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Comprehensive review of energy storage systems technologies, objectives, challenges, and future trends

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ABSTRACT

Energy storage is one of the hot points of research in electrical power engineering as it is essential in power systems. It can improve power system stability, shorten energy generation environmental influence, enhance system efficiency, and also raise renewable energy source penetrations. This paper presents a comprehensive review of the most popular energy storage systems including electrical energy storage systems, electrochemical energy storage systems, mechanical energy storage systems, thermal energy storage systems, and chemical energy storage systems. More than 350 recognized published papers are handled to achieve this goal, and only 272 selected papers are introduced in this work. A comparison between each form of energy storage systems based on capacity, lifetime, capital cost, strength, weakness, and use in renewable energy systems is presented in a tabular form. Selected studies concerned with each type of energy storage system have been discussed considering challenges, energy storage devices, limitations, contribution, and the objective of each study. The integration between hybrid energy storage systems is also presented taking into account the most popular types. Hybrid energy storage system challenges and solutions introduced by published research are summarized and analyzed. A selection criteria for energy storage systems is presented to support the decision-makers in selecting the most appropriate energy storage device for their application. For enormous scale power and highly energetic storage applications, such as bulk energy, auxiliary, and transmission infrastructure services, pumped hydro storage and compressed air energy storage are currently suitable. Battery, flywheel energy storage, super capacitor, and superconducting magnetic energy storage are technically feasible for use in distribution networks. With an energy density of 620 kWh/m3, Li-ion batteries appear to be highly capable technologies for enhanced energy storage implementation in the built environment. Nonetheless, lead-acid batteries continue to offer the finest balance between price and performance because Li-ion batteries are still somewhat costly. The applications of energy storage systems have been reviewed in the last section of this paper including general applications, energy utility applications, renewable energy utilization, buildings and communities, and transportation. Finally, recent developments in energy storage systems and some associated research avenues have been discussed. Academics and engineers interested in energy storage strategies might refer to this review.

1. Introduction

In the past few decades, electricity production depended on fossil fuels due to their reliability and efficiency [1]. Fossil fuels have many effects on the environment and directly affect the economy as their prices increase continuously due to their consumption which is assumed to double in 2050 and three times by 2100 [6]. Fig. 1 shows the current global installed capacity of energy storage system ESS. China, Japan, and the United States are among the most used countries for energy storage systems. RESs are eco-friendly, easy to evolve, and can be applied in all fields like commercial, residential, agricultural, and industrial [2]. Many problems are accomplished with applying the RESs, such as intermittency, poor load following, and non-dispatchable. Using an energy storage system (ESS) is crucial to overcome the limitation of using renewable energy sources RESs. ESS can help in voltage regulation, power quality improvement, and power variation regulation with ancillary services [3]. The use of energy storage sources is of great importance. Firstly, it reduces electricity use, as energy is stored during off-peak times and used during on-peak times. Thus improving the efficiency and reliability of the system. Secondly, it reduces the amount of carbon emitted. Thirdly, these systems are used to supply energy to

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List of abbreviations

ESS	Energy Storage System
RESs	Renewable Energy Sources
SMES	Superconducting Magnetic Energy Storage
CAES	Compressed Air Energy Storage
FES	Flywheel Energy Storage
PHES	Pumped Hydro Energy Storage
BESS	Battery Energy Stotage System
HESS	Hybrid Energy Storage Systems
EESS	Electeical Energy Storage System
ECESS	Electrochemical Energy Storage System
MESS	Mechenical Energy Storage System
TESS	Thermal Energy Storage System
CESS	Chemical Energy Storage System
SCs	Supercapacitors
EV	Electric Vehicle
BEV	Battery Electric Vehicle
HEV	Hybrid Electric Vehicle
PEV	Plug-in hybrid Electric Vehicle
FB	Flow Battery
DOD	Depth of Discharge
Li-Ion battery	Lithium-ion battery
NiCd	Nickel - cadmium battery
NaS	Sodium Sulfur battery
LAES	Liquid Air Energy Storage
SHSS	Sensible heat storage systems
LHSS	Latent heat storage system
TCESS	Thermo chemical energy storage systems
FC	Fuel Cell

consumers in remote areas far away from the grid as well as reduce the intermittency of renewable energy [4,5], and [6]. Energy can be stored in many forms, such as thermal, mechanical, chemical, or electrochemical energy. Besides, it can be stored in electric and magnetic fields resulting in many types of storing devices such as superconducting magnetic energy storage (SMES), flow batteries, supercapacitors, compressed air energy storage (CAES), flywheel energy storage (FES), and pumped hydro storage (PHS) 96 % of the global amplitude of energy storage capacity is shared by the PHS. Super-capacitor energy storage, battery energy storage, and flywheel energy storage have the advantages of strong climbing ability, flexible power output, fast response speed, and strong plasticity [7]. More development is needed for electromechanical storage coming from batteries and flywheels [8].

With the rapid rising of the development of ESS and due to the enormous energy storage potential, all the efforts of researchers are focusing on giving reviews on the types, characteristics, advantages, limitations, comparison, electrical vehicle, evaluations, challenges, and applications of ESS. Some reviews are discussed, presented and compared with our work in a tabular form in Table 1.

Table 1 revealed that no review had included every one of the previously listed points. For this reason, this review has included new developments in energy storage systems together with all of the previously mentioned factors. Statistical analysis is done using statistical data from the “Web of Science”. The number of papers with the theme “Energy storage” over the past 20 years (2002–2022) is shown in Fig. 2 and it is deduced from it that ESS is a hot research field with extensive attention (see Fig. 3).

Figures (4-9) show the number of published papers and number of citations that interested in ESS technologies using the keywords (thermal energy storage system, pumped hydro energy storage, supercapacitors, SMES and battery) over the last 17 years. As can be observed in Figs. 4 and 8, there are also a lot of studies on thermal and battery energy storage, which is a hot spot of ESS and suggests that the authors are more interested in these. Furthermore, the number of papers reviewing ESS keeps rising each year, showing that ESS is a popular area of research that is receiving a lot of attention. For more clarification review, all figures have been merged in to one figure (Fig. 9). It can be observed that the number of research in ESS technologies continues to increase in the last 17 years.

In this paper, different types of energy storge are presented. Various ESS features, advantages, and limitations are discussed. In addition to, hybrid energy storage systems and some of its combinations are listed here. Furthermore, several applications of ESS along with challenges and new trends in ESS are critically reviewed.

The rest of this paper is as follows, section 2 discusses the different types of ESS, their operation, characteristics, advantages, limitations and applications. Hybrid energy storage systems in addition to several typical HESS combinations are presented in section 3. In section 4, the challenges for integrating ESS is discussed. The selection criteria for ESS is listed in section 5. Furthermore, in section 6, the applications of ESS are presented. Section 7 discusses new trends in ESS. Finally, conclusion inferred from this review paper and recommendatios are listed in section

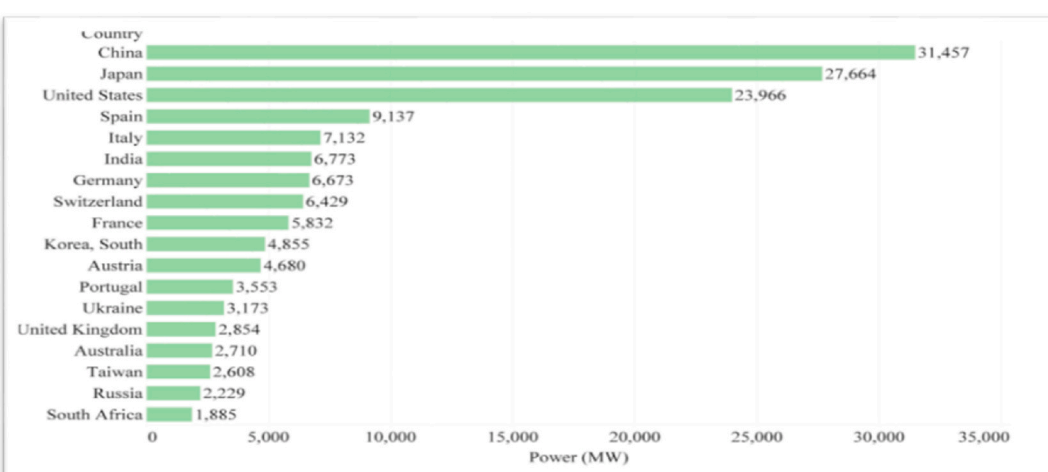


Fig. 1. Global scenario of energy storage adoption [7].

Table 1
Some reviews focusing on storage energy.

Ref.	Types	Advantages	Limitations	Comparison	Electrical vehicle	Selecting criteria	Applications	Challenges
[1]	✓	✓	✓	×	×	×	×	×
[2]	✓	✓	✓	✓	×	✓	✓	×
[9]	✓	✓	✓	×	×	×	×	×
[10]	✓	✓	✓	✓	×	✓	✓	✓
[11]	✓	✓	✓	✓	×	✓	×	✓
[8]	✓	✓	✓	×	×	×	✓	×
[12]	✓	✓	✓	✓	×	×	×	✓
[13]	×	×	×	✓	×	×	×	✓
[14]	✓	✓	✓	✓	×	✓	×	×
[15]	✓	✓	✓	✓	×	✓	✓	×
[16]	✓	✓	✓	✓	×	✓	✓	✓
[17]	✓	✓	✓	✓	×	✓	✓	×
[18]	✓	✓	✓	✓	✓	×	✓	✓
Our work	✓	✓	✓	✓	✓	✓	✓	✓

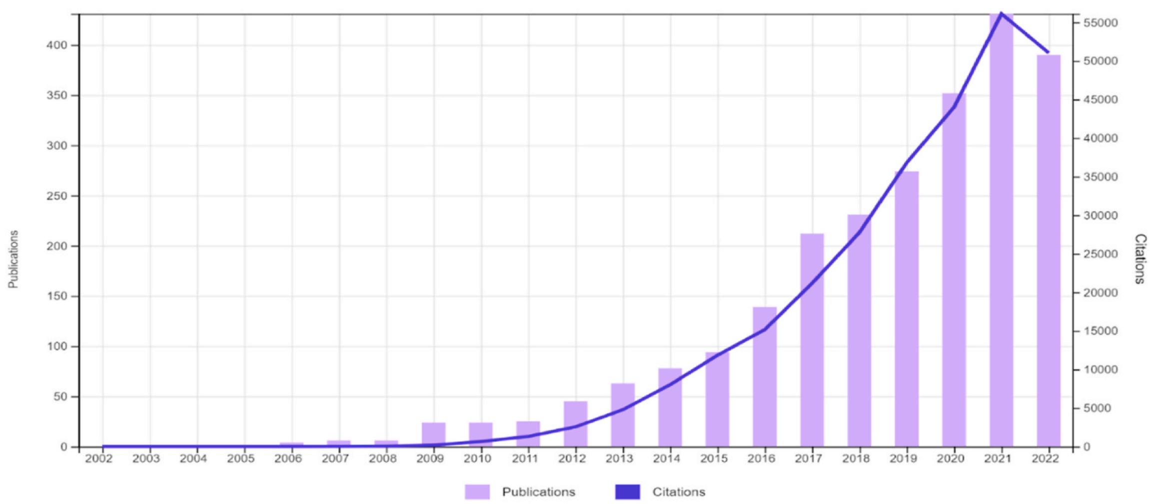


Fig. 2. Number of articles and citations reviewing ESS over the last 20 years.

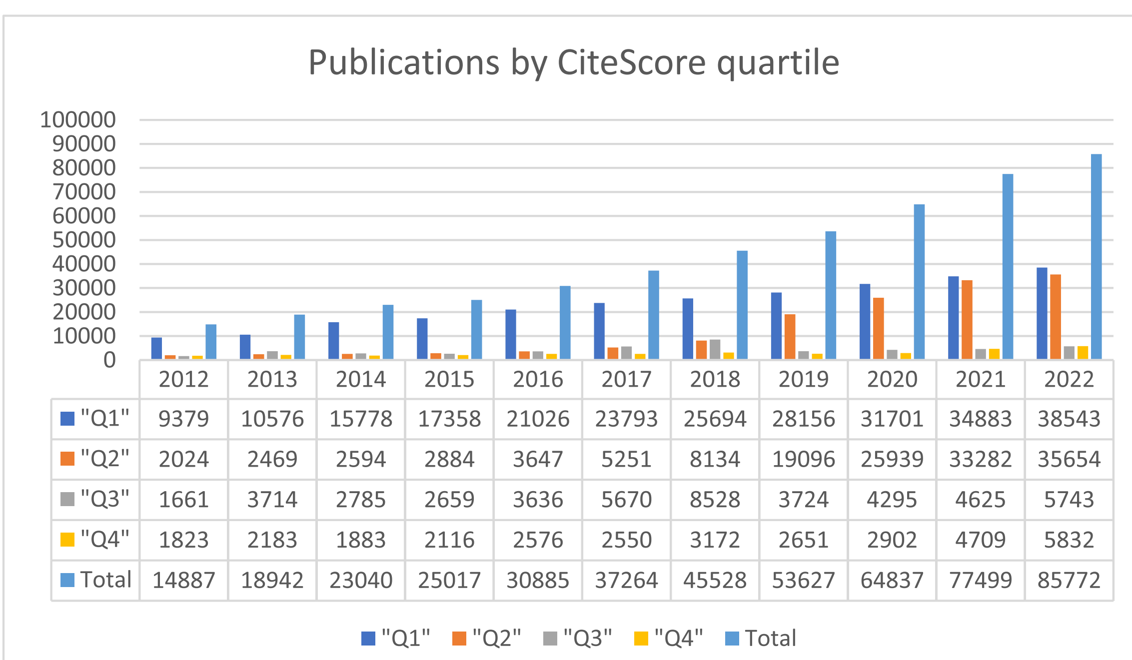


Fig. 3. Publications by CiteScore quartile from Scival.

