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Latest Energy Storage Trends in Multi-Energy Standalone Electric Vehicle Charging Stations: A Comprehensive Study

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Abstract: The popularity of electric vehicles (EVs) is increasing day by day due to their environmentally friendly operation and high milage as compared to conventional fossil fuel vehicles. Almost all leading manufacturers are working on the development of EVs. The main problem associated with EVs is that charging many of these vehicles from the grid supply system imposes an extra burden on them, especially during peak hours, which results in high per-unit costs. As a solution, EV charging stations integrated with hybrid renewable energy resources (HREs) are being preferred, which utilize multi-energy systems to produce electricity. These charging stations can either be grid-tied or isolated. Isolated EV charging stations are operated without any interconnection to the main grid. These stations are also termed standalone or remote EV charging stations, and due to the absence of a grid supply, storage becomes compulsory for these systems. To attain maximum benefits from a storage system, it must be configured properly with the EV charging station. In this paper, different types of the latest energy storage systems (ESS) are discussed with a comprehensive review of configurations of these systems for multi-energy standalone EV charging stations. ESS in these charging stations is applied mainly in three different configurations, named single storage systems, multi-storage systems, and swappable storage systems. These configurations are discussed in detail with their pros and cons. Some important expectations from future energy storage systems are also highlighted.

Keywords: electric vehicle charging; energy storage configurations; future energy storage; multi-energy systems; renewable energy; standalone charging stations

Citation: Ali, A.; Shakoor, R.; Raheem, A.; Muqeet, H.A.u.; Awais, Q.; Khan, A.A.; Jamil, M. Latest Energy Storage Trends in Multi-Energy Standalone Electric Vehicle Charging Stations: A Comprehensive Study. *Energies* **2022**, *15*, 4727. https://doi.org/10.3390/en15134727

Academic Editors: Haifeng Dai and Muhammad Aziz

Received: 28 April 2022
Accepted: 22 June 2022
Published: 28 June 2022

1. Introduction

Energy has become a prime topic of interest globally these days. The development of a country can be accessed from its energy production and consumption patterns. The growing human population is resulting in the rise of power usage both for residential and commercial applications. It requires an appropriate increment in power generation proportionally. Conventional methods of power production have proved to be insufficient and the root cause of adverse environmental, financial and social implications. So, research is more focused on energy resources that are environmentally friendly and auto replenish themselves, such as wind, biogas, solar and geothermal energy. These are called green energy resources, and power production from these green renewable energy resources (REs) is on the rise. Different energy management schemes are being developed to effectively use these resources in power production [1–3]. Antiquated grids are being replaced by modern grids that are decentralized and smart [4,5]. To avoid the fast depletion of fossil fuel and carbon emissions, it is suggested that there should be a higher mix of renewable energy in worldwide power generation [6]. The application of fossil fuels in long-term power production is also not feasible [7]. The main problem involved in the replacement of fossil fuels with REs is their unpredictable nature and less stability [8], but these factors can be controlled to some extent by using a combination of REs with and without traditional sources of power generation. These combinations representing the most appropriate solution for each situation are termed hybrid systems. Advancement in research has proved that the future belongs to these RE-based hybrid systems [9]. RE-based hybrid systems are being more and more developed [10], stable, and organized with every passing day. Besides producing power during peak and off-peak hours for conventional grids, these hybrid systems have wider applications in the development of energy-efficient buildings [11–13], power generation for remote sites [14–16], ship power supplies [17–19], production of pure water and its desalination [20,21], production of gas [22] and for electrical vehicle charging [23–25].

Presently, most vehicles use fossil fuels for energy production, which is indirectly the biggest source of environmental pollution. Fossil fuels are non-renewable, so the price of these fuels always increases. Growing oil prices and carbon emission is a major concern for vehicle manufacturers, and plugin electric vehicles (PEVs) are being considered the best alternative to fossil fuel vehicles. Almost all developed countries, such as the United States, China, Germany, Japan, and Australia, are developing their infrastructure and technologies related to EVs [26–31]. Different energy management schemes are being devised to integrate EVs with our energy systems quickly and efficiently [32]. It is predicted that EVs will contribute a major share of future sales of new vehicles [33].

It may be good news for environmental consideration, but it also raises a serious question of how the growing electricity demand of these EVs will be satisfied by insufficient present generation systems. The immediate solution to this problem is to increase the burning of fossil fuels for electricity generation in traditional power plants, but this may result in increasing air pollution, which is the biggest cause of fatality [34]. Researchers are more focused on developing RE-based hybrid systems as future sources of electricity generation for charging EVs [35–38]. These EVs come with a portable charger and can be charged at home, but it takes too much time to charge a single vehicle. So, vehicle owners prefer to charge their vehicles in a fast-charging station, where it merely takes less than an hour to fully charge the vehicle.

To make RE-based hybrid PEV charging stations more economic and efficient, substantial research is being conducted on these systems [39–43]. Storage is also a core component in these hybrid systems to provide peak shaving and lessen the charging time [44]. The increasing share of RE generation results in frequent durations of excess electricity and less electricity generation due to intermittency involved with the use of these resources, which makes it compulsory to use the storage system [45].

The main benefit of storage is to stock the surplus energy and provide it when needed [46,47]. Especially for RE-based standalone hybrid EV charging stations, storage is obligatory, and it can even take up to 51% of the total plant's capital cost [48]. Storage-based standalone hybrid PEV charging stations have pulled in extensive consideration these years. Storage can either be used in distributive or collective form with RE-based hybrid systems [49]. Charging and discharging strategies of storage systems exhibit a deep impact on the operation of standalone hybrid PEV charging systems. It is estimated that the cost of the microgrid can be reduced by optimized charging techniques [50]. The type and size of the storage system also inflict a deep impact on overall system cost due to the capital involved in its installation and maintenance cost. Storage with greater size will cause an increment in cost, while a diminutively sized storage may prove to be insufficient. So, the size of storage should always be properly optimized to ensure the reliable and profitable operation of the hybrid system [51]. A comprehensive review of storage sizing methods for different types of renewable energy resources is presented in [52]. Several mechanical, electrical, electromechanical, electrochemical, and thermal storage systems have been developed to be used in grid-connected and standalone hybrid systems.

