, thermoelectric generators, antennas, among others [11].

In alignment with the smart city concept, supercapacitors possess the potential to contribute to the development of greener, more sustainable, and efficient power systems. A notable example is within public transportation systems. In urban smart environments, power sources transition to a DC-based configuration, incorporating distributed energy sources such as photovoltaic cells and fuel cells. With urban environments designed with numerous distributed power sources connected to distribution lines, energy storage assumes a significant role within the system. Both battery energy storage systems and supercapacitor energy storage systems, as well as hybrid configurations, can be implemented at various scales, making them well-suited for the smart city concept [12]. The smart city concept relies heavily on sensor networks and Internet of Things (IoT) devices and applications. As energy demands in sensor devices increase, there arises a need to store energy for blackout periods. Recognizing that batteries offer only temporary solutions, supercapacitors emerge as a solution for high-energy storage applications requiring high-voltage and high-current drive [13]. Recent research indicates that supercapacitors are suitable for a wide range of applications, including IoT, consumer products, white goods, office automation, long-term battery backup, and energy harvesting [1, 13]. To address powering challenges that may arise at remote nodes and in extreme weather conditions, fully functional IoT devices have been designed based on energy harvesting with supercapacitors and batteries serving as storage elements [12].

In recent years, economic trends have spurred the generation of electric power from renewable energy sources. Consequently, the concept of the microgrid has emerged, representing an off-grid or grid-connected energy system capable of functioning independently or in conjunction with other microgrids [14]. Broadly, such systems can deliver electric power from either a single source or multiple sources, such as wind and solar energy, while integrating energy storage within the system [15, 16]. Supercapacitors are increasingly employed to regulate microgrid voltage and enhance system stability. Recent research has demonstrated the utilization of supercapacitors to manage the error component of battery current in proposed control schemes. This addition to microgrid infrastructure not only enhances voltage regulation capabilities but also prolongs battery life [17, 18].

Supercapacitors are increasingly utilized in both AC power systems, specifically Energy Storage Systems (EES), and DC power sources. The advancement of voltage balancing techniques for serially connected supercapacitors holds the promise of significant enhancements to High Voltage Direct Current (HVDC) transmission systems. The ample capacity of supercapacitors enables efficient energy storage for small consumers within short durations. Their primary advantage in energy systems lies in their high-power density, allowing them to effectively address large consumption peaks. When integrated with power electronics circuits, supercapacitors can inject energy into EES precisely when needed, thereby paving the way for novel developments in circuitry and control algorithms [1]. A noteworthy application of supercapacitors in DC power supplies is in low-pass filters, offering parameters previously unattainable [19].

Electrically driven vehicles represent one of the most significant ecological advancements, considering the prevalence of conventional pollution of the environment. Globally, there is growing interest in hybrid vehicles, which exhibit lower fuel consumption and significantly reduced emissions of harmful pollutants compared to traditional vehicles. In broad terms, hybrid vehicles can be defined as vehicles that utilize a combination of energy production and storage technologies. They amalgamate the desirable attributes of conventional vehicles, such as long range and acceleration, with those of electric vehicles, including zero emissions, quiet operation, and the utilization of braking energy [20]. Experience has shown that it is not imperative to immediately establish a comprehensive network of charging stations to boost the adoption of electric vehicles, as users are willing to charge their vehicle batteries at home. The prospect of supermarkets, parking garages, and restaurants providing charging stations for customers is highlighted as the next step in this progression [20, 21].

Supercapacitors are increasingly utilized, and are anticipated to continue to be, in power electronics configurations of medium power, serving as reservoirs of electrical energy during transition phases. There exists a tangible prospect that they will soon supplant bulky inductors, which also serve as significant sources of electromagnetic interference. In such applications, supercapacitors must possess both high capacitance and relatively high operating voltage, necessitating regular cell binding and associated challenges. It is imperative for the internal resistance to be minimal, while leakage current is of lesser concern. A notable example of supercapacitor utilization is in a Buck-Boost converter equipped with a supercapacitor to capture braking energy [1].

Conclusion

Supercapacitors find extensive use owing to their high-power density, enabling rapid charge and discharge cycles, along with a vast number of charge/discharge cycles [22]. The improved performance of supercapacitors is paving the way for new application domains, as outlined in this paper. The expansion of the industry in this realm leads to price reductions and enhances system performance.

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Застосування суперконденсаторів у розумних середовищах

Відповідно до концепції "розумного міста", суперконденсатори забезпечують потенціал для створення більш екологічних, стійких та ефективних енергосистем у різних галузях промисловості. Завдяки використанню розподілених джерел енергії, таких як фотоелектричні елементи та паливні елементи в розумних міських середовищах, джерела живлення поступово переходять на використання моделі на основі постійного струму. Оскільки міське середовище охоплює багато розподілених джерел енергії, під'єднаних до розподільчих ліній, зберігання енергії стає вирішальним фактором системи. Як акумуляторні системи зберігання енергії, так і системи зберігання енергії на суперконденсаторах, а також гібридні комбінації можуть бути реалізовані в різних масштабах, що робить їх ідеальним рішенням для розумних міст. Сенсорні мережі та пристрої та додатки Інтернету речей (IoT) відіграють важливу роль у розвитку "розумних" міст. З огляду на те, що батареї є обмеженим варіантом розв'язання проблеми, суперконденсатори забезпечують можливість зберігання великої кількості енергії для застосунків, що потребують високовольтних і сильнострумових приводів. Нещодавні дослідження підкреслюють придатність суперконденсаторів для широкого спектра застосувань, зокрема Інтернету речей, споживчих товарів, побутової техніки, автоматизації офісу, довготривалого резервного живлення та збору енергії.

Ключові слова: суперконденсатор, розумне середовище, інтеграція великого масштабу, енергоефективність.