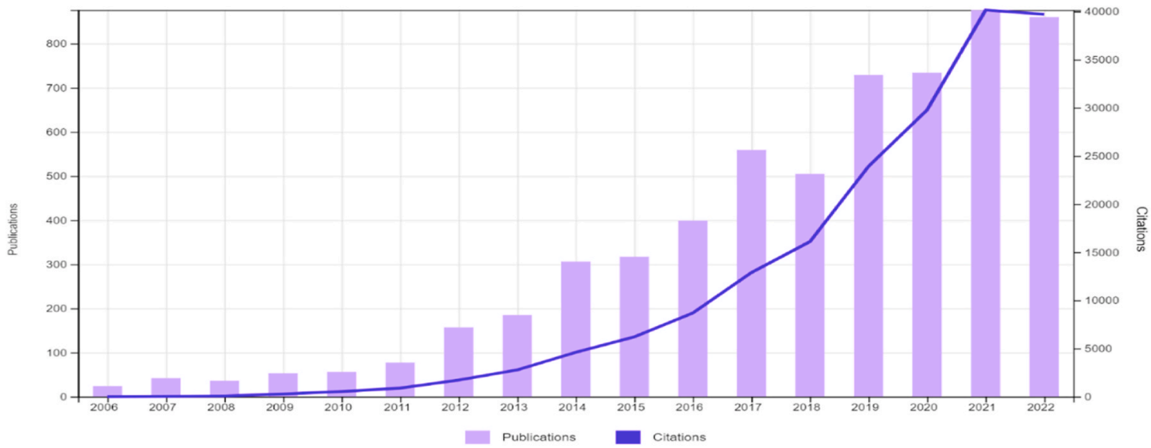


Fig. 4. Number of articles reviewing TESS over the last 17 years.

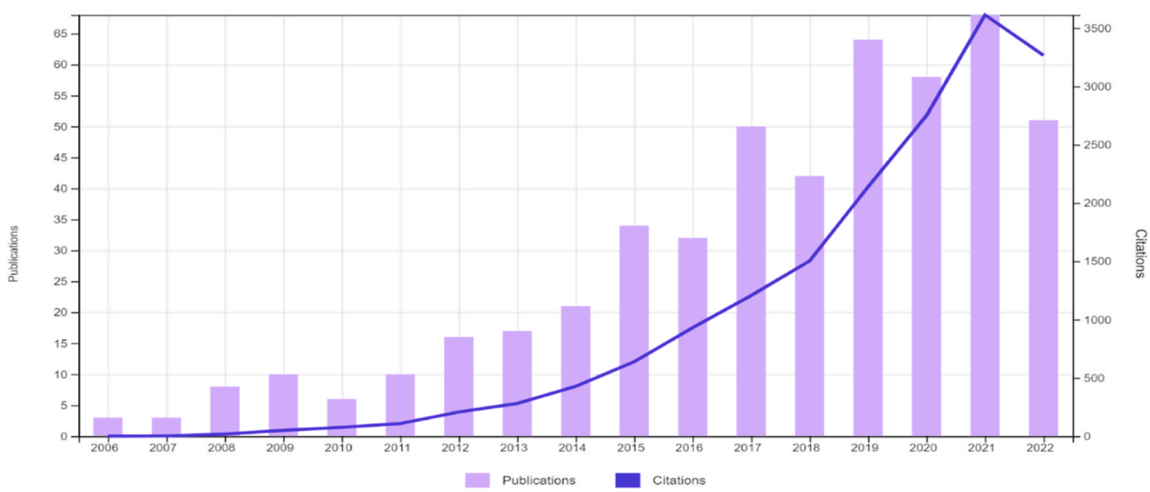


Fig. 5. Number of articles reviewing hydropower over the last 17 years.

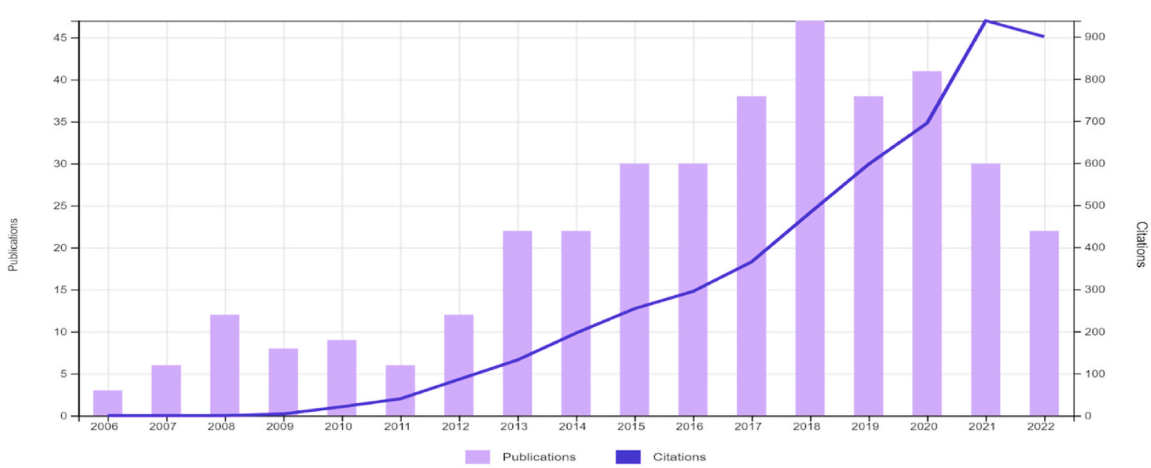


Fig. 6. Number of articles reviewing Super capacitors over the last 17 years.

8.

2. Types of energy storage

Energy storage technologies can be categorized based on the stored energy form (as shown in Fig. 10) to Ref. [9].

1. Electric energy storage systems EESS
2. Electrochemical energy storage systems ECESS
3. Mechanical energy storage systems MESS
4. Thermal energy storage systems TESS
5. Chemical energy storage systems CESS

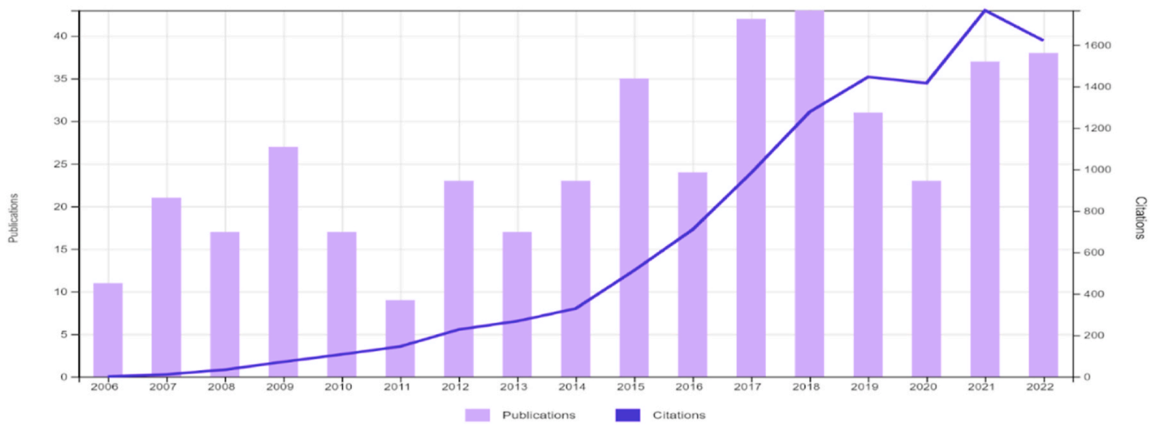


Fig. 7. Number of articles reviewing SMES over the last 17 years.

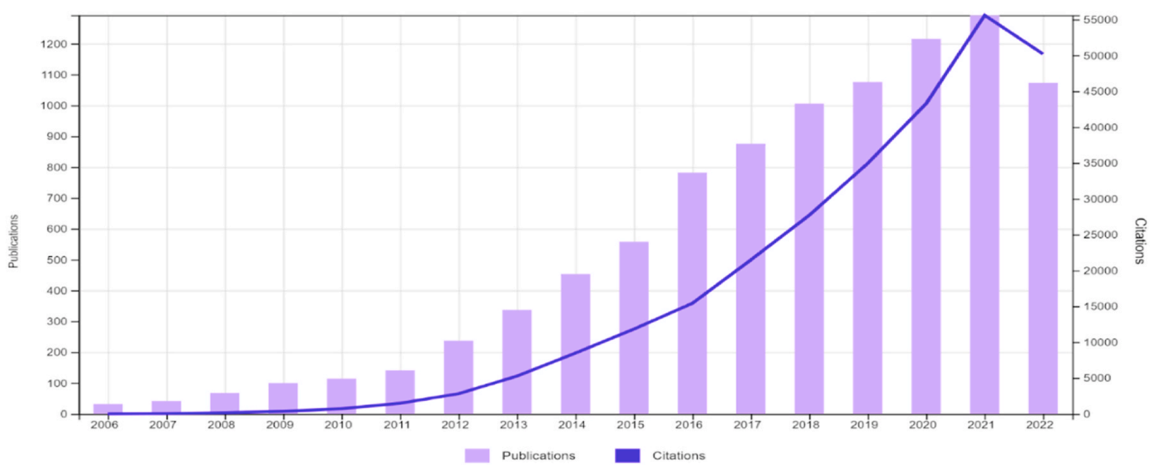
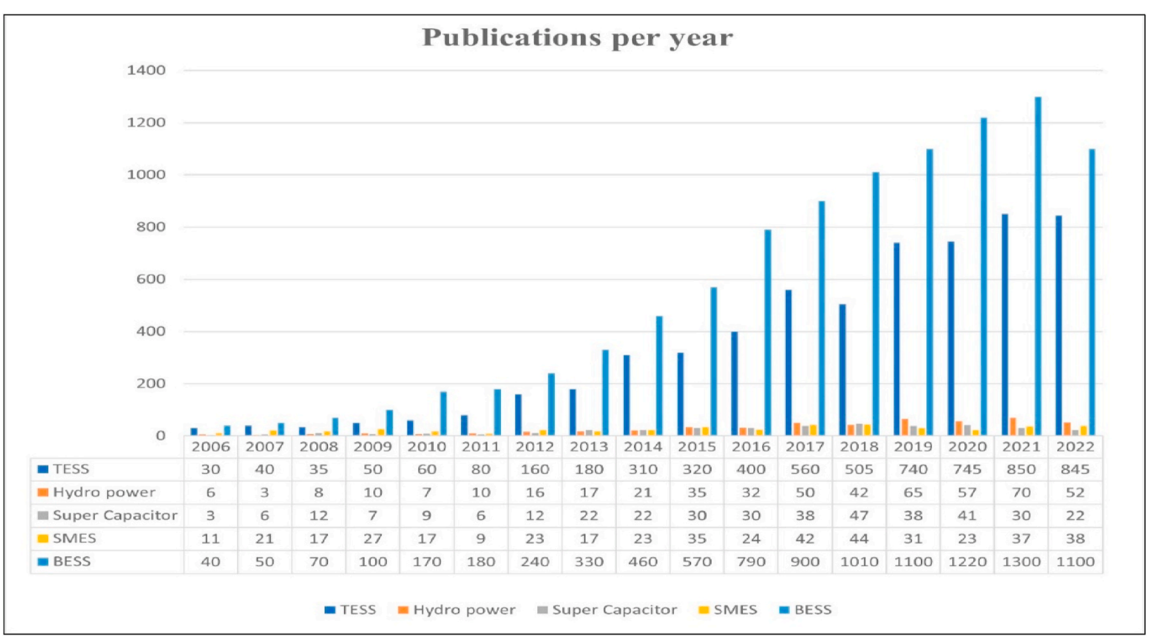


Fig. 8. Number of articles reviewing battery energy storage system BESS over the last 17 years.



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
TESS	30	40	35	50	60	80	160	180	310	320	400	560	505	740	745	850	845
Hydro power	6	3	8	10	7	10	16	17	21	35	32	50	42	65	57	70	52
Super Capacitor	3	6	12	7	9	6	12	22	22	30	30	38	47	38	41	30	22
SMES	11	21	17	27	17	9	23	17	23	35	24	42	44	31	23	37	38
BESS	40	50	70	100	170	180	240	330	460	570	790	900	1010	1100	1220	1300	1100

Fig. 9. survey of ess growth technology over the last 17 years.

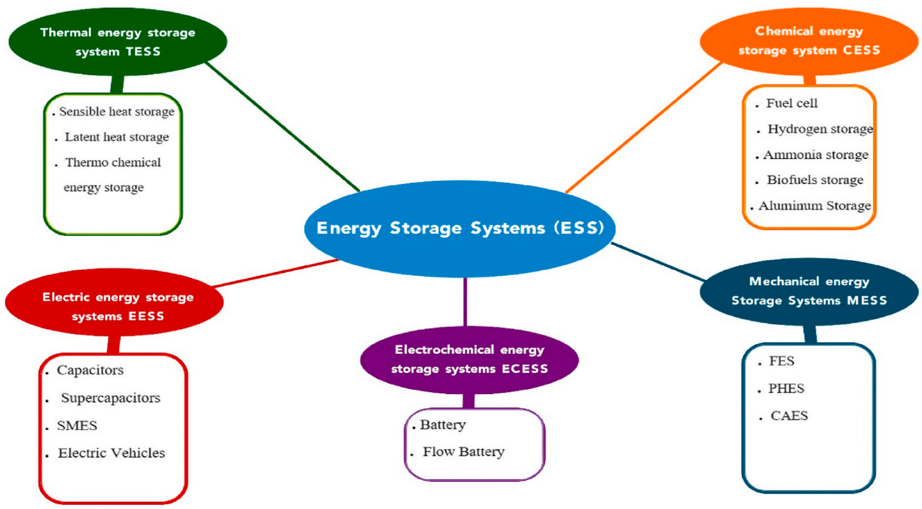


Fig. 10. Classification of energy storage technologies.

2.1. Electric energy storage systems (EESS)

It can be categorized to electrostatic and magnetic systems. The capacitor and the supercapacitor are electrostatic systems while the SMESS is a magnetic system [9].

2.1.1. Capacitors (Cs)

Two metal plates called electrodes separated by dielectric layer form the electric capacitor. One plate is charged while the other plate is induced by an opposite sign charge [19]. The energy is stored on the surface of the metal electrodes. This type storeenergy for extremely short periods [12]. Fig. 11 shows a schematic diagram for a capacitor. Plates size the distance between plates and the dielectric material are the factors affecting the capacitor energy capacity [14]. The capacitors are suitable for small scale power applications as they have an instant recharge capabilities and long lift cycle. For large scale applications, it will be very expensive [7].