Over the past years, noticeable research has been conducted to improve the characteristics of energy storage systems [53]. Most of this research work is focused on the size and capacity optimization, modeling, and applications of the storage system in RE-based hybrid EV charging stations [54–57]. However, there are not many studies present in the literature on configurations of energy storage systems being employed in standalone RE-based hybrid EV charging stations.

This paper presents a comprehensive review of the latest energy storage configurations being applied in the RE-based standalone EV charging stations. These configurations can be divided into three main categories, named single storage configuration, hybrid storage configuration, and swappable storage configuration. Each configuration is discussed in detail. Different types of storage devices are also presented with their merits and demerits and how these storage devices are being used in EV charging stations. A general cost comparison is presented for all these energy storage configurations. Important requirements from the future energy storage systems are also indicated, which are necessary to make future standalone RE-based EV charging stations more economic and energy efficient.

The rest of the paper is distributed as follows: Section 2 provides a basic overview of a standalone PEV charging station. Section 3 provides complete details of different ESS configurations in RE-based standalone hybrid EV charging stations. Section 4 highlights some important expectations from ESS in the future. Finally, Section 5 gives the conclusion.

2. Standalone Plugin Electric Vehicle Charging Station

A standalone or remote hybrid PEV charging station is a station used to charge the EVs in remote areas using power generated from independent renewable energy resources only without having any interconnection with the conventional grid systems. The basic structure of a standalone hybrid PEV charging station with an integrated storage system is given in Figure 1.

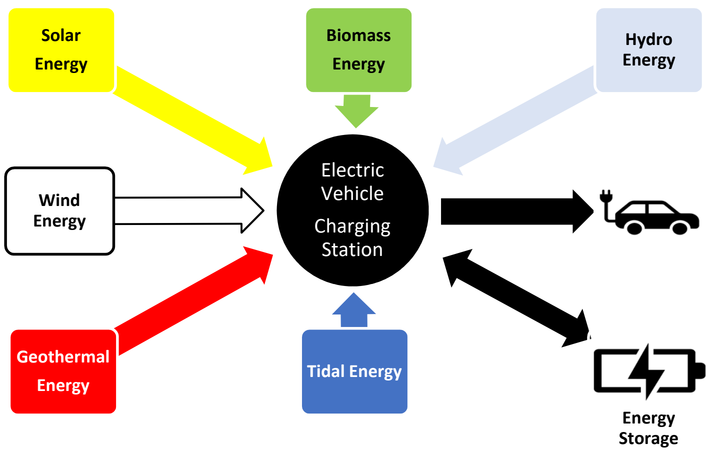

Figure 1. RE-based standalone plugin electric vehicle charging station.

This system employs green energy for electricity generation and has storage to cover up the uncertainty of these REs while improving the charging time. The infrastructure of an electric vehicle charging station falls under four major categories, named (1) charging station without ESS, (2) charging station with ESS, (3) charging station with REs, ESS and grid integration, and (4) charging station with REs, ESS without grid supply [58]. This paper is focused on ESS configurations in EV charging stations with REs; ESS but without the grid supply.

There can be different modes of operations in a standalone charging station, such as generation to vehicle (G to V), generation to storage (G to ESS), storage to vehicle (ESS to V), vehicle to storage (V to ESS), and vehicle to vehicle (V to V) [59]. Storage involved with these charging stations can also be of different types depending upon the sources of generation and storage time requirements. Table 1 shows the different types of storage systems being used in RE-based hybrid EV charging stations.

Table 1. Types of storage used in multi-energy EV charging systems.

Storage Technology	Storage Type
Mechanical	Flywheel Storage, Pumped Hydro Energy Storage (PHES), Compressed Air Energy Storage (CAES).
Electrical	Super Capacitor, Super Magnetic Storage
Electrochemical	Battery Storage (Li-ion, NiCad, Lead Acid, NaS)
Chemical	Fuel Cells, Hydrogen Storage, Biofuels
Thermal	Hot and Cold-Water Storage, Molten Salt Storage, Latent Heat Storage

3. RE-Based Hybrid Standalone PEV Charging Station Configurations

These are sustainable charging stations that utilize multi-energy REs in combination to generate the electricity required for the charging of PEVs. Standalone hybrid charging stations provide electrical energy without any connection with the main grid. So, these systems must be equipped with appropriate storage technology to meet the load demand during night or peak times. Besides providing safety from power fluctuations, storage in these isolated charging stations also serves the purpose of other ancillary services [60]. Researchers have proposed different ESS configurations while designing these remote charging stations [61].

The ESS in standalone hybrid PEV charging stations mainly falls in the following three types of configurations.

3.1 Single energy storage system configuration.
3.2 Hybrid energy storage system configuration.
3.3 Swappable energy storage system configuration.

3.1. Single Energy Storage System Configuration

In this configuration, electricity is supplied using a combination of locally available renewable energy resources with a single type of energy storage system. These systems are simple in design and usually less expensive due to only one type of storage being present. A basic structure of this configuration is shown in Figure 2.