2.1.2. Supercapacitors (SCs)

To conquer the problems mentioned above of the capacitors, the supercapacitors or ultracapacitors are patented by the Japanese company Nippon Electric Company in 1975 [20]. Compared with conventional capacitors, supercapacitors have very high output power of (50–100 KW), high charge density, life likelihood of 12 years, 500,000 times life cycle and high self-discharge [15]. Therefore, SC are suitable for application which required instant high output power like engine cranking applications of hybrid vehicles and permanent magnet synchronous generator. SCs and Cs have identical operating principles. Despite, in SC, electrolytic physical barrier comprising of activated carbon is used as a dielectric which allows ionic conduction, and this assists the SC to have large specific area and so high energy density [21]. The other difference is in the electrode materials, SCs use carbon nano

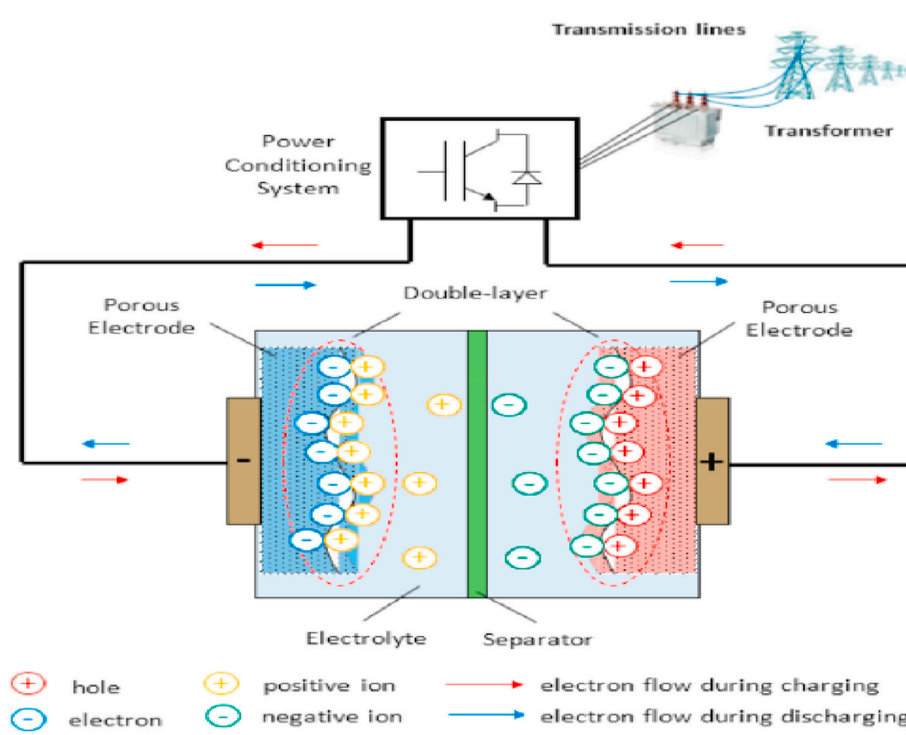


Fig. 11. Schematic diagram for a capacitor [11].

tube electrode which provide a tiny splitting up distance and a huge amount of charge is absorbed and hence improving the energy density [21]. Applying the electric field, the electrolyte performs as a dielectric and an ion absorption layer is generated on the activated carbon fibers [21]. The charging and discharging occur on this ion absorption layer. The schematic of supercapacitor is represented in Fig. 12. Many papers have been published about SC applications and to upgrade its control strategy.

2.1.3. Superconducting magnetic energy storage (SMES)

SMES can be made up of a superconducting coil which has no electrical resistance near absolute zero temperature that can store electric energy in the form of magnetic field created by DC current passing through it and there is no energy loss in the coil. The second part of SMES is cryogenically cooled refrigerator which keep the coil at a cryogenic temperature by utilizing liquid helium or nitrogen and therefore there is some energy losses (about 2–3% of energy) is lost related with cooling system [2]. The third part of SMES is a power conditioning system to convert the stored energy to an AC power [9]. The coils temperature must be below its critical temperature. The schematic diagram of a SMES is shown in Fig. 13.

SMES has very long lifespans (30 years), cycle life, high efficiency (95–98 %), short time for complete discharge (less than 1 min), fast response speed, very low power loss, high power density, and very high discharge rates [16,17,22,23]. During discharging, the SMES can provide huge amount of energy to the grid during a break of a second (milliseconds) [12].

The major drawbacks of SMES units are the performance problems due to the strong magnetic field, high cooling demand, high-priced raw materials, complex design, high capital cost ($104/kWh), high self-discharge rate (10–15 %/day), temperature sensitivity and pricy in operation [24,25].

Current curiosity in SMES is because of the capability to operate microgrids on the residential and utility scale [27]. The research fields of SMES are mainly focused on reducing the cost of superconducting coils and liquid nitrogen cooling systems; and developing high-temperature superconducting coil (HTS) materials with lower low-temperature sensitivity (working at around 70 K) and capital cost [18,44]. SMES applications include load leveling, system stability, voltage stability, frequency regulation, transmission capability enhancement, power quality improvement, automatic generation control, and uninterruptible power supplies [2,28].Accordinr to Refs. [7,9,29], and [30], Table 2 has been derived including different characteristics of EES devices.

2.1.4. Electric vehicles (EVs)

Electric vehicles use electric energy to drive a vehicle and to operate electrical appliances in the vehicle [31]. The spread of electric vehicles, commonly known as zero-emissions vehicles, will gradually replace older fuel vehicles and enormously reduce greenhouse gas emissions [18]. There are many technologies that can be utilized in EV such as SC, batteries, FC, or hybrid ESS [32] as shown in Fig. 14. EV can be categorized in to hybrid EVs (HEV), battery powered EVs (BEV), plug-in hybrid EVs (PEV), photovoltaic EVs (PEV), and fuel cell EVs (FCEV) [33]. The major barriers of EVs are that the charging is not fast enough and charging facilities are not highly accessible in most cities and the cost is disproportionate, roughly 1/3 of the cost of EV is employed for the ESS technology on the car [18]. Table .3 summeriezes the characteristics of different types of EVs.

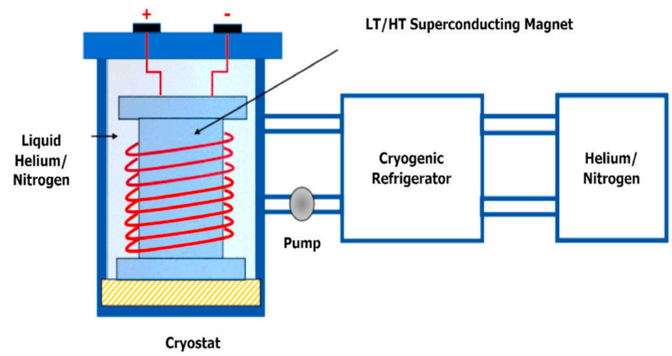


Fig. 13. Superconducting magnetic energy storage [26].

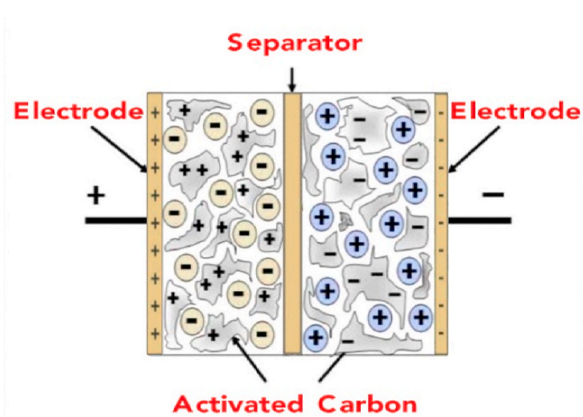


Fig. 12. Schematic diagram of an individual cell of a SC.

2.1.4.1. Battery electric vehicle (BEV). BEV or "pure electric vehicles" as there is no fuel tank and the electricity is totally served by the battery [34]. It is comprised of a huge rechargeable battery. This battery is charged from the grid or any external source using a charging plug [36]. BEVs charging takes roughly 6–8 h for slow charging and 20–40 min with a fast charger [37]. For the fully charged battery, BEV tracks 100 km–250 km distance [38]. BEVs are appropriate for short distances. Battery temperature affects the performance of the battery and life cycle [39]. The BEV storage capacity is above 100 kWh [35]. Due to this substantial reserve capacity, it is used for minimizing renewable energy fluctuations and stabilizing the voltage and frequency of the grid [40]. The illustrative structure of BEV is presented in Fig. 15. The improved version of BEV such as HEV and PHEV are discussed to increase the covered distances.

2.1.4.2. Hybrid electric vehicle (HEV). HEV is a combination of two or more types of energy and power sources. Power source like battery, fuel cell FC, SC, internal combustion engine (ICE), and energy source like battery, FES, or regenerative braking [34] are used for combining the profits of ICEVs and EVs [41]. Available hybrid powertrain configurations have been described, categorized, and totally analyzed in previous literature reviews [42–44]. Energy management strategy (EMS), which copes with the power distribution between power sources according their own control guidelines, has been significantly studied with different objectives like fuel usage minimization [45,46] emission diminishing [47], and battery lifetime [48]. The profit of HEV is that when the primary fuel (diesel, gasoline) storage tank runs out of during driving the ICE then the secondary source will operate as a backup system to the driveline with its maximum range [49].

2.1.4.3. Plug-in hybrid electric vehicle (PEV). The PEV is a form of HEV in which the battery is charged from an external source. PEV can run on both battery and gasoline. These batteries can be charged at a charging station or at home using an ordinary plug or by a regenerative braking system [34]. For short distances, it uses battery banks and for long distances, it utilizes gasoline power when battery power is depleted [50]. Because of decreasing moving parts of PEV, it has lower maintenance cost. The typical configuration of PEV is presented in Fig. 16. There are two ways of working of PEV. The first one is grid to the vehicle

Table 2
Characteristics of different EES devices.

EESS	Capacity (MW)	Lifetime (Years)	Capital cost (€/kWh)	Strength	Weakness	Use in RE Systems
Capacitor	0.05	5	897	High power density	Small capacity	No use
Supercapacitor	0.3	20	1795	- High charge -Discharge efficiency (95 %) -Fast response -High efficiency -Long lifetime	-Low voltage -High self-discharge rate -High capital cost	Wind parks
SMES	0.1–10	20	8974	-High cycles of charging- discharging -High power density -Fast response -High efficiency	-High cost -High self-discharge rate -High capital cost	Wind parks

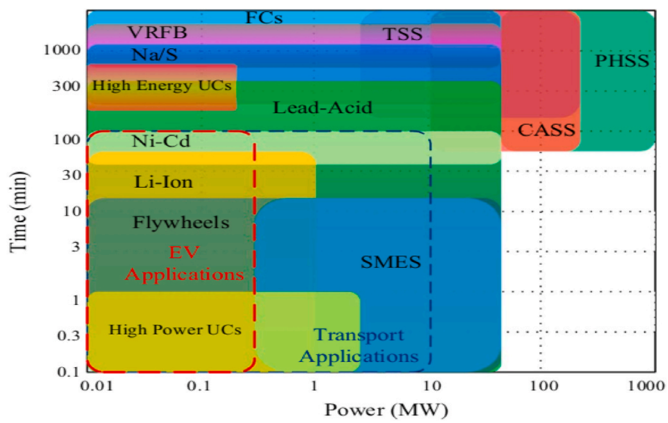


Fig. 14. Suitable technologies for EV [32].

Table 3
The characteristics of different types of EVs [34,35].

Characteristic	BEV	PHEV	FCEV
Energy system	-Battery -UC	-Battery -ICE -UC	-FC -Battery -UC
Energy source	-Charging power station	-Charging power station -Fuel pump -Gasoline	-Hydrogen fuel
Energy supply capacity	-Limited by battery -Capacity	-Limited by battery -capacity	-Unlimited
Carbon emissions	-Zero emissions	-Some emissions	-Zero emissions
Price factors	-Battery price -Market electricity -Price	-Battery price -Market electricity -Price -Gasoline price	-Battery price -Market electricity -Price - Fuel price
Advantage	-Zero emissions -Independence on fossil fuels	-Less emissions -Long-distance covered	-Zero emissions -High efficiency
Disadvantage	-High initial cost -Battery replacement	-Dependence on fossil fuels -Higher cost	-Hydrogen fuel storage -High cost of fuel
Degree of application	-Extensive use	-Being popularized	-Test stage

(G2V) whereby, the battery charges from the grid to drive the vehicle and charge the battery. The second one is the vehicle to grid (V2G) in which the battery provides power to the grid to overcome the grid overload problem [31]. In regenerative braking mode, the traction motor acts as a generator to charge the battery [51]. PEV can drive for a proper distance, but it has some drawbacks like its initial cost is higher than BEV and it produces more emissions than BEV. Owing to these reasons, BEV is obtaining more approval than PHEV [34].

2.1.4.4. EVs utilization as ESS. The market for electric vehicles (EVs) is growing quickly on a global scale. It is expected that market share will rise significantly in next few years [52]. Globally, there were more than 5 million electric vehicles (EVs) in use in 2018. It is anticipated that this number will increase rapidly to 44 million by 2030 [52]. The power system has traditionally struggled to balance generation and load demand; however, EV integration into the grid presents additional difficulties. The growing popularity of electric vehicles (EVs) presents substantial operational difficulties for the power grid since the patterns of EV charging and discharging need to be carefully controlled to maintain system stability and dependability. It is more difficult to balance the supply and demand of electricity when EV charging is dynamic and renewable energy sources are sporadic [53]. To solve these issues, numerous approaches and technologies are being developed, including as vehicle-to-grid (V2G) technology, smart charging infrastructure, and sophisticated grid management systems. These technologies allow for bidirectional power transfer between EVs and the grid, improve grid flexibility, and optimize EV charging and discharging patterns [54].

EV batteries have a fast reaction time, which makes them ideal for auxiliary functions like frequency regulation. EV batteries can play a significant role in preserving grid stability and balancing the frequency of the power system due to their quick response to variations in power supply or demand. This increases the potential value of EVs in sustaining the overall performance and dependability of the power grid and makes them a desirable alternative for providing auxiliary services [55]. To optimize EV integration benefits while preserving system stability, effective coordination between renewable energy generation, EV charging, and grid operations is essential. For EVs to be seamlessly integrated into the power grid, standards, incentives, and policies must be established in close coordination with automakers, energy providers, and regulatory agencies [56]. Some work contributions with several issues using EESS are tabulated in Table 4.

2.2. Electrochemical energy storage systems (ECESS)

ECESS converts chemical to electrical energy and vice versa [14]. ECESS are Lead acid, Nickel, Sodium –Sulfur, Lithium batteries and flow battery (FB) [9]. ECESS are considered a major competitor in energy storage applications as they need very little maintenance, have high efficiency of 70–80 %, have the greatest electrical energy storage (10 Wh/kg to 13 kW/kg) [15] and easy construction, [1]. However, there are some barriers high maintenance costs in large-scale facilities, their lifetime depend on depth-of-discharge (DoD) and relative low cycling times [9].

2.2.1. Lead acid batteries

The most heavily used rechargeable battery is the lead–acid battery [80]. They are composed of lead dioxide (PbO_2) as the positive electrode and lead dioxide (PbO_2) as the negative electrode immersed in an electrolyte mitigated solution of sulfuric acid (H_2SO_4) [81]. Lead–acid batteries have very tiny response time, little daily self-discharge rates, relatively high efficiencies, small capital costs, and can be stablished for

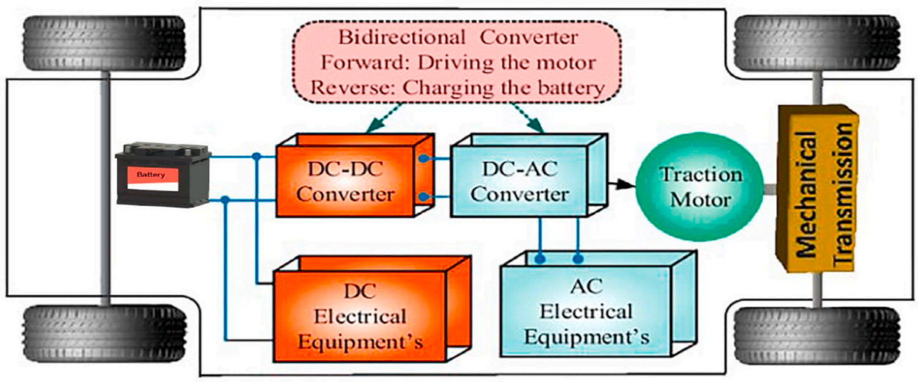


Fig. 15. typical structure of BEV.

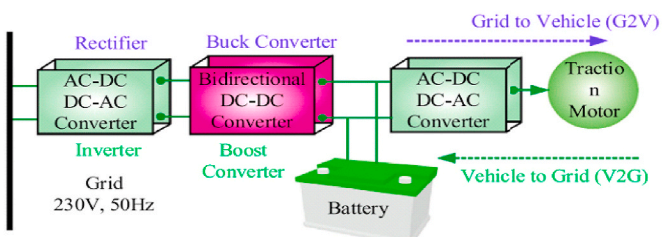


Fig. 16. Typical structure of PEV [31].

the large scale applications [82]. On the other hand, they have restricted life cycle, usually require a ventilation system, and charging and discharging process are not identical [83]. The schematic diagram for led acid batteries during charging and discharging is shown in Fig. 17.

2.2.2. Lithium-ion battery (Li-Ion battery)

This type of battery is very appropriate for portable applications such as laptops and mobile phones because of its low weight, good performance, fast response time, and high cycle effeciency. Also, It can also be used to improve the performance of EVs [12]. In a Li-Ion battery, the cathode is made of a lithium metal oxide, such as LiCoO2 and LiMO2, and the anode is made of graphitic carbon as shown in Fig. 18 [82]. The Li-Ion battery current research spotlights on using nanoscale materials for improving the power capability of the battery and heightening battery specific energy by progressing advanced electrode materials and electrolyte solutions [82].

2.2.3. Nickel - cadmium battery (NiCd)

These batteries are commercially used since about 1915. The two electrodes of these batteries are nickel hydroxide and metallic cadmium. The electrolyte is made of an aqueous alkali solution as presented in Fig. 19 [82]. NiCd batteries have low maintenance, relative high efficiencies, and the ability to work in a wide range of low temperatures (from $-20\ ^\circ C$ to $-40\ ^\circ C$). However, they can affect the environment as cadmium and nickel are toxic heavy metals, NiCd batteries cost is up to 10 times greater than the Li-ion batteries [85]. NiCd battery can be used for large energy storage for renewable energy systems. The efficiency of NieCd battery storage depends on the technology used during their production [12].

2.2.4. Sodium sulfur battery (NaS)

In the NaS battery, molten sodium and molten sulfur compose the two electrodes and uses beta alumina as the solid electrolyte. A scheme of a NaS battery cell is shown below in Fig. 20 [82]. This battery can supply high rated capacity than other types of batteries (up to 244.8 MWh). So, it is built for high power energy storage applications [86]. This storage system has many merits like there is no self-discharge, high energy densities (150–300 Wh/L), high energy efficiency (89–92 %), low maintenance and materials cost, non-toxic materials, and materials can be recycled [87]. NaS batteries used for grid connected applications like power quality enhancing and peak shaving [85]. However, the demerits are high operating cost (80 $/kW/year) to obtain liquid electrodes, and a high temperature (574–624 K) chemical reaction is required. So, an additional system is used which adds an extra cost and it is suitable only for large scale power system applications [85]. The research mainly focuses on improving the cell performance and decreasing the high temperature operating costs [1].

2.2.5. Flow batteries (FBs)

Flow battery consists of two liquid electrolytes which stored in two dissolvable redox couples enclosed in external tanks to increase the energy storage capacity [88]. These electrolytes can be pumped from the tanks to the cell stack, and they are separated by a microscopic membrane to allow a restricted ions number to pass over it. Through the electrolyte solutions reduction oxidation reactions, the electricity is produced [89]. The flow battery schematic diagram is shown in Fig. 21. Unlike the FC, the chemical reactions taking place inside the flow batteries are reversible. So, it can be recharged without replacing the electroactive material. The FB's power rating relies upon the stacks number of the cell and the electrode size [15]. FB can release huge amount of energy at a high discharge rate and has a good life cycle (10, 000 full cycles during their lifetime) [90]. FBs have tiny response time, have high efficiency, and operate near to the ambient temperature [85]. Evaluation of various battery technologies' parameters in a comparison is presented in Table 5. In addition to, some characteristics of every type from electrochemical energy storage systems ECESS including their strength and weakness issues are presented in Table 6.

It has been noticed from Table 7 above that there are plenty of papers that concerned with challenges and limitations of batteries (Li- io battery, Na–S battery and lead acid battery). Batteries can be used in different systems as grid connected or isolated systems providing the advantages of minimizing cost (total cost, maintenance cost or investment cost), preventing voltage fluctuation in LV distribution network, maximizing PV utilization and minimizing losses. There are various optimization techniques that can be used for catching these benefits.

2.3. Mechanical energy storage system (MESS)

MES is one of the oldest forms of energy that used for a lot of applications. It can be stored easily for long periods of time. It can be easily converted into and from other energy forms [15]. Three forms of MESs are drawn up, include pumped hydro storage, compressed air energy storage systems that store potential energy, and flywheel energy storage system which stores kinetic energy.

Table 4
Challenges and limitations of EESS.

Ref	Challenge	ESS Device	Isolated/Grid connected	Limitation	Contribution
[19]	Minimize operating cost (fuel + startup cost)	SMES	Islanded	Power quality is not improved	Using the modified LR-PSO method on IEEE 10-unit thermal bus system with and without SMES
[23]	Control SMES terminal voltage	SMES	Grid connected	Power quality is not improved	A new security circuit is proposed for highly inductive loads to ensure safe operation in case of fault.
[57]	Control of SC'SOC Minimizing Power loss	SC	Isolated	Cost is not considered	The strategy improved the reliability of the system and reduced the required communication data.
[58]	Control fluctuation of wind power	SC BESS	Grid connected	High cost	Design system composed of HESS to control wind power fluctuations by using fuzzy logic control.
[59]	Minimize cost Minimize fuel Minimize system efficiency	SC BESS	Isolated	Power quality is not improved	Design a HESS used for distributed generation system to meet the demand for a UK family and reduce the generator operating time.
[60]	Using SC to control high voltage ride through (HVRT) for wind turbine generation system.	SC	Grid connected	The overall power quality is unsatisfactory	Design a control system for wind turbine generator to control HVRT using SC.
[61]	Controlling system frequency.	SC	Grid connected	Cost is not considered	Using fuzzy logic control strategy for control frequency of DFIG, SC and wind farm system under variable wind speed.
[62]	- Control SOC of SC Minimize DC voltage fluctuation	SC	Isolated	Power quality is not improved.	EMS depends on using SOC of SC and DC voltage fluctuation as a reference to perform a double closed loop to control SC.
[63]	-Minimize DC voltage fluctuation. -Control SOC of SC.	SC	Isolated	Cost is not considered	Design a three-level bidirectional DC-DC converter to control the SC power flow. Using model predictive control to control the converter.
[64]	Optimal design of SMES system	SMES – BESS	Grid connected	Lack of ESS control	Design micro grid system with SMES integrated system of capacity 1.2 MW for a micro grid system
[65]	Reduce system cost	SMES	Grid connected	Power quality is not improved	Using an adaptive fractional-order sliding-mode control (AFOSMC) to improve the dynamic response of SMES against various operating conditions
[66]	Mitigate the fluctuations of PV output during a cloud passing.	SMES BESS	Grid connected	Cost and losses are not considered	Using HESS composed of high temperature superconducting coils based superconducting magnetic energy storage (HTS SMES) and battery for voltage control.
[44]	Voltage control of DC grids connected to wind farms	SMES	Grid connected	Cost is not considered	Design of SMES system. control system of SMES
[67]	Smoothing the output of the wind farms	SMES	Grid connected	losses are not taken into account.	Improving the wind farms transient stability using a control strategy of the SMES in parallel with voltage source inverter.
[68]	Improve the grid power quality	SMES	Grid connected	High system cost	Adding SMES in VSC based active filter for reducing THD.
[69]	Control the fluctuation of frequency due to transient load changes.	SMES	Isolated	Losses are not considered	Design the fuzzy PI controller for SMES.
[70]	Compensate voltage fluctuations for a grid connected hybrid renewable system	SMES BESS	Grid connected	Neglecting losses and cost.	Using battery and SMES based dynamic voltage resistor for compensating voltage fluctuations.
[71]	Smoothing output power for DFIG and PMSG.	SMES	Grid connected	Battery degradation is not considered	Usin transient voltage control (TVC) method to reduce the PCC'VD and enhances the overall system performance
[72]	Design a multistage SMES	SMES	Isolated	Cost is not considered.	Design a multistage SMES and study the system performance with the conventional SMES and multistage SMES.
[73]	Optimization the SMES coil dimensions	SMES	Isolated	Power quality is not improved	Using a multi- objective function GA to minimize the coil losses.
[74]	- Increasing system efficiency - Minimizing cost	SC BESS	Isolated	Battery degradation is not considered	Design a bidirectional DC_DC converter for HESS for EV and HEV.
[75]	Control SOC of SC banks	SC BESS	Isolated	Battery degradation is not taken into account	Design a new multi-source inverter MSI for integration SC and B for EV.
[76]	-Control SOC of SC -Minimize the system cost	SC BESS	Grid connected	Power quality is not improved	Dynamic wireless power transfer WPT system for charging EV.
[77]	-Minimize system cost -Control SOC of SC	SC Li-ion Battery	Grid connected		Optimal design of EV based HESS composed of Li-ion B and SC to minimize the system cost, improve power quality, and increase the overall efficiency.
[78]	Control current and voltage of the system.	SC BESS	Isolated	Cost is not considered	Control strategy for EV based on HESS composed of SC and B to control SOC of SC and prolong battery life.
[79]	Minimize battery current ripples and SC current fluctuation.	SC li-ion Battery	Isolated	Cost is not considered	Implementation fuzzy logic on EV based on HESS

2.3.1. *Flywheel energy storage (FES)*

FES was first developed by John A. Howell in 1983 for military applications [100]. It is composed of a massive rotating cylinder which is sustained over a stator and electric motor/generator is jointed with the flywheel. In FES, kinetic energy or rotational energy is transformed to electrical energy by using electric generator on the discharging mode and vice versa on the charging mode. Permanent magnet machines are commonly used for FESs because of their high efficiencies, high power densities, and low rotor losses [101]. The FES capacity is proportional to its mass and the square of speed [9]. Its efficiency relies on the energy storage usage time. FES is not suitable for storing energy on long-term basis so, it is combined with other devices [14]. The schematic diagram of FES is presented in Fig. 22. The flywheel is kept on a low pressure state to reduce the frictional losses [10]. FES can be used for load levelling and peak shaving and reducing the RES intermittencies by supplying real power to the system when necessary [102,103]. Because of FES fast response, it can be used for enhancing system stability for penetration RES in power systems [104]. Relied on rotational speed, the FES can be classified into two categories: low-speed FES (less than 6000 rpm) and high-speed FES (about $10^4 - 10^5$ rpm) [17,21]. The low speed FES is suitable for power reliability applications, and it has low cost. High speed FES is good for traction and aerospace applications and its cost is five times larger than low speed FES [10]. FES has many merits like high power and energy density, long lifetime and lower periodic

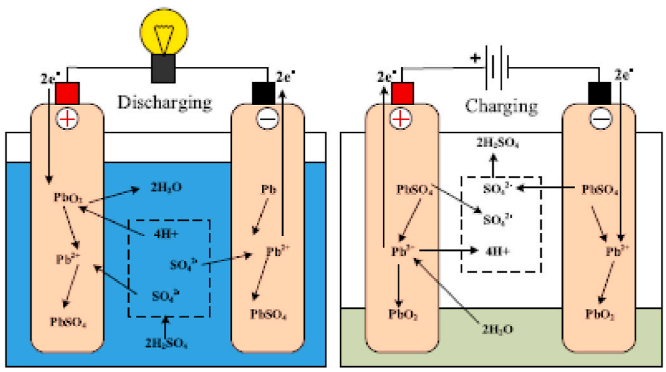


Fig. 17. Schematic diagram for lead acid batteries during charging and discharging [84].

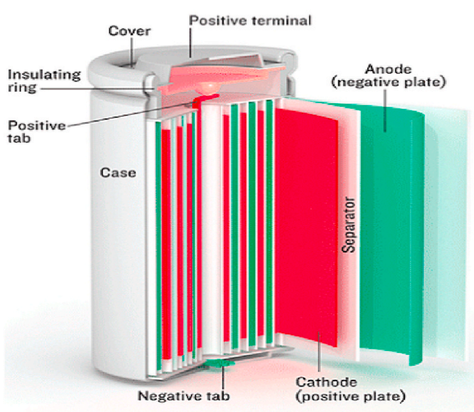


Fig. .18. Li-Ion batteries cell structure [82].

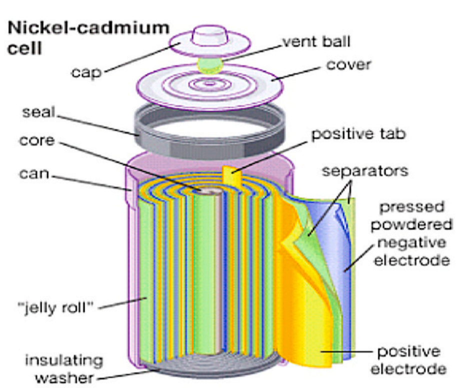


Fig. 19. Nickel–Cadmium cell [82].

maintenance, small recharge time, temperature insensitivity, 85%–90 % efficiency, high charging and discharging rate, large energy storage capacity, and clean energy. On the other hand, it has some demerits, small discharge time, intricate structure, mechanical stress, protection anxieties because of high rotor speed and breaking likelihood, and high cost [102].