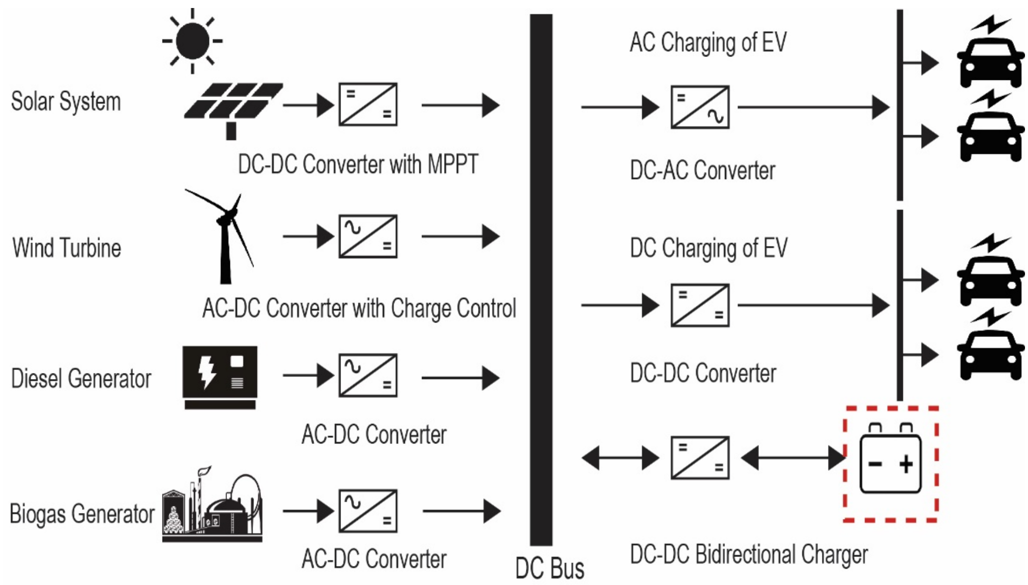

Figure 2. Standalone plugin electric vehicle charging station with single energy storage.

Although this system uses renewable energy resources for electricity generation, a diesel generator can also be included to take up the load in case of any emergency. Battery storage is considered more efficient and cost effective while utilizing a single storage configuration, especially Li-ion batteries [62]. The transformation of the battery starts with the lead acid, advancing to nickel-based batteries and modern types of lithium batteries [63]. The time of arrival of an electric vehicle is another important factor to determine the charging time of the battery and the price of per unit energy required for this purpose.

In [64], the authors designed a wind, solar and Li-ion battery-based plugin electric charging station, considering both the time of arrival and state of charge of EVs. The design was optimized using a genetic algorithm. Different configurations of the system were tested, and it was concluded that a standalone hybrid system with a single storage configuration requires less investment and higher income from supplying electricity to the electric cars as compared to a conventional grid configuration. Although battery replacement cost becomes higher in the case of a standalone system as compared to others, it is balanced with zero cost of buying energy from the grid.

Herman Jacobus and Kanzumba Kusakana [65] designed a wind-solar-based standalone hybrid electric tuk-tuk charging station with lead-acid storage and carried HOMER simulations to prove that a RE-based hybrid system with lead-acid battery storage is the most economical solution to charge more than one tuk-tuk in a single day. Karmaker et al. designed a low-cost PEV charging station for Bangladesh based on solar and biogas-based generation. A 100 Ah lead-acid battery bank containing 25 batteries was used for the storage of excess power in this system and state of charge (SOC) was also considered for the optimization purpose. It was concluded that with lead-acid storage, the proposed system has the lowest cost of energy (COE) and payback duration [66]. The main problem associated with lead-acid batteries is their low life. Battery life produces a deep impact on the overall cost of the power system [67]. Narayan et al. introduced a usage model of battery, based upon fading of dynamic capacity, and compared lifetimes of different batteries for the same load and same hybrid systems design. This comparison is shown in Figure 3 [68]. It is estimated that the $LiFePO_4$ battery has more lifetimes compared to others. The life of battery storage depends upon its charge and discharge cycles and after a specified cycle, the battery reaches the end of its useful life [69]. After that, the waste of batteries produces environmental pollution. As compared to battery storage, hydrogen-based fuel cells have a permanent lifetime and less cost. This type of storage can also be used to directly fuel hydrogen vehicles.

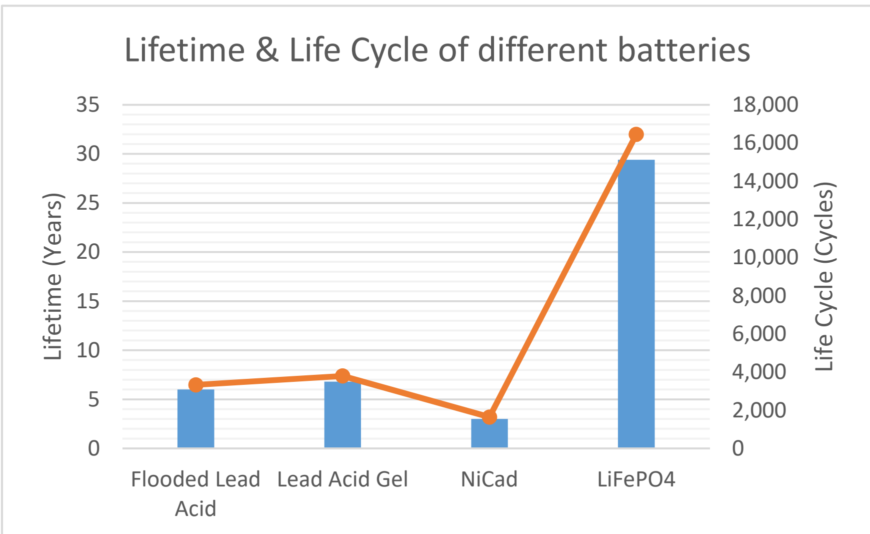

Figure 3. Comparison between lifetime and life cycle of different batteries.

In [70], Hassan Fathabadi proposed a novel multi-energy standalone system to charge plugin EVs with a single storage configuration. This proposed system compromises wind–solar resources for electricity generation and hydrogen-based 5 kWh fuel cell stack for storage purposes. The storage system was compared with a 6.5 kWh Li-ion battery storage, with the conclusion that hydrogen-based storages are less expensive and more beneficial to be used in a standalone hybrid system because this provides the best solution to many charging and discharging cycles required in a standalone multi-energy PEV charging stations. Shahab Afshar et al. proposed that instead of fixed, there should be a moving EV charging station to reduce the traveling time and distance of EVs [71]. However, this concept has some limitations associated with it, such as the energy consumed by the mobile charging unit itself, charging time, and most importantly it can only charge a single vehicle at one time. Due to these limitations, this concept requires more research before its practical implementation.

Flywheels are mechanical storage devices and possess high power and low energy density as compared to batteries. Flywheels are mechanical storage devices and possess high power and low energy density as compared to batteries. Basic parts of flywheel storage are the vacuum chamber, rotor, electric motor, bearings, and power electronics circuit [72]. Flywheel storage is considered the most cost effective for applications where fast response is required [73]. Dogan Erdemir and Ibrahim Dincer designed renewable energy-based standalone PEV fast-charging stations for two different locations in Canada and Turkey. It was proved that the inclusion of flywheel storage in both of these charging stations significantly reduces the power requirement of the system but with the problem that the flywheel requires more charging time than the EVs for its most economic operation [74]. Single-type storage systems are economical to use, and the charging system becomes less complex with this type of storage configuration.

3.2. Hybrid Energy Storage System Configuration

The low service life of energy storage systems is their main disadvantage in the utilization of RE-based hybrid systems [75]. Several other advantages and disadvantages of various type of storage systems are given in Table 2 [76]. Researchers have proposed combining more than one type of energy storage system to form a hybrid storage configuration [77–80]. This combination mostly depends upon the nature of RE resources being used for electricity generation and provides better results in terms of storage capacity and economy. Mostly, high power storage systems are designed to provide high power for a shorter duration while high energy storage devices serve the purpose of providing average power over a longer period. The best results in terms of the economy can be achieved by using the combination of high power and high energy storage devices.

Table 3 shows some high power and high energy storage devices [81]. This type of hybrid storage system has the advantage of utilizing the plugin EV as a storage medium to store the excess amount of electricity during off-peak hours and provide this electricity back to the charging station during peak hours, thereby supporting the other local energy storage systems. A basic structure of this system is given in Figure 4.

Wenlong et al. proposed a combination of battery and supercapacitor-based storage systems for standalone microgrids [82]. The reason to use such a hybrid system is that batteries have a high energy storage capacity while the supercapacitor is a high-power storage device.

Another two-layered hybrid energy storage system was proposed by Liu et al. In this system, the authors used a combination of Li-ion and led acid batteries to supply power for normal loads, while supercapacitor-based storage was also introduced in this system to cope with sudden power fluctuations [42].

To overcome the aging and high initial cost involved with the batteries, Abdulla Al Wahedi and Yusuf Bicer proposed a standalone hybrid EV charging station with a combination of Li-ion batteries, hydrogen, and ammonia-based storage to charge approximately 50 vehicles in a single day [83]. In [84], Qun Guo et al. presented a risk-based assessment model of a standalone EV charging station that uses solar energy and a diesel generator to provide electricity and hybrid storage of fuel cells and hydrogen. This type of system is equally beneficial to charge both EVs and hydrogen storage vehicles. Higinio Sánchez-Sáinz et al. also proposed a standalone RE-based hybrid EV charging station based on PV and wind resources.

Table 2. Pros and cons of different storage systems.

Storage Type	Advantage	Disadvantage
Lead Acid Battery	Cheap and high-power capacity	Less Efficient, Cause environmental pollution
Li-ion Battery	High efficiency and more energy density	High cost for commercial applications
Super Capacitor (SC)	Long life and more efficiently	Less energy density, Fewer applications
Compressed Air Energy Storage (CAES)	High power capacity and long life	Less efficient, siting problem
Flywheels	Power capacity, lifetime and efficiency are higher	Less energy density
Pumped Hydro Energy Storage (PHES)	Very high-power capacity and long life	Not fit for every site, environmental issues, moderate efficiency
Superconducting Magnetic Energy Storage (SMES)	High power capacity and high efficiency	Huge production cost, Low energy density
Hydrogen Energy Storage	Free from GHS emission, high energy density and most suitable for hydrogen fuel vehicles	Obscure storage and transportation requirements, expensive & low efficiency

Table 3. High power and high energy storage.

High Power Storage	High Energy Storage
Supercapacitor Flywheel Lead Acid Battery	CAES Li-ion Battery Fuel Cell