2.3.2. Pump hydro energy storage (PHES)

PHES composed of two natural or manufacturing positioned/designed at higher and lower heights [14]. In Fig. 23, the components of PHES is presented which involve: upper reservoir, lower reservoir, motor, generator and inlet valve. When the electricity demand is low, the water is lifted from the inferior reservoir to the higher one and vise versa when the demand is high. The electricity is then generated from the stored water to supply power for momentary peaks or for unpredicted outages [12]. To produce a variable output power, the inlet water flow is controlled using gates and variable-speed drives can be utilized for regulation while charging [7]. PHES needs some conditions like, location existence besides difference in height [7]. PHES has many advantages such as long life time (40–60 years), fast response time, low cost, high efficiency, ability to store enormous amounts of energy, and very low self-discharge rate [103,105]. In contrast, it has some disadvantages such as it needs huge water source, massive environmental affect, and not much possible sites [103].

2.3.3. Compressed air energy storage (CAES)

CAES uses compressed and pressured air to store energy [106]. Compressor, underground storage unit, and turbine, are the main CAES components. The air is compressed and stored at a high pressure in an underground chamber and when needed, it expanded. The air is compressed while off peak and this stored energy is used during peak time. While peak time, the compressed air is fed to a combustion chamber which mixed with fuel to generate electricity [10]. The schematic of CAES plant is shown in Fig. 24. CAES and PHES are the available largest scale energy storage systems. Compared with PHES, CAES is smaller in size, its construction sites are more prevalent. So, it offers a large-scale widespread storage network [107]. It is more convenient for frequency regulation, energy arbitrage, and load levelling [15]. To enhance the CAES efficiency, the released heat from the compression stage, stored and used while expansion process and this improve the overall system efficiency by 10 %–15 % [12]. The CAES life cycle is approximately 40 years [103]. CAES has many merits like, it can store massive amount of energy, it has high efficiency 70 %, fast response, and low cost. On the other hand, it has some demerits such as, the need for enclosed storage cavern, economical for a storage period of up to one day only and not yet completely advanced [103]. The researchers focus on Liquid Air Energy Storage (LAES) as liquefied air is thick, so it is more convenient for long-term storage, Advanced Adiabatic CAES and Supercritical Compressed Air Energy Storage [108]. Some characteristics of different types of mechanical energy storage systems including their strength and weakness issues are tabulized in Table 8. Also, some papers that concerns with several issues using MESS is tabulized in Table 9.

Table 9 indicates the concerned challenges and limitations of MESS (PHES, CAES and FES). All types can be utilized for both grid connected and isolated systems. It can be concluded that all mentioned types can reduce cost and control system voltage. CAES can control both active and reactive power and the SOC. Also, PHES has the ability to smooth fluctuations of Photovoltaic Power and improve system reliability. Different optimization starategies have been applied to achieve these advantages.

2.4. Thermal energy storage systems (TESS)

Heat or cold is stored in TESS for later use. These systems consist of a heat storage tank, an energy transfer media, and a control system. Heat is stored in an insulated tank using a specific technology [12]. Utilizing these systems reduces energy consumption and overcome the problem of intermittency in renewable energy systems [82]. TESS has some advantages like, clean energy source for generating electricity, reducing heating or cooling energy demand for buildings, low initial cost, reducing emissions, increasing continuity, and reducing maintenance cost [85,121]. On the other hand, some concerns should be considered such as: increasing complexity, the overall efficiency for TESS is low (30–50 %), thermal losses, and the possible prescribed space [121]. A simplified TES diagram is presented in Fig. 25. TESS is mostly utilized for industrial, residential buildings for generating electricity besides producing water, and is often used in PV systems which guarantee collecting much amount of energy from the sun [10,12]. Thermal energy can be stored in the form of latent heat, sensible heat, and reversible

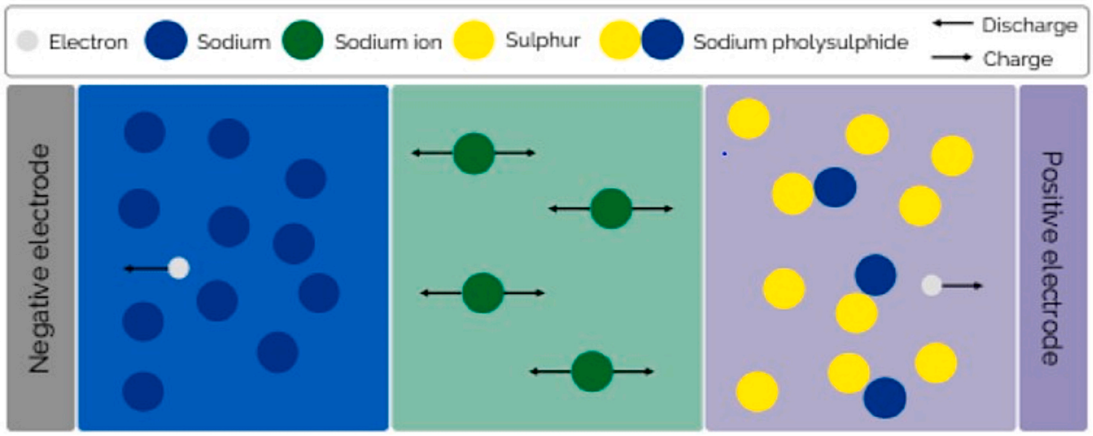


Fig. 20. Schematic diagram of NaS battery [82].

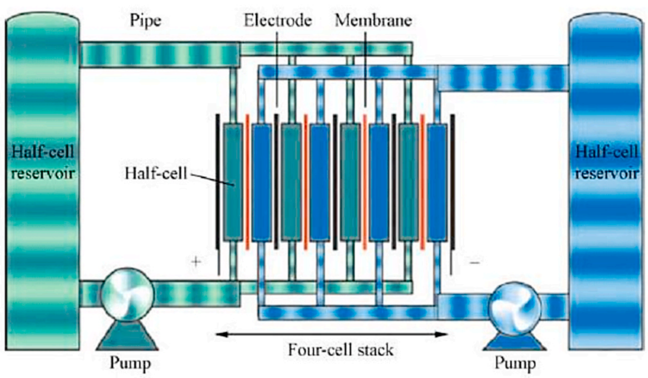


Fig. 21. Schematic diagram of flow battery [10].

Table 5
Comparison between parameters for different battery technologies.

Parameters	Lead-Acid battery	Li-Ion battery	Flow battery
Efficiency	75 %–80 %	80 %–86 %	60 %–70 %
Energy density	50 Wh/kg to 100 Wh/kg	200 Wh/kg to 350 Wh/kg	20 Wh/kg to 70 Wh/kg
Power density	10 W/kg to 500 W/kg	100 W/kg to 3500 W/kg	n. a
Life cycle	500 to 2000	1000 to 5000 cycles	>10000
Calendar life	5 years–15 years (depending on temperature and soc)	5 years–20 years (depending on temperature and soc	10 years–15 years
Depth of discharge	70 %	Up to 100 %	100 %
Self- discharge	0.1 % per day to 0.4 % per day	5 % per month	0.1–0.4 % per day
Power installation cost	150 €/kW to 200 €/kW	150 €/kW to 200 €/kW	1000 €/kW to 1500 €/kW
Energy installation cost	100 €/kWh to 250 €/kWh	300 €/kW to 800 €/kW	300 €/kW to 500 €/kW

thermochemical reactions [122].

2.4.1. Sensible heat storage systems (SHSS)

In SHSS, the heat is stored by increasing the medium temperature without transition its initial phase. The stored energy is proportional to material mass, the charging/discharging temperature change, and the specific heat capacity [17]. SHSS is the cheapest and simplest TESS. Materials used for this system can be divided into liquid and solid. Water

Table 6
Strength and weakness for electrochemical energy storage systems ECESS.

Storage type	strength	weakness	Use in RE systems
Lead-Acid battery	-Fast reaction speed -Low self-discharge rate -High cycle efficiency -Low capital cost	-Low energy density -Impact on the environment	Wind parks, PV
Li-Ion battery	-High energy density -Fast reaction speed -Low self-discharge rate -Long cycle life -High reliability	-Require working temperature -Need overcharge protection	Wind parks
NaS battery	-High energy density -Low self-discharge rate -Fast reaction speed -Nontoxic materials	-High internal resistance -Sodium corrosion -Additional system for high temperature heating	Wind parks
NiCd battery	-High energy density -Long cycle life -High reliability	-Environmental hazards -Affected by memory effect	Wind parks, PV
Flow battery	-Fast reaction speed	-Environmental issues -No large-scale application experience	Wind parks

is the most material used because of its low cost, availability, and high specific heat capacity [121]. Thermal oil and molten salt are utilized for high-temperature applications. Solid materials like: rocks, sands, gravel, wood, ceramics, and concrete [123] that are used for high-temperature applications although they have higher cost and lower energy density than liquid materials [121]. SHSS storage efficiency is (50%–90 %) [121].

2.4.2. Latent heat storage system (LHSS)

Thermal energy is stored in the form of latent heat when a substance undergoes a transitional phase and its state changes from one form to another. The most famous transition state is the change of the state of matter from a solid form to a liquid form [121]. Moreover, it can be changed from solid to liquid or liquid to gas and vice versa [4]. The used materials called phase change materials (PCM) [17]. Throughout the

Table 7
Challenges and limitations of batteries for different systems as ESS.

REF	Challenge	ESS Device	Isolated/ Grid connected	Limitation	Contribution
[91]	-Minimize cost	Battery	Grid connected	Power quality issue is unsatisfactory	Optimal allocating of the batteries in the distribution system with PV generation.
[92]	-Minimize cost	Lead acid battery	Grid connected	Power quality is not improved	Minimizing the total cost of the grid connected system. Optimal size, location of lead acid battery and optimal operation are studied.
[28]	-Minimize battery maintenance cost -Minimize losses	Battery	Grid connected	Optimal charge/ discharge of BESS is complicated	Optimal sizing a daily charge /discharge of BESS in LV distribution network with high PV penetration is studied.
[93]	-Minimize operational and investment cost	Li- io battery	Isolated	Trapping solver in local optima	Using a combination of self-adapted evolutionary strategy with Fischer–Burmeister algorithm to minimize the investment and operational cost for hybrid RE system.
[94]	-Minimize investment cost Minimize Energy error	Na–S battery	Isolated	Power quality is not improved	Using grey wolf optimization method for sizing electrical energy storage system in microgrids
[95]	-Minimize investment cost	Battery	Grid connected	Battery degradation is not considered	Optimization of BESS for different ownership structures in a peer-to-peer energy sharing community
[96]	-Sizing and allocation of battery banks -Optimal number and location of switching devices -Equipment cost	Battery	Grid connected	Power quality is not improved.	Using the Non-Dominated Sorting Genetic Algorithm II (NSGA-II) for optimal design for distributed networks using ES devices.
[97]	-Minimizing total cost	Battery	Grid connected	Lack of battery control algorithm	Preventing over and under voltage in radial LV distribution network.
[98]	-Maximize PV utilization -Minimize battery degradation	Battery	Grid connected	Complex computations	Using a combination of Model Predictive Control (MPC) strategy and Benders decomposition technique. Longer for planning distributed battery storage
[99]	-Minimize system cost	Battery	Isolated	Slow convergence	Using Cuckoo Search algorithm for optimal sizing of a remote hybrid renewable energy System. Comparing the results with GA and PSO.

material's phase change, the heat is stored or emanated, and the medium's temperature is constant. The material, during charging, absorbs heat and its temperature rises until its melting point [124]. At this point, the material absorbs heat to change its phase while its temperature stops rising. LHSS charging and discharging relies upon the utilized PCM melting and solidification [125]. PCM can be categorizes into organic and inorganic. Paraffin, fatty acid, esters, alcohols, glycols, and eutectics are deemed as organic PCM. Whilst salt hydrates, nitrate salts, carbonate salts, chlorine salts, sulfate salts, fluorine salts, hydroxides, metal, alloys, and salt eutectics are deemed as inorganic PCM [126]. LHSS has a storage efficiency of (75 %–90 %) and its capacity if 4 times larger than of a SHSS [127]. LHSS is more thermal behavior stable whilst charging and discharging processes than SHSS [128]. Nowadays, bio-based PCM is taking more interest as they are relied on renewable raw materials and they have lower flammability compared to paraffin [107]. LHSS research is mainly focused on the presenting new storage media and enhancing thermodynamic properties of the existing ones [129]. A new PCM is examined that it is fatty acid derivative of vegetable and animal oils [130].

2.4.3. Thermo chemical energy storage systems (TCESS)

In this type, the heat is not stored directly but utilizes a physicochemical process [14]. The heat is consumed during charging process and released during discharging [12]. Absorption and adsorption of energy is an example of physicochemical process [126]. Fig. 26 represents the working principles of a TCESS. During charging, a thermo chemical material *C* absorbs energy and gets separated to 2 materials *A* and *B*. This reaction is called endothermic. While discharging, the stored heat is released as the materials *A* and *B* pose initial material *C* and this is called exothermic [6]. The materials *A* and *B* are stored in separated

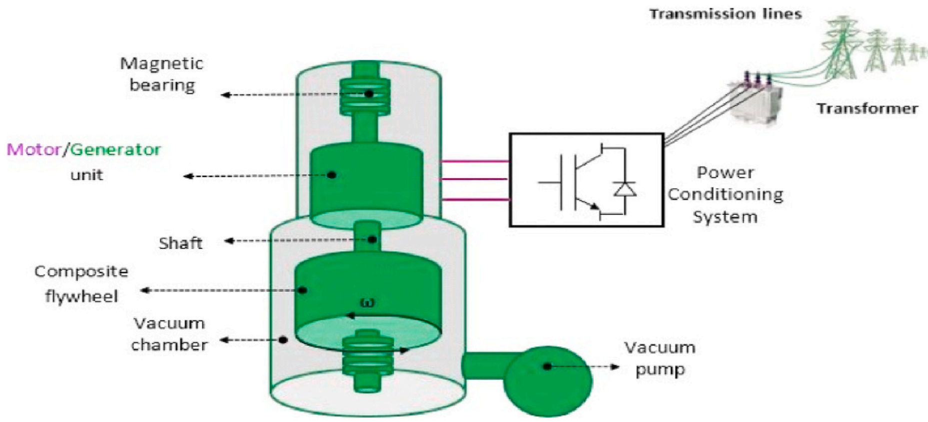


Fig. 22. Schematic diagram of flywheel energy storage system source [102].