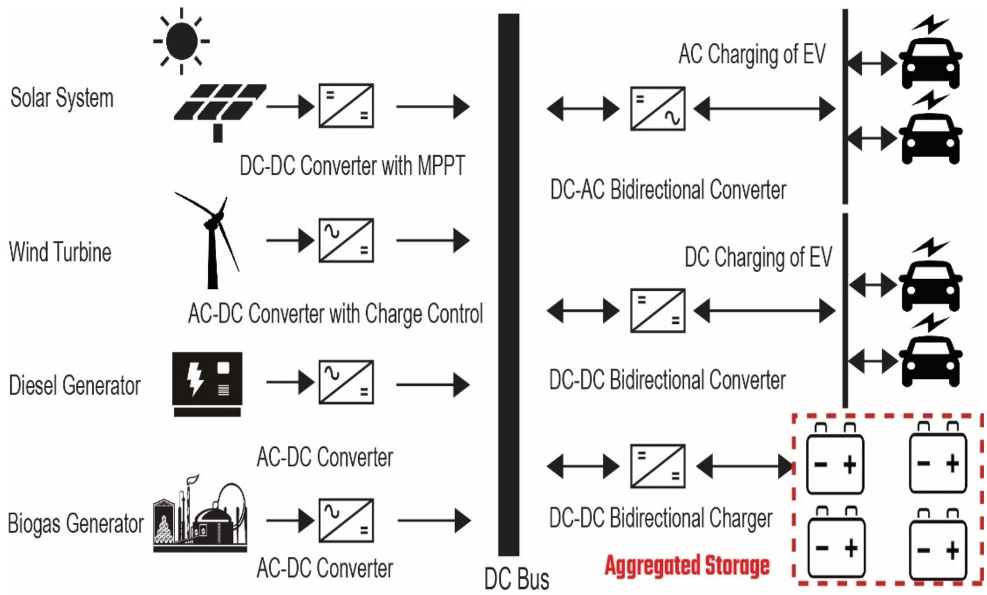

Figure 4. Standalone plugin electric vehicle charging station with hybrid energy storage.

Both battery and hydrogen storage are incorporated in charging stations to charge electric as well as hydrogen fuel vehicles [85]. Doudou N. Luta and Atanda K. Raji used hybrid hydrogen and supercapacitor-based storage for off-grid applications, such as car charging and electricity production for residential use. It was concluded that hydrogen storage increases the overall cost of the system, and it requires more research to reduce its cost for application in future storage systems [86]. Mechanical storage is considered best to supply high power for a shorter duration, and it is mostly used in conjunction with other storage technologies. It also can stabilize the high-power oscillations [87]. However, flywheel storage systems have a problem of high self-discharge. The use of flywheels with other storage systems is more beneficial. A flywheel can increase the lifetime of a lead-acid battery by 3 times its original value and 3.6 times for Li-ion batteries when hybridized [88]. Guezgouz et al. proved that the hybrid configuration of PHES and batteries becomes more reliable and cost economical in RE-based standalone power supply systems [89]. However, PHES storage requires special geographical requirements so it cannot be used everywhere, such as other batteries. This multi-storage or hybrid storage technique is the most popular storage configuration in recent research on standalone EV charging stations because it provides a compromise between high power and high-density storage devices.

3.3. Swappable Storage System Configuration

A swappable storage system is another concept in EV charging system technology. In this type of configuration, the low battery of the EV is replaced with the fully charged battery readily available in the charging station. The battery swapping type charging station framework mostly consists of a charging station area in which the EV enters and exits freely. It includes a battery stacking unit for receiving the battery, a battery replacement robot, which is mounted in the charging station area to perform the battery substitution activity, a data acknowledgment unit to acquire data about the EV that enters the charging station, such as information on a kind, size, charging state, delivery date, charging date or the type of the battery. It also includes a charging station control unit that permits the swapping activity of the battery to be performed by controlling the battery swapping robot. A basic structure of this type of charging station is given in Figure 5.

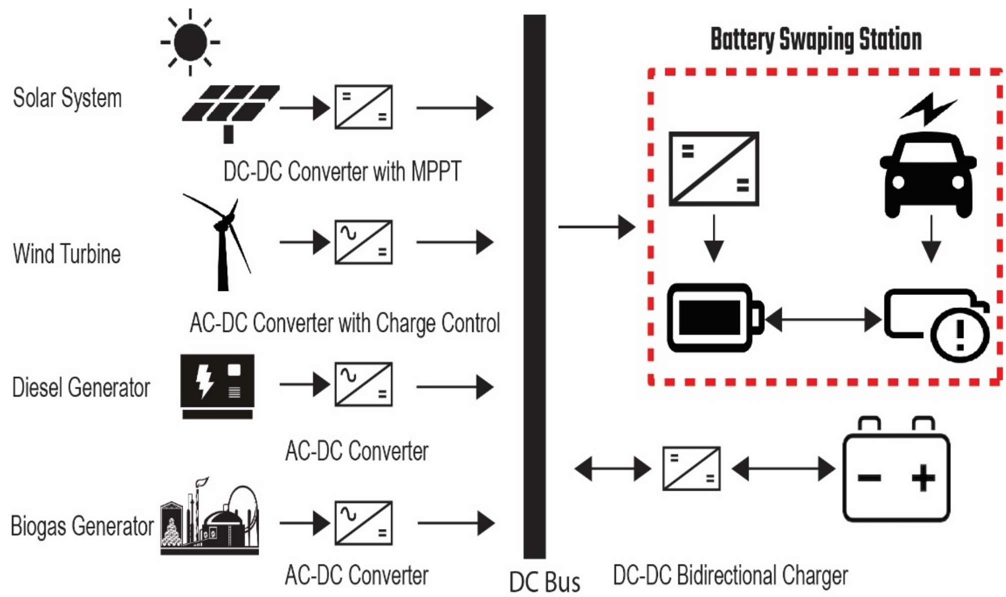

Figure 5. Standalone plugin electric vehicle charging station with swappable energy storage.