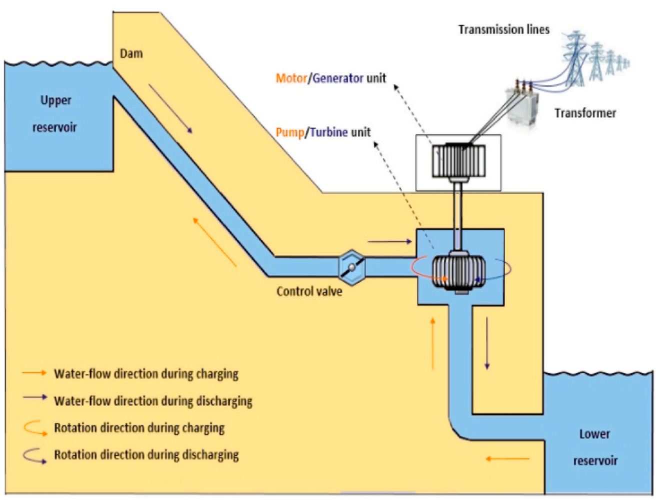


Fig. 23. Pumped hydro storage systems [12].

rooms, so, there is no self-discharging [9]. TCESS storage efficiency is (75%–99 %). TCESS has higher energy capacity than SHSS and LHSS and they are able to store energy for long periods with very low energy losses [126]. The strength and weakness of TESS and their use in RES systems are presented in Table 10. Also, some papers that concerns with several issues using TESS are tabulized in Table 11.

Table 11 presents challenges and limitations of TESS. All TESS can be used in different systems (grid connected or isolated systems) and it cab be integrated with other storage devices such as BESS. All types can improving the battery life cycle and reduce total system cost and CO_2 emission. LHSS can reduce energy loss.

2.5. Chemical energy storage systems (CESSs)

Chemical energy is put in storage in the chemical connections between atoms and molecules. This energy is released during chemical reactions and the old chemical bonds break and new ones are developed. And therefore the material's composition is changed [9]. Some CESS types are discussed below.

Table 8
Strength and weakness for mechanical energy storage systems.

	Strength	Weakness	Use in RE systems
Flywheel Energy Storage	-High energy density -Fast charging speed -Long lifetime -High cycle efficiency	-Low power density -High self-discharge -High cost -Heavy maintenance workload	Wind parks
Pumped hydro storage systems	-High capacity -Long lifetime -Low maintenance cost	-Large unit size -High capital cost -Terrain constrains -Centralized	Wind parks, hydro electrics
compressed air energy storage	-Long lifetime -Fast reaction speed -Environmentally friendly -High capacity -Low cost	-High requirements for geographical environment -Low round trip efficiency -Need underground cavities	Wind parks, hydro electrics

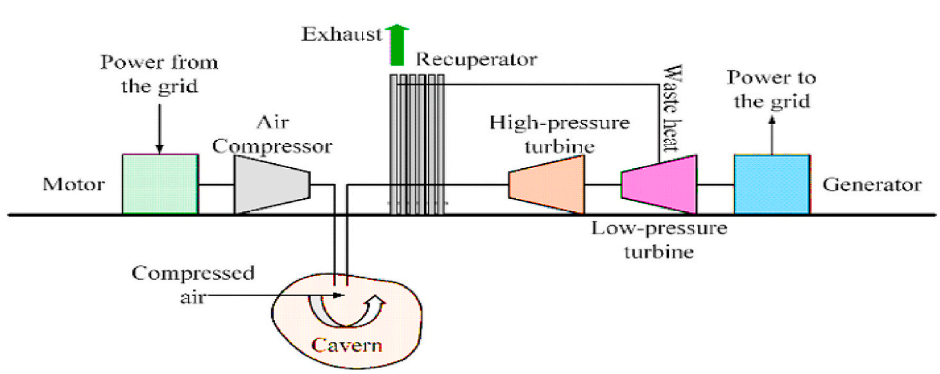


Fig. .24. Schematic diagram of (CAES) Plant [10].

Table 9
Challenges and limitations of MESS for different systems.

Ref	Challenge	ESS Device	Isolated/Grid connected	Limitation	Contribution
[109]	-Minimize cost Minimize losses	FES	Isolated	Power quality is not improved	Planning ESS with studying the effects of transmission losses and increased penetration of RE.
[110]	-Control DC link voltage Control FES speed	FES	Grid connected	PQ is unsatisfactory	Control of FES in case of Uncertainties using tube based MPC.
[111]	-Minimize cost Minimize losses	PHES	Grid connected	PQ is not improved	Using Multi-Objective Particle Swarm Optimization (MOPSO) to get the optimal size of standalone system and comparing the results of this method with GA, Simulated Annealing method (SA) and weighted sum approach (WSA).
[112]	Minimize cost	CAES	Isolated	Computational complexity	Using modified bacteria foraging algorithm to get the optimal configuration of HES based CAES and comparing the results with differential evolution.
[113]	Minimize the overall cost	CAES	Grid connected	Power quality is not improved	Using The Monte–Carlo simulation method to estimate the (electrical, thermal, gas load, wind turbine and electricity price) uncertainties. Considering P2G technology, along with the CAES system, reduce gas costs and the total operating cost of EHS and reduce the amount of electricity sold from the upstream network.
[114]	Control active power, reactive power, and SOC.	CAES	Grid connected	Cost is not considered	Implement a transient stability model of a system composed of two CAES. Studying the effects of cavern sizes on the system frequency
[115]	Minimize system cost	CAES	Isolated	Computational complexity	Using Monte Carlo simulation (MCS) to study the benefits of utilizing CAES for RES.
[116]	Control system voltage	PHES	Isolated	Cost is not considered	Generating a continuous power from PHES for a hybrid system consists of
[117]	Minimize cost	PHES	Isolated	Computational complexity	mixed-integer linear programming (MILP) for short term scheduling for WTHS
[118]	Smoothing Fluctuations of Photovoltaic Power	PHES	Grid connected	Cost is not considered	Using fuzzy CEEMDAN algorithm to calculate the target power combined system composed of cascade hydro stations, PV, and PHES.
[119]	-Minimize the integral of time multiplied absolute error (ITAE).	PHES BESS	Isolated	Degradation of BESS is not considered. Cost is not considered.	Using coyote-optimization algorithm (COA) to control MG system containing of wind, solar, biodiesel and a storage system composed of (mini-PHES and BESS) for getting a reliable system performance.
[120]	Cost reduction	PHES BESS	Isolated	Battery degradation is not considered	Using HOMER to perform comparative analysis for nine HRES.

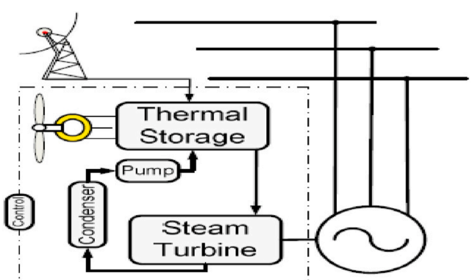


Fig. 25. TES simplified diagram [82].

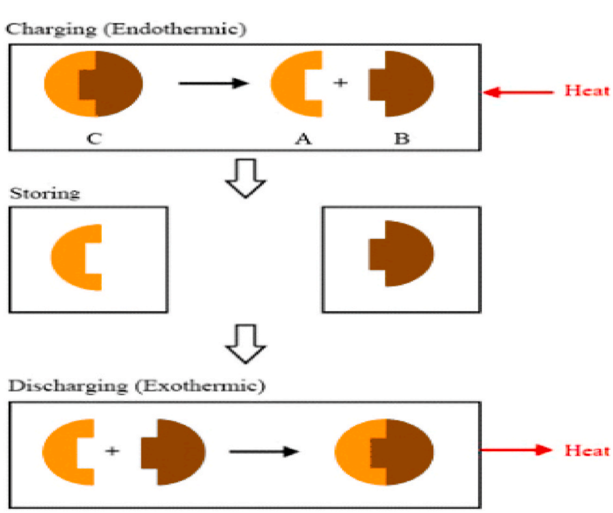


Fig. 26. Working principles of a TCESS [10].

Table 10
Strength – weakness of TESS and their use in RES systems [9].

TESS	strength	Weakness	Use in RES system
SHSS	-No toxic or expensive materials used -Many available materials -Low price	-Small energy density -High cycle efficiency -Energy density affected by the materials	Solar panels, geothermal
LHSS	-High energy density -Small range of temperature change	-Differentiation of PCM volume per cycle -High demand for PCMs	Solar panels, geothermal and PV
TCESS	-High efficiency -High energy density -Long term stable storage period -Low energy loss	-High manufacturing cost -Low efficiency -Poor heat transfer performance	No use

2.5.1. *Fuel cells FC*

Fuel cells receive an inflow of fuel from an external source and convert it into electrical output. This fuel can be (hydrogen, methanol, or hydrazine) or it can be obtained indirectly from converting (natural gas, ammonia, ethanol, or hydrocarbon gases) into a hydrogen. The anode is a hollow vessel lined with a layer of porous carbon on which hydrogen is pushed, and the cathode has the same composition as the anode and oxygen is pushed on it, where the porous carbon allows the contact of the anode and cathode with the electrolyte solution [68]. Hydrogen gas enters from the inlet in a very large amount and oxidation occurs at the barrier each atom loses an electron and turns into a positive ion. The electrolyte membrane allows the H^+ to flow from anode to cathode but does not permit the electrons flow electrons are released to the cathode using an external circuit where oxygen from air is supplied and reduction occurs. The unreacted oxygen is exited from the other side. The resulting water vapor is collected and condensed and used as drinking water in spacecraft [34]. The cell reactions are represented below in Fig. 27 [10].

$$\text{Anode} : H_2 \Rightarrow 2H^+ + 2e^-$$

Table 11
Challenges and limitations of TESS for different systems.

REF	Challenge	ESS Device	Isolated/ Grid connected	Limitation	contribution
[131]	Minimize energy loss.	LHSS	Isolated	Power quality is not considered.	Utilizing a cascaded latent thermal energy storage (CLTES) based on a control charging method to improve the charging and discharging thermal energy.
[132]	Improve the battery life cycle.	TESS with Li-ion battery	Isolated	Cost is not considered.	Introduced a HESS composed of TEES with Li-ion battery to solve the overheating problem and improve the battery life cycle.
[133]	Thermal management of li-ion bettery using Graphene -enhanced hybrid PCM	LHSS Li-ion battery	Isolated	Power quality is not considered	Using Graphene -enhanced hybrid PCM for solving the overheating problem for li-ion battery
[134]	Minimize total system cost	TESS	Isolated	Power quality is not considered.	Comparing operation strategies of two HTESS. The first one is composed of two tank TES and the other consists of packed bed TES
[135]	-Minimize CO_2 emission Minimize system cost	TESS	Isolated	Overall power quality is not improved	Using TES for increasing primary energy efficiency in industrial aspects and as a result minimizing the total cost.
[136]	-Finding optimal sizing Minimize levelized cost of energy.	TESS BESS	Isolated	Power quality is not improved	Using GA-PSO for finding the optimal sizing of a system composed of concentrated solar power, TES and battery.

$$\text{Cathode}: 2O_2 + 2H^+ + 2e^- \Rightarrow H_2O$$

$$\text{Overall}: H_2 + \frac{1}{2}O_2 \Rightarrow H_2O$$

FCs are categorized based on the used electrolyte. These are: alkaline FC, phosphoric acid FC, solid oxide FC, molten carbonate FC, proton exchange membrane FC (PEMFC), and direct methanol FC. Among all,

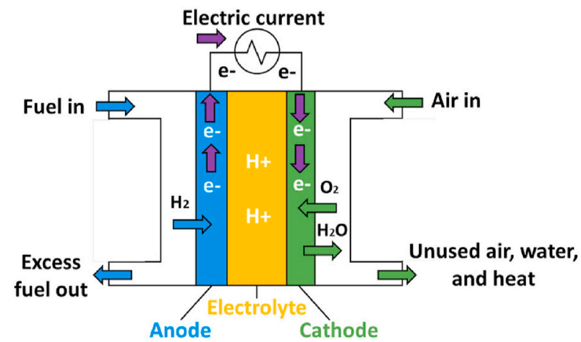


Fig. 27. The schematic diagram of the fuel cell [138].

alkaline FC has an efficiency of 60 % whereas the PEMFC delivers 58 % and molten carbonate gives 47 %. PEMFC is ideal for transport applications owing to its low operating temperature, quick start-up, and rapid load with low voltage and high current [137]. Most of the fuel cells currently in existence are in their early stages and are used in some limited applications such as aerospace and as a generation back-up in large scale grid [105].

2.5.2. Hydrogen storage

This technology is composed of an electrolyser to transform the electrical energy into hydrogen, a reservoir to store the produced hydrogen, and a conversion system like FC to convert the chemical energy to an electrical form. The produced hydrogen is stored, liquified or compressed. The chemical process of hydrogen production is shown in Fig. 28. The major merit of hydrogen is that there is no emission of harmful gases [1]. For renewable energy sources, the excess electricity is used for water electrolysis to split the water into its basic components (hydrogen and oxygen) then they are stored in tanks where hydrogen may be consumed in one of three ways [103]. Directly as a fuel: hydrogen can be transformed to electricity through a FC or combustion engine. As a feedstock: by chemical combination of hydrogen and carbon dioxide to produce synthetic natural gas ($2H_2 + CO_2 \Rightarrow CH_4 + O_2$) which can then be injected into natural gas pipelines. Blended with natural gas: hydrogen may be injected into some natural gas pipeline systems to supply infrastructures or end-use devices. Compared to the other energy storage technology, hydrogen technology cost is very low however, its efficiency is not very high So, it is suitable when the total amount of energy stored is more valuable than efficiency [139]. The different hydrogen storage mechanisms are as follows: liquid hydrogen storage, compressed and stored in a pressure tank, physical adsorption in carbon, complex compounds, and metal hydrides.A comparison of

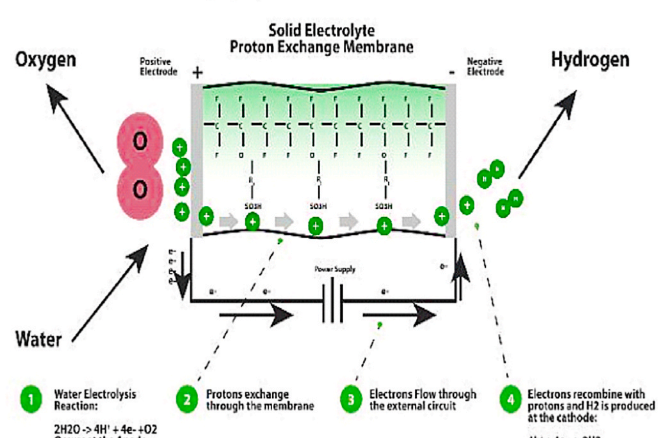


Fig. 28. Scheme of chemical process of hydrogen production [103].

hydrogen storage capacity is presented in Fig. 29 [1].

2.5.3. Ammonia storage

Ammonia can be easily stored in large quantities in liquid form, making it an ideal chemical store for renewable energy. The idea stems from the fact that there is excess energy during the night and can be used in the production of ammonia and then stored for use when needed. Storing hydrogen in large quantities is difficult and expensive, while ammonia is easier and cheaper to store and transport, and it can easily be cracked to provide hydrogen gas when needed and used in fuel cells [140].

2.5.4. Biofuels

Biofuels, are a eco-friendly, locally available, sustainable, and reliable fuel obtained from renewable sources [141]. Plants are a source of biofuels, as they work to trap sunlight in the form of chemical energy inside them through the process of photosynthesis, and this energy can be used to suitable forms and used for energy needs. Biofuels provide 3 % of the world's transportation fuel. Biofuels are in the form of liquid or gaseous fuels that are produced from biomass by chemical, thermal, or biological processes. Liquid fuels, like, ethanol, methanol, biodiesel, and gaseous fuels, like hydrogen and methane [141]. Liquid biofuels can be utilized in transportation, engines, or fuel cells to generate electricity. The USA, Brazil, Germany, Argentina, and China are the leading countries in the production of biofuels in the world, where they produced together 80.2 % of the world biofuel production in 2018 [96].

2.5.5. Aluminum energy storage

Aluminum is inexpensive and abundant, as it is the third most abundant element on earth. Excess electricity from renewable energy sources is used to produce the first aluminum using corundum. Solid aluminum can be stored and transported easily and used when needed without safety concerns. Upon discharge, the aluminum first oxidizes, producing hydrogen, heat, and aluminum oxide. These by-products can be used as sources of energy [142]. Several papers that concern with several issues using chemical energy storage systems are tabulized in Table 12.

Table 12 indicates It has been noticed challenges and limitations of CESS. It can be used in different systems (grid connected or isolated systems) and cab be integrated with other storage devices such as BESS. All types have the potential in minimizing cost, reducing CO_2 emission, increasing the battery life time, minimizing losses, improving system reliability.

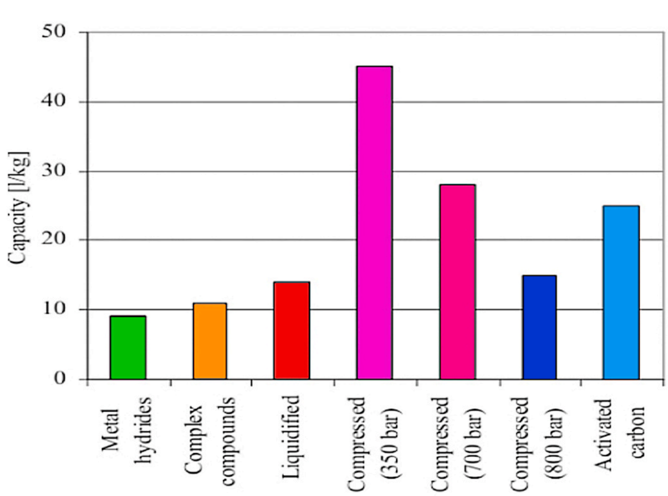


Fig. 29. Comparison of hydrogen storage capacity [1].

3. Hybrid energy storage system (HESS)

HESS is made by integrating more than one type of energy storage systems. It has a great importance, as renewable energy sources have intermittent characteristics in energy production and it is difficult for a single energy storage system to meet the energy requirements of a particular consumer [7]. ESSs can work in either of two modes: high-power mode and high-energy mode. High-power ESSs like (flywheel ES, SMES, SCES, BESS, etc.), respond fast (few seconds to a few minutes) and has high power density. They can used for voltage stabilization and improve the power system dynamic response. On the other hand, they have high self-discharge rate and high cost per unit capacity so, they are not appropriate for large capacity and long-term storage [150]. While high-energy ESSs such as (PHS, CAES, fuel cells, BESS, etc.) respond slowly, and they have high energy density so, they can used for long-term energy systems. Their demerits are that they have a short cycle life, cannot be charged and discharged rapidly, and are not suitable for real-time scenarios requiring dynamic compensation [151]. Both modes are used for a single HESS application. HESS may improved performances, enhanced efficiency, increased life expectancy, and lessened costs [152]. HESSs can be used in several applications, such as in hybrid electric vehicles, fuel-cell-powered electric vehicles, renewable energy supply systems utilizing battery/hydrogen combination, grid-tied HESS in local or provincial use, and large-scale wind and solar farms [151]. At present, HESS has come to be one of the hot investigated fields all over the world. Here are several typical HESS combinations.

3.1. Super capacitors and batteries

So many papers have been published for introducing using the combination of super capacitors and batteries for optimizing the performance of Electric Vehicle (EV). In Ref. [75] authors proposed a Muti Source Inverter for active control of energy storage systems in EV applications and a Space Vector Modulation technique and a deterministic State of Charge (SOC) controller are also introduced for control of the switching actions and the operation of the SC bank. The convenience of this configuration has checked out by MATLAB. The adaptation of the HESS containing SC and battery in the DC distribution network that can restrain DC voltage flicker and enhance the system stability, is presented in Ref. [153]. In Ref. [154], authors studied the use of bidirectional two-quadrant frontend dc–dc converter to control the energy flow between the Lithium-Ion battery bank and super capacitor (SC) bank. This model offers good dynamic performance and well-organized output voltage. Implementation of Fuzzy Logic control for EV using SC and Li-ion battery is presented in Ref. [79].

3.2. SMES and batteries

A study in Ref. [155] proposed the using of SMES and battery storage system to stabilize a photovoltaic based microgrid. A comparison, using MATLAB, between the system containing the SMES-battery and the system of battery only is carried out. The study proved that the SMES-battery is better in dealing with the microgrid transient faults and the it can reduce the fault current to avoid an unnecessary off-grid. In Ref. [66], the design of high temperature superconducting with the battery to form HESS is proposed. The paper showed that; this configuration can reduce the voltage fluctuation due to cloudy events and by using low resistance of high temperature superconducting cables, the voltage profile can be improved. Authors in Ref. [156] introduced the design and implementation of SMES-battery hybrid energy storage system in electric vehicle (EV). It used a novel nonlinear robust fractional-order control of SMES-battery to optimize the power demand. A case study is carried out to verify the effectiveness of this control strategy in improving the battery life cycle and compared with other control methods.

Table 12
Challenges and limitations of CESS for different systems.

REF	Challenge	ESS Device	Isolated/Grid connected	Limitation	contribution
[143]	-Minimize total life cycle cost Improve system reliability.	Hydrogen	Isolated	Power quality is not improved.	Optimal sizing of stand-alone system consists of PV, wind, and hydrogen storage.
[144]	Minimize life cycle cost	Hydrogen BESS	Isolated	Battery degradation is not considered.	Modelling and optimal design of HRES.The optimization results demonstrate that HRES with BESS offers more cost effective and reliable energy than HRES with hydrogen storage.
[145]	-Minimize total net present cost TNPC -Minimize loss of power supply probability (LPSP)	FC	Isolated		Multi-objective design of HESS composed of PV, FC and diesel generator to supply power for an off-grid community.
[146]	Improve system reliability -Minimize Loss of Power Supply Probability (LPSP), levelized Cost of Energy (LCOE) and Net Present Value (NPV). Minimize CO_2 emissions	FC BESS	Isolated	Computational complexity	Using multi objective PSO algorithm for optimal design of HRES.
[147]	Minimize Loss of Power Supply Probability (LPSP)	FC BESS	Isolated	Battery degradation is not considered	new real-time optimization algorithm based on Lyapunov optimization framework and novel queueing theory is proposed to optimal design the SMG with BSS.
[148]	Cost reduction Increase lifetime	FC BESS	Isolated	Power quality is not improved	experimental plat- form designed and constructed to test operation modes for hydrogen renewable power plants integrating HESS
[149]	Minimize net present value of the operation cost. Increase lifetime	Hydrogen BESS	Isolated	Power quality is not improved	Techno-economic optimization for HRES for off grid applications using Linear Programming.

3.3. Flywheel and batteries

In [157], authors provided a study of using a hybrid energy storage system combined of battery and flywheel to mitigate load fluctuations in electric ships. A typical prediction algorithm was developed for demonstrate the validation of this strategy. Authors in Ref. [158] proposed the installation of flywheel/battery HESS in a house on the island in Greece for supplying the house with loads and a financial accounts are made for analysis its economic feasibility. In Ref. [159], authors represented a residential Micro-Grid, consists of a photovoltaic plant integrated with a flywheel/battery HESS. A Matlab Simulink model (for AC and DC bus configurations) is developed. From the results, it is showed that the AC bus MG is the better in interfacing with the grid than the DC bus MG (peak current value is reduced by 58 % and transient time is 30 % shorter).

3.4. Compressed air and supercapacitor

In [160], aurhors introduced a HESS composed of CAES system and super capacitors SCs to improve the power quality of the power grid. A control strategy is developed for the system to track the 24 h power demand curve effectively. Authors in Ref. [161] proposed a CAES – SCs HESS to improve the voltage stability. Also, SCs can be used as a filter to smooth the power outputs.

3.5. Thermal energy storage and batteries

Authors in Ref. [132] introduced a HESS composed of thermal energy storage system TES with Li-ion battery to solve the overheating problem while using Li-ion battery only and improve the battery life cycle. In Ref. [133], authors examine HESS consists of TESS and batteries for heat handling battery management problem and reliability improvement the battery.

4. Challenges for integrating energy storage systems

Reliability and sustainability are the main aspects related to integrating ESSS to the modern power networks. However, this can be challenged. Hence, the next challenges should be considered for success integration of ESS [162].

4.1. Battery degradation

One of the main problems associated with batteries, is degradation problem. Owing to, rising in battery temperature because of the charging and discharging cycling and aging problem that affects the battery performance over the time. In Ref. [163], it is represented a control strategy to manage a BESS in a microgrid for enhancing the ESS life time based on battery SOC and maximum capacity. The overall BESS life span enhanced by 57 %.

4.2. Battery SOC effects on ESS

Energy storage systems' stability and performance are highly affected by the SOC. Some works have been studied these goals. A piecewise linear SOC controller has been created to stop BESS depletion before it reaches minimum levels for integrating SOC into low-inertia power systems' primary frequency control [164]. Furthermore, another research has looked into SOC balancing control in distributed battery systems. Researchers have used multi-agent consensus theory and dynamic event triggering coordination algorithms to efficiently accomplish SOC balance while consuming less communication [165]. Also, fractional-order modeling and Kalman filters improve estimation accuracy and dependability, demonstrating decreased errors compared to standard approaches under diverse working situations [166]. Accurate SOC estimation is also essential for supercapacitor functioning. All of these investigations indicate how SOC has a major impact on energy storage systems.

4.3. ESS sizing and allocation

The sizing and placement of energy storage systems (ESS) are critical factors in improving grid stability and power system performance. Numerous scholarly articles highlight the importance of the ideal ESS placement and sizing for various power grid applications, such as microgrids, distribution networks, generating, and transmission [167, 168]. Numerous crucial factors must be taken into account for Energy Storage System (ESS) sizing that is optimal. Market pricing, renewable imbalances, regulatory requirements, wind speed distribution, aggregate load, energy balance assessment, and the internal power production model are some of these factors [169]. An ideal ESS size that guarantees a steady supply of energy can be achieved by carefully taking into account all of these factors [170]. An ESS that is appropriately sized and distributed can save costs, improve the use of renewable energy, and help with frequency management, all of which improve grid dependability and lower operating costs [171]. To address the difficulties in ESS planning, design, and implementation, sophisticated approaches, algorithms, and optimization techniques are being created, opening the door for more research and innovation in this area [172,173]. In distribution networks with high Distributed Generation (DG) penetration, the placement of energy storage systems (ESSs) is critical to addressing controlling voltage and system losses. Numerous approaches have been put out to optimize the placement and sizing of energy storage systems (ESSs) [174]. In order to identify the most efficient ESS size and location, these optimization procedures frequently use multi-objective functions that take into consideration PV panel power, self-consumption schemes, and the direction of demand growth. Distribution networks may experience better overall system efficiency, decreased losses, and improved voltage management by carefully choosing where to install energy-storage sensors using multi-objective optimization models and thorough sensitivity indices [175]. In order to facilitate power allocation to various storage technologies inside the hybrid energy storage system HESS, a basic optimization approach for choosing a low-pass filter's cut-off frequency has been proposed in Ref. [168]. The features of storage technologies are greatly impacted by the optimal cut-off frequencies that are determined by the optimization framework. This highlights the significance of precise power allocation for efficient grid support functions.

4.4. *ESS financial feasibility*

Understanding the technical sides of ESS technology and its application's economic viability is essential to assure the technology practicality. However, ESS's economic studies were quite restricted, where most of them, only the system capital cost was covered. For a comprehensive technoeconomic analysis, should include system capital investment, operational cost, maintenance cost, and degradation loss. Table 13 presents some of the research papers accomplished to overcome challenges for integrating energy storage systems.

It can be conclded from Table 13 that there are various solutions to overcome challenges facing integrating energy storage devices in isolated or grid connected systems. Utilization of HESS (SC + fuel cell, SMES + battery, battery + SC, etc) and applying optimization technique for optimal allcation or sizing of each device will lead to reducing cost, expanding ESS life time, improving efficiency and minimizing battery degradation.

5. Choosing principles for energy storage systems

There are many factors for selecting the suitable energy storage devices such as [34,182]:

- Capacity: The system energy stored is determined based on the capacity
- Power: How quickly the stored energy discharged and charged is determined based on the power.
- Efficiency: It expresses the amount of energy lost during the storage period and during the charging/discharging cycle, as it is the ratio between the energy provided to the consumer to the energy required for charging.
- Storage period: Denotes how long the energy is stored.
- Charge and discharge time: Expresses the time for charging and discharging.
- Lifetime: Denotes the time to use energy storage equipment.
- Cost: Depends on the storage equipment capital and operating costs and its life span.

Selection the superlative ESS for different applications is essential. In applications that require fast response such as frequency modulation, reactive power support, smooth transmission, and power quality improvement where millisecond response time is vital. FES, SMES, SC, and some batteries are highly recommended. Besides they have high efficiency and long lifetime. However, they have small energy ratio. ESS based on energy storage with hourly level response time is needed for energy time shift and capacity unit applications. PHES and CAES can be used for these applications [183]. Lead-acid batteries are used in many applications such as UPS, power quality and frequency regulation due to their cost, reliability, and ripening of technology. In fact, the Li-ion battery has high efficiency and a large energy ratio, but its cost is high, therefore its use in power applications is limited [184]. The CESS and ECESS typically have greater efficiency but shorter response time. Moreover, MESS and TESS have longer discharge time and response speed. On the other hand, for the lifetime specification, the longer life span time, the lower replacement costs [1]. Table 14 represents the general characteristics for some of the above discussed ESS to help the reader for choosing the appropriate ESS for its application [185]. presented some indicators to facilitate decision-making/design of various storage technologies include storage capacity, maximum charge/discharge power, depth of charge, durability, cost, maximum self-discharge rate and storage weight.