Charging an EV at dedicated charging stations requires much time as compared to conventional fuel vehicles, and this is the major concern in the adoption of EVs [90]. The alternative approach lies in the development of battery swapping stations. There are two major requirements of a swapping station: one is to standardize the EV batteries and the other is to develop a proper business model for the price allocation and operation of these stations. Neubauer J. and Pesaran A. devised a detailed economic comparison process to calculate the cost of battery-swapping station business startup [91]. J. Yang et al. considered the satisfaction of an EV owner in optimal planning of battery-swapping station [92]. Mingfei Ben et al. used a robust optimization approach to optimally size a standalone renewable energy battery-swapping station [93]. Zubaida Fakhruddin Khan and Rajesh Gupta designed a standalone EV battery-swapping station using wind energy and eight lead-acid batteries. These batteries provide backup during wind fluctuations and act as swappable storage for approaching vehicles [94]. Van Ga Bui et al. proposed the utilization of hydrogen cylinders as a suitable storage option for two-wheeler EVs [95]. Steffen Schmidt proposed that there should be a loan scheme for the battery exchange process to boost its economic and environmental benefits [96]. Another interesting approach proposed by Sujie Shao et al. is to use a battery swapping van. This van is equipped with a positioning and communication system for the battery charge management system. It can take batteries from a RE-powered remote charging station to the EVs anywhere according to the set priority [97]. EVs mostly use Li-ion batteries and owners are not required to purchase these batteries. These batteries are leased to the owners to reduce the price of EVs significantly [98]. A. Rezaee Jordehi et al. worked on the placement of standalone battery-swapping stations with PV, wind, and geothermal generation, while having PHES as an energy storage option [99]. Yang Li et al. introduced a bi-directional model to reduce the cost of an isolated RE-based microgrid and increase the profit of its associated battery-swapping station [100]. The cost of battery replacement and its charging in a standalone battery-swapping station is a major factor that can be lowered by using an effective energy management strategy. A. Rezaee Jordehi et al. worked on the energy management of battery-swapping stations with microgrids [101]. Mostly, the battery swapping configuration is utilized in the grid-connected systems because it becomes easy to charge the batteries during the off-peak time and use these batteries for swapping and storage for the station during peak hours. Table 4 indicates some recent research work related to the storage configuration in EV charging stations.

Table 4. Battery configurations in recent research works.

Ref	Battery Configuration	Generation Resources	Type of Storage	Advantages	Disadvantages
[64]	Single Storage	Wind and Solar	Li-ion Battery	• Considered arrival time and state of charge of vehicles. • The high energy density of storage.	• The high capital cost of Li-ion batteries.
[65]	Single Storage	Wind and Solar	Lead Acid Battery	• The low capital cost of storage.	• Less storage life and high replacement cost.
[66]	Single Storage	Solar and Biogas	Lead Acid Battery	• 34.68 percent reductions in CO_2 emission with the use of lead-acid battery storage and biogas with solar	• Adverse environmental impacts of the lead-acid battery.
[70]	Single Storage	Wind and Solar	Fuel Cell	• A novel Step size MPPT algorithm. • Permanent life of storage.	• Expensive hydrogen storage.
[74]	Single Storage	Wind and Solar	Flywheel	• 20 years lifetime of storage. • Economic single storage configuration.	• Charging time is more. • The energy density of storage is less.

Table 4. *Cont.*

Ref	Battery Configuration	Generation Resources	Type of Storage	Advantages	Disadvantages
[82]	Hybrid Storage	Solar	Li-ion Battery and Super Capacitor	• Application of SC to increase the lifetime of batteries. • Economic system design. • Long life of energy storage • Li-ion storage has better energy storage density as compared to lead-acid batteries.	• SC is only used to handle power fluctuations. • The size of storage becomes large.
[83]	Hybrid Storage	Wind and Solar	Li-ion Battery, Ammonia, Hydrogen Storage	• Economic Operation of the remote station for charging 50 vehicles.	• A limited number of Charging cycles for Li-ion batteries. • The low energy density of storage. • Charging of FC vehicles is not discussed
[84]	Hybrid Storage	Solar	FC and Hydrogen	• Provision to charge both EV and FC vehicles. • Uncertainty of solar, FC and hydrogen is considered in the risk-averse model.	• Expensive storage facility. • Usage of diesel generators as backup supply becomes uneconomical for the fuel deprived countries.
[85]	Hybrid Storage	Wind and Solar	Battery and FC	• Separate charging of both EVs and FC Electric Busses.	• The additional cost of Hydrogen storage. • SOC of vehicles not considered.
[86]	Hybrid Storage	Wind and Solar	FC and SC	• Economic combination of high energy density FC with high power density SC.	• High self-discharge of SC. • No specific design for car charging.
[87]	Hybrid Storage	Solar	Flywheel and LiFePO4	• Stabilization of high-frequency power oscillations. • LiFePO4 is thermally more durable.	• The low overall energy density of the storage system. • High Cost.
[93]	Swappable Storage	Solar	Li-ion Batteries	• Optimized size of generation and ESS. • The high charging time problem is eliminated.	• No specific energy management technique. • Only PV generation becomes expensive.
[94]	Swappable Storage	Wind	Lead-acid batteries	• Low-cost system. • Intermittency in wind energy is addressed.	• Lead-acid batteries cause environmental pollution. • Low storage life.
[99]	Swappable Storage	Solar, Wind and Geothermal	Li-ion Batteries, PHES	• Optimized placement of battery swap station in a microgrid.	• Geographical Limitation.
[100]	Swappable Storage	Wind and Solar	Li-ion Batteries	• Optimal bi-level scheduling between the isolated microgrid and battery swap station. • Maximization of profit.	• The reactive power of the microgrid is not taken into account.
[101]	Swappable Storage	Wind and Solar	Li-ion Batteries	• Economic Energy management scheme of a micro-grid. • Reactive power of micro-grid is also included in the energy management scheme.	• Vehicle-specific design of BSS. • Only for Tesla EVs.

Cost is another major factor that affects the utilization of different types of energy storage configurations. The cost of any configuration directly depends upon the type of storage devices being used in it. Generally, a single storage configuration requires low capital cost as compared to the hybrid storage configuration because a hybrid storage configuration involves more than a single type of storage, which increases the initial cost. Per unit energy cost of hybrid storage configuration becomes low due to the involvement of high power and high energy density storage devices. A swappable storage configuration is more environmentally friendly, but a complex infrastructure is required for this configuration which makes it less economic [102–105]. However, future advancements in this configuration may make it cost efficient.