From Tables 14 and it is apparent that the SC and SMES are convenient for small scale energy storage application. Besides, CAES is appropriate for larger scale of energy storage applications than FES. The

Table 13
Solutions for energy storage systems challenges.

Ref	Challenge	ESS Device	Isolated/Grid connected	Limitation	Contribution
[176]	Minimize energy cost	Battery –SC	Grid connected		Design of the battery degradation process based on the characterization of semi-empirical aging modelling and performance. Modelling of the dynamic behavior of SCs.
[177]	Minimize system cost	Battery Hydrogen storage	Isolated	Battery degradation is not included.	Four different practical case studies, i.e., an off-grid rural village, telecom tower, stand-alone welding shop, and a backup for lift load system are selected to demonstrate the proposed sizing methodology.
[178]	High cost Battery degradation	Battery Hydrogen storage	Isolated	Allocation is not concerned	Using evolutionary algorithms and mixed integer linear programming for sizing a MG containing PV panels, a BSS and HSS.
[179]	-Reduce system cost, improve efficiency	SMES - lead-acidbattery	Grid connected	Battery aging is not considered	The performance of the proposed system is applied on a residential PV system in case of load leveling and system efficiency.
[180]	Minimize energy cost	Hydrogen fuel cell - SC	Isolated	Battery aging is not taken into account	The allocation of supercapacitor enables to mitigate the draw of high power consumption, to avoid all fast charge/discharge cycles and consequently to minimize the number of used batteries.
[181]	-Expand ESS lifetime Minimize energy cost	Li-ion Battery – SC	Isolated		The study considers the SOC of both battery and SC to ensure long lifetime.

Table 14
General technical specifications of energy storage techniques [1,10,186,187].

Energy storage system	Power Rating	Discharge	Energy density Wh/kg	Energy cost €/KWh	Lifetime Efficiency
PHSS	100–4000 MW	1 hr–24 h	0.5–1.5	50–150	70–85 %
FES	0.002–20 MW	msec to 40 Min	5–130	1000–3500	90–95 %
CAES	50–300 MW	1he- 24 h	30–60	10–120	70–80 %
Ni-CD	0.001–0.1 MW	0.0003–1 h	40–60	200–1000	60–91 %
Li-ion	0.001–0.1 MW	0.0167–1 h	75–250	200–1800	85–100 %
Nas	0.5–50 MW	0.0003–2 h	150–240	200–900	85–90 %
Hydrogen	0.001–50 MW	14 hr- 24 h	800–10000	1–15	20–50 %
Supercapacitor	0.01–1 MW	msec to minute	0.1–15	300–4000	90-95^
SMES	10 kW-10MW	msec to seconds	0.5–5	700–7000	80–90 %

CAES and PHES are suitable for centered energy storage due to their high energy storage capacity. The battery and hydrogen energy storage systems are perfect for distributed energy storage. Presently batteries are the commonly used due to their scalability, versatility, cost-effectiveness, and their main role in EVs. But several research projects are under process for increasing the efficiency of hydrogen energy storage system for making hydrogen a dated future ESS.

6. Applications of energy storage systems

Energy storage is utilized for several applications like power peak shaving, renewable energy, improved building energy systems, and enhanced transportation. ESS can be classified based on its application [188].

6.1. General applications

There are many general applications for ESS such as solar water heating, solar air heating, solar cooking, solar greenhouses, space heating and cooling in buildings, off-peak electricity storage, and waste heat recovery [189]. Also, applications of FES are presented in Ref. [190], involve uses in a variety of industries and frequency regulation due to its advantages, including its high energy storage density, quick charging and discharging times, and extended service life.

6.2. Energy utilities

Energy storage posted at any of the five main subsystems in the electric power systems, i.e., generation, transmission, substations, distribution, and final consumers. Some of the applications of ESS include transmission system congestion decreasing, storing energy during off peaks for using during on peaks, voltage and frequency control, reparation for unpredictable emergencies like generation unit failure, and providing a real-time balance between generation and load [139]. Using ESSs in public utilities is a significant way to control the intermittent nature of RE sources like wind and solar power [191]. By reducing variations in the production of electricity, energy storage devices like batteries and SCs can offer a reliable and high-quality power source [192]. By facilitating improved demand management and adjusting for fluctuations in frequency and voltage on the grid, they also contribute to lower energy costs. Authors in Ref. [193] represented some of these applications such as increasing RE penetration, load leveling, frequency regulation, and offering operating reserve. In Ref. [194], authors discussed some of energy storage technologies used in grids and the requirements to decrease costs and enhance performance for these technologies to expand their market penetration. Some applications of ESS application are summerized in Table 15.

6.3. Renewable energy utilization

The greater the use of renewable energy sources, the greater the need of energy storage sources to store energy in off-peak times and use it at on-peak ones, in addition to the continuous intermittent in the renewable energy sources [7]. Authors in Ref. [197], recommended that ESS that are scalable, resilient, and minimal maintenance, such as, FES, SC, SMES and most batteries, may be appropriate for distributed renewable

Table 15
ESS applications [195,196].

ESS			Application requirements			PHS	CAES	BESS	FES	SC	SMES
Application			Power rating (MW)	Discharge durations (HRs)	Response time						
Electric supply		Supply system capacity	1–1000	4–6	Mins	✓	✓				
		Load leveling Peak shaving	10–1000	2–10	Mins	✓	✓	✓			
Additional survices		Load following	10–1000	2–4	Mins	✓	✓	✓			
		Spin and non spin reserves									
		Fast response spinning reserve	10–1000	1–2	<30 Sec	✓	✓	✓			
		Voltage and frequency regulation	1–1000	15-30 Min	Immediate			✓	✓		✓
		Black start	100–1000	1–6	Secs	✓	✓	✓			
Renewables integration		Renewable back up	0.0001–400	2–4	Mins	*	*	*			
		RE grid integration (brief duration) Fluctuation decreasing	0.2–400	10-15 Sec	Secs -Mins		*	*	*	*	*
Grid system	Transimission	Transimission congestion reassurance	0.25–400	2–6	Mins	*	*	*			
	Distribution	Reduce outage frequency UPS	0.002–10	4–10	Secs- Mins			*	*		
		Voltage support	10–100	>15 Min	<1/4 cycle	*		*	*	*	*
Customers	End user	Enhance power reliability	0.002–10	2-5 Min	<1/4 cycle			*	*	*	
		Enhance power quality	0.002–10	10-15 Sec	<1/4 cycle			*	*	*	*

energy. Technologies that combine a solar energy source with ES are reviewed in many papers [198,199]. [101,200] recommended that FES are favorable devices for combination with wind and PV systems unlike to BESS as they are fast response.

6.4. Buildings and communities

Energy storage is used to facilitate the integration of renewable energy in buildings and to provide a variable load for the consumer. TESS is a reasonably commonly used for buildings and communities to when connected with the heating and cooling systems. Wide research is represented on storage materials, latest developments, conditions and performance, and restrictions for buildings uses [201,202], and [203]. In Ref. [204], authors indicated that the use of FES in buildings with installed solar PV panels greatly lowers system costs. Zero Energy Buildings (ZEBs) has gained a lot of attention over the past decade. TESS is a appealing option for the ZEBs improvement by decreasing the energy utilization of the buildings, enhancing system efficiency, and lowering the peak load [123].

6.5. Transportation

There are many requests for ESS that used in EVs such as, high power density, fast discharge, specifically when accelerating, extreme efficiency, easy control and regenerative braking capacity [7]. The highly used primary ESS in EVs are batteries. On the other hand, SC has high power densities than battery. So, a combination between Battery and SC for EVs can improve the performance for EVs, aircraft, and ships [188]. FES has also been applied for extended time in transportation systems [101]. It can deal well with unpredictable power consumption as it has high power density and it can be used as the main source of energy for propulsion [200]. Various constrains occur when using Li-ion batteries for transportation. in Ref. [205], recommended some methods for enhancing Li-ion batteries for EVs such as the use of organic instead of inorganic ones.

6.6. Applications of hybrid energy storage systems

The ability of hybrid energy storage systems (HESS) to integrate multiple storage technologies and provide high-energy and high-power densities makes them useful in a variety of sectors [30]. When it comes to electric vehicles, HESS is essential because it supplies the power and energy density required for performance and acceleration, going beyond what can be achieved with one storage technology alone. Furthermore, by facilitating a more sustainable energy ecology, HESS plays a key role in improving the efficiency and stability of electrical grids with a high penetration of renewable energy sources [206]. Batteries-Supercapacitor HESS is being more widely used in domains such as microgrids, smart grids, energy systems, and renewable energy integration [207]. This is because of its effectiveness in efficiently controlling power and energy. Additionally, in order to meet decarbonization regulations and run on sustainable electrical energy, the marine industry is increasingly using Battery Energy Storage Systems (BESS) in hybrid propulsion vessels.

7. New trends in energy storage systems

There are many trends in ESS. Top topics of storage energy are electric vehicles, thermal energy storage, lithium sulfur batteries, methane production, hydrogen storage, geothermal heat pumps, lithium-ion batteries, microgrids and supercapacitors. Some of research directions of each topic and some published papers are also listed in Table 16. The energy storage technology is well covered in this review. The use of ESS is crucial for improving system stability, boosting penetration of renewable energy, and conserving energy. Electricity storage systems come in a variety of forms, such as mechanical, chemical, electrical, and electrochemical ones. In order to improve performance, increase life expectancy, and save costs, HESS is created by combining multiple ESS types. Different HESS combinations are available.

Table 16
New trends in energy storage systems.

Topic	Research directions	Some published papers
Electric Vehicles	Charging stations	[208,209]
	Vehicle to grid	[210,211]
	Vehicle routing	[212,213]
	Location problem	[214,215]
	Wireless chareging	[216,217]
	Plug-in hybrid vehicles	[218]
Thermal energy storage	Heat transfer enhancement	[219,220]
	Low-temperature thermal energy storage	[221–223]
	Phase Change Materials	[224,225]
	Melting process	[226,226,227]
	Latent Heat (horizontal LH, cascaded LH, and reverse LH)	[228–230]
Lithium Sulfur Batteries	High-performancelithium–sulfur batteries	[231–233] [234]
	Accelerating electrochemical reactions	[235]
	Alleviating the self-discharge	[236,237]
	Solid-state lithium-sulfur batteries	
Methane Production	C O_2 methanation	[238,239]
	Low-Temperature Methanation	[240,241]
Hydrogen Storage	Solid state hydrogen	[238,242,243]
	Liquid organic hydrogen	[244,245]
	Dehydrogenation	[246,247]
	Adding graphene on the hydrogen storage	[248–250]
Geothermal Heat Pumps	Modelling	[251]
	Performance Optimization	[252,253]
	Hybrid system based geothermal energy	[254–256]
Lithium-ion batteries	High performance of lithium-ion batteries	[257,258, 258–261]
Microgrids	MG integrating EV	[262]
	Management of ESS in MGs	[263]
	MG with hydrogen energy storage	[264]
	Frequency control of standalone MG	[265–267]
	Optimal scheduling of MGs based ESS	[268,269]
Supercapacitors	High-performance electrode material for SC	[270–272]

chemical, electrical, and electrochemical ones. In order to improve performance, increase life expectancy, and save costs, HESS is created by combining multiple ESS types. Different HESS combinations are available.

The energy storage technology is covered in this review. The use of ESS is crucial for improving system stability, boosting penetration of renewable energy, and conserving energy. Electricity storage systems come in a variety of forms, such as mechanical, chemical, electrical, and electrochemical ones. In order to improve performance, increase life expectancy, and save costs, HESS is created by combining multiple ESS types. Different HESS combinations are available.

Hybrid electric vehicles, fuel cell-powered electric vehicles, grid-tied HESS, large-scale wind and solar farms, and several other applications are just a few of the many uses for HESSs. This article discusses several challenges to integrating energy-storage systems, including battery deterioration, inefficient energy operation, ESS sizing and allocation, and financial feasibility. It is essential to choose the ESS that is most practical for each application. FES, SMES, SC, and certain batteries are strongly advised for applications requiring quick response, such as frequency modulation, reactive power support, seamless transmission, and power quality enhancement. On the other hand, hourly level response time applications like capacity unit and energy time shift can make use of PHES and CAES. Additionally, new developments in energy storage systems (ESS) such as geothermal heat pumps, microgrids, SCs, methane generation, thermal energy storage, lithium sulfur batteries, electric vehicles, and hydrogen storage are covered in this overview.Due to ESS's high prominence as a study area, there are numerous search directions listed for each topic.

8. Conclusion

The energy storage technology is well covered in this review. The use of ESS is crucial for improving system stability, boosting penetration of renewable energy, and conserving energy. Electricity storage systems come in a variety of forms, such as mechanical, chemical, electrical, and electrochemical ones. In order to improve performance, increase life expectancy, and save costs, HESS is created by combining multiple ESS types. Different HESS combinations are available.The energy storage technology is covered in this review. The use of ESS is crucial for improving system stability, boosting penetration of renewable energy, and conserving energy. Electricity storage systems (ESSs) come in a variety of forms, such as mechanical, chemical, electrical, and electrochemical ones. In order to improve performance, increase life expectancy, and save costs, HESS is created by combining multiple ESS types. Different HESS combinations are available.

Hybrid electric vehicles, fuel cell-powered electric vehicles, grid-tied HESS, large-scale wind and solar farms, and several other applications are just a few of the many uses for HESSs. This article discusses several challenges to integrating energy-storage systems, including battery deterioration, inefficient energy operation, ESS sizing and allocation, and financial feasibility. It is essential to choose the ESS that is most practical for each application. FES, SMES, SC, and certain batteries are strongly advised for applications requiring quick response, such as frequency modulation, reactive power support, seamless transmission, and power quality enhancement. On the other hand, hourly level response time applications like capacity unit and energy time shift can make use of PHES and CAES. Additionally, new developments in energy storage systems (ESS) such as geothermal heat pumps, microgrids, SCs, methane generation, thermal energy storage, lithium sulfur batteries, electric vehicles, and hydrogen storage are covered in this overview.Due to ESS's high prominence as a study area, there are numerous search directions listed for each topic.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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