4. Expectations from Future Energy Storage Systems

4.1. High Power Density

The rated power output of a device divided by its volume is called its power density [106], and it is measured in W/kg or W/L. It is expected for future energy systems to have high power density because a high-power density energy storage system can provide electricity with high power quality and large currents. I-ion and NaNiCl2 batteries are examples that present high power density systems.

4.2. High Energy Density

The amount of energy present in a unit volume of storage is termed energy density. A high energy density storage is recommended for future energy storage applications. Generally, high power density storage devices tend to have low energy density. An ideal storage system should have very high energy and power density so that it can provide quick power to the system and for a longer duration. Figure 6 represents a power density and energy density comparison of some famous energy storage systems.

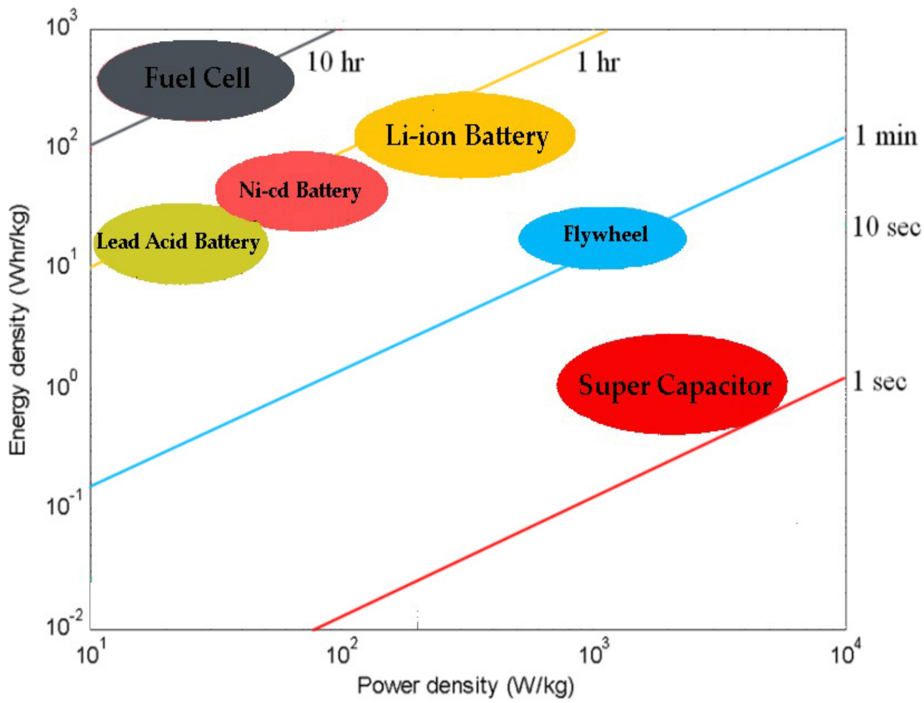

Figure 6. Power density and energy density interconnection of energy storage systems.

4.3. Environment Friendly

Environmental protection is the main objective in the development of future energy storage systems. These storage systems should have no adverse effects during and after their usable lifecycles and these must have a larger contribution in reducing the greenhouse gas emission [107,108]. The large-scale utilization and production of batteries is a source of environmental pollution because it is associated with the outflow of hazardous gases and waste chemical materials, and presently, CAES or PHES are good alternatives to battery energy storage systems [109,110].

4.4. High Response Time

The response time of a storage system indicates how fast that storage system releases the stored energy. Future energy storage systems should have a high response time with high power density to overcome the sudden voltage fluctuations in power systems. Flywheel energy storage has the highest response time in order of milliseconds but lower energy densities [111].

4.5. High Efficiency

Efficiency is related to the losses occurring in energy storage systems. There is a term called round trip efficiency, which is a ratio between electric output and electric input for a single charge/discharge cycle. Future energy storage systems should have high efficiency and negligible energy losses. An energy system with 100% round trip efficiency is called an ideal system. Flywheel and supercapacitor storage systems have the highest efficiency (>90%), but these devices have the problem of high self-discharge [112]. The energy efficiency of some important storage technologies is given in Figure 7 [113].

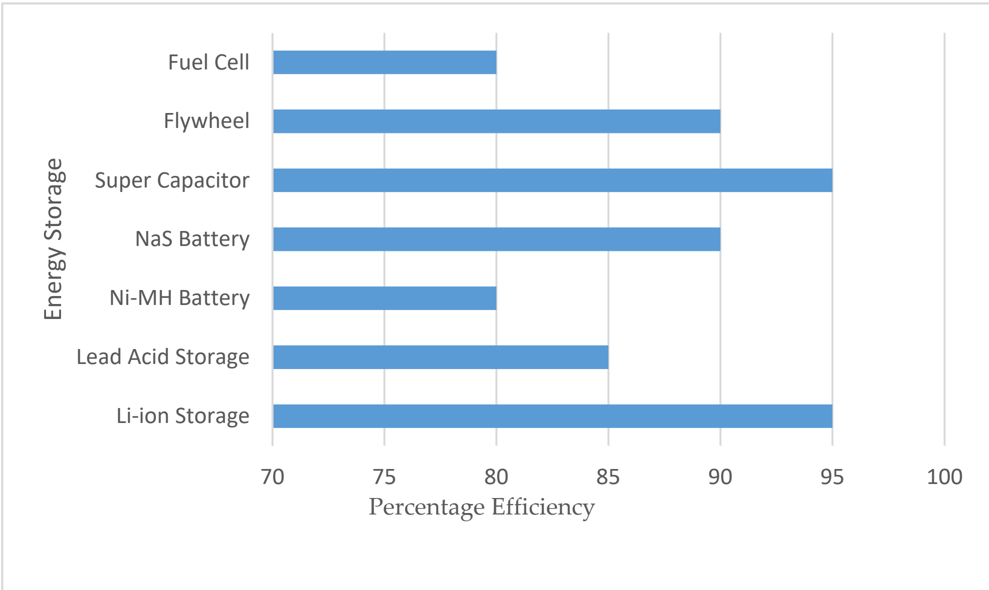

Figure 7. Energy efficiencies of different types of storage systems.

4.6. Low Cost

Cost is another factor that largely depends upon the construction, type, and capacity of the energy storage system. The cost of energy storage directly affects the initial and operational cost of the complete charging station. Many advanced energy storage systems are still much expensive. Future charging systems should have lower costs and higher storage capacities to make charging stations more economical. Battery-based storage systems have the lowest cost when a smaller number of cycles are involved, but these types of storage systems have several other associated disadvantages.

4.7. Maintenance Requirement

The operational cost of EV charging stations varies directly with the maintenance and replacement cost of energy storage systems. A low-cost energy storage system may result in a high per-unit cost at the consumer end if its maintenance cost becomes high. Future energy systems should be maintenance free as much as possible to avoid this extra burden of maintenance cost.

4.8. Recharge Time

Recharge time is another important factor for future energy storage systems. It is the measure of time required for a full discharge energy storage to attain full charge. It depends upon the type of energy storage systems, and manufacturers try their best to keep it as low as possible.

4.9. Self-Discharge Rate

Energy storage capacities of different types of storage systems are given in Table 5 [49,114]. Due to internal reactions in energy storage systems, the charge stored in these systems decay over time. The self-discharge rate of an energy system indicates how long an energy storage system can keep the energy stored.

Table 5. Energy storage capacities of different devices for EVs.

ESS Type	Storage Capacity (MWh)
Flywheel	0–25
Fuel Cell	0–50
Lead Acid Storage	0.3–50
Super Capacitor	<0.28
Li-ion Battery	0.3–25

Future energy systems must have negligible self-discharge rates to keep the energy stored for longer durations.

5. Conclusions

In this paper, three main configurations of energy storage systems are comprehensively reviewed with their applications in standalone RE-based hybrid EV charging stations. Each of the different energy storage systems are compared based on their costs and benefits. Prime requirements from the modern energy storage systems are also discussed at the end. Storage can be configured as a single storage unit only to minimize the cost and space requirements. A single type of storage is cheap, but it cannot guarantee the per unit energy price reduction of the overall system. Each single energy storage unit has its unique properties, and it becomes much more economical for the system if we combine two or more different types of energy storage systems and obtain the benefits from both. Research has proved that the combination of these multiple storages enhances their lifetime and makes the system more durable. Swappable storages are another important concept in the utilization of energy storage. In this technique, a storage unit can be swapped directly with the storage unit of an approaching electrical vehicle. Although this technique is time saving and efficient for a single type of storage technology, it becomes complex to handle multiple types of electric vehicles, each with a different type of storage unit installed.

It can be concluded from this review that energy storage is a vital part of remote/standalone EV charging stations. Old storage technologies, such as lead-acid batteries and PHES, are receiving less attention as compared to new and advanced storage technologies, such as flywheels, modern flow batteries, and CAES. Although a single type of storage becomes economical from the operational point of view, it is practically much more difficult to incorporate a single type of energy storage system for divergent applications. Hybrid energy storage systems are replacing the conventional single type of storage systems because these systems are proved to be better in covering up the drawbacks of single energy storage systems. High charging time is another problem for EV owners; charging stations utilizing swappable battery storage are currently the best solution to this problem. However, there must be standardized energy storage technology for different manufacturers and energy management systems for EVs to gain more benefit from swappable battery storage systems. Batteries are a good option for long-term storage, but they have several environmental issues.

The future of multi-energy standalone EV charging stations requires attention in two major areas: social and economic. Firstly, the social and environmental impact of these charging stations should be investigated and secondly, energy storage systems of the future must be more efficient, having a low cost, low self-discharge rate, high life, high energy, and power densities. There has been a significant advancement in the development of future energy storage technologies. Metal–air, graphene, solid-state, lithium–sulfur, and aluminum-based storage systems are being developed, which provide high energy density with a large life cycle and less cost. CAES has high energy and power density with less maintenance cost, but these storage systems require specific geological conditions. PHES, ultra capacitors, and flywheels are better energy storage options, but these devices require a high initial cost. Highly efficient and cheap hydrogen and ammonia storage are also being investigated as a future energy storage option in standalone EV charging stations.

Author Contributions: A.A.: writing, methodology, and original draft preparation; R.S. and H.A.u.M.: supervision, A.R.: draft revision; Q.A.: Proof Reading; A.A.K.: writing-review and editing; M.J.: funding. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to thank Islamia University Bahawalpur & Technical Education and Vocational Training Authority, Punjab, Pakistan, for providing a formal atmosphere to conduct this research.

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

Nomenclature

BSS	Battery Storage System
CAES	Compressed Air Energy Storage
ESS	Energy Storage System
EVs	Electric Vehicles
FC	Fuel Cell
HRE	Hybrid Renewable Energy
HRES	Hybrid Renewable Energy System
MPPT	Maximum Power Point Tracking
REs	Renewable Energy
PEVs	Plugin Electric Vehicles
PHES	Pumped Hydro Energy Storage
SC	Supercapacitor
SCFC	Super Capacitor Fuel Cell
SMES	Superconducting Magnetic Energy Storage
SOC	State of Charge

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