Comparative Analysis on Various Types of Energy Storage Devices for Wind Power Generation

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Abstract. Specifically for wind and photovoltaic, energy Storage is well regarded as an important tool for renewable energy. Distributed generation could also give benefits, but the position and use of wind energy are almost reciprocal to the PV system. So the needs of energy storage devices are coming into account for enhancing the power generations. This chapter gives brief idea about the conventional and flow based battery system for energy storage in power system. Here various conventional battery system compared with flow battery system for maintaining the power stabilities and power quality. The objective for this study is to find the better energy storage device which can regulate both stability and efficiency of the renewable energy system. Basically wind energy battery storage systems are depicted here with their construction, operation and usability. This paper can be effective for the researchers to study and to implement the better energy storage device in the wind or solar system to regulate the power quality. A brief comparison was highlighted in the discussion section for better analysis.

1. Introduction
The most popular traditional energy storage used in wind grid integration systems is batteries. Unless followed by an electrical transformer to transform DC power to AC power and vice versa, DC power stored and used by batteries. Various types of batteries are available for various applications. Heavy duty, deep cycle batteries engineered for maximum durability and maximum span of life are needed for wind turbine grid integration applications so that they can be fully charged and discharged. The creation of a high charging rate and lighter batteries is still underway.\[1\][2] This is due to Europe's
generation overcapacity, which results in a limited price gap between electricity and does not have incentives to invest in energy storage for arbitrage purposes. [3] Furthermore, there are legislative impediments to the implementation of such programs. High network costs, a lack of a legal concept for storage facilities, ambiguous grid access conformity and efficiency criteria, and a lack of commercially available ancillary utility offerings are just a few of them. [4] Furthermore, there are knowledge differences in terms of co-located project technological capacities and limitations. Co-locating wind and storage systems may have a range of advantages: It has the potential to reduce the amount of power that is curtailed at periods of grid congestion or system volatility. [5][20] It may aid in the maintenance of generation schedules transmitted to system operators, eliminating imbalance charges and preventing fines for failing to meet system output commitments. [6][21] It can make it possible for wind power to provide a broader spectrum of ancillary resources, such as frequency containment reserve (FCR), increased reactive power provision, and even black start capability. [7][19] Storage can help wind farms lower ramp speeds and smooth out energy production in limited power systems with reliability problems. Using examples from main underway initiatives, this paper explores the future functionalities of co-located wind energy and storage projects. It draws on data from Wind Europe's online database of co-located projects, which was created with the intention of enhancing industry awareness. [8] Globally, about 400MW of co-located projects have been identified, with about three-quarters of them already operational. Finally, the paper provides a series of policy suggestions aimed at improving the market design for all storage initiatives, especially those that are co-located [2].

2. Wind Energy System

Energy conservation isn't a modern concept. Energy storage has been used for hundreds of years, but the key use is now energy arbitrage or energy time shift: storing power during less demand and injecting it back into the grid during maximum demand, usually on a normal period, to support the system's equilibrium. Since the electricity production mix in the past was almost entirely made up of fossil fuels, nuclear power, and hydropower, and generation instability was not a big concern, the need for energy storage was limited and economically unattractive. [9] The share of variable renewable energy supplies (VRES) in the energy mix grows, availability becomes more volatile and weather-dependent. As a result, by delivering services around the current electricity, capacity, and ancillary services sectors, energy storage could become more relevant. [10]

![Figure 1. Generation Share of Wind Power](image1.png)
![Figure 2. Wind Power Conversion Systems](image2.png)

It can also open up new opportunities and facilities. In recent years, this has been reflected in the rapid growth of battery technologies (particularly lithium-ion) for stationary energy systems. Energy storage systems contend with other forms of reliability and adequacy for today's utilities, such as demand side control, flexible generation, and power exchanges by interconnects. [11] Its success is therefore primarily determined by its cost structure, cost-cutting ability, and, most importantly, the configuration and organization of the energy market. [18] This paper examines the possible importance of energy storage devices for power grids, as well as whether they can be co-located with wind turbines to provide additional benefits. [3][12][22]
3. Electrical Energy Storage System

For storing energy in all of its ways, a wide variety of technologies are possible (electrochemically, mechanically, thermally and electrically). [4] There are other ways to convert electricity into other energy carriers, such as hydrogen, which can then be preserved as a gas, liquid, or even solid. The different developments are illustrated in Figure 3. [1][2]

![Block Diagram of Electrical Energy Storage System](image)

Figure 3. Block Diagram of Electrical Energy Storage System

Storage systems are being constructed using a range of technologies, each with its own set of performance characteristics that make it appropriate for specific grid services. Long discharge times (tens of hours) and high capacity are possible with established large-scale technologies like pumped hydro and compressed air energy storage. Innovative materials, such as low-cost membranes for flow batteries, sodium-based batteries, high-voltage capacitors, broad band gap materials, and power electronics systems, allow improved energy storage system costs, service life, reliability, and power density [13] [14]. Electrochemical batteries and flywheels, on the other hand, are based on lower-power applications or those with shorter discharge cycles (a few seconds to several hours). Switches, inverters, and controllers are examples of power electronics that enable electric power to be precisely and quickly regulated. [15][16].

4. Grid Energy Storage Technologies

The importance of energy storage is heavily influenced by the demands of the energy system. Smaller and independent electrical grids, for example, are heavily reliant on energy storage because it helps to manage supply and demand without depending on energy exchanges with other networks and can offer a wide variety of frequency management services to ensure grid reliability. Figure 4 depicts the different technologies, which are categorized according to their form, as well as the time of discharge and the region of functionality where they are most efficient [17][18].

![Various Technologies of Battery charging and discharging System](image)

Figure 4. Various Technologies of Battery charging and discharging System

![Battery Storage System with the Grid](image)

Figure 5. Battery Storage System with the Grid
However, because of specific geographical conditions and related environmental approvals, the scope for constructing a new PHS and CAES installation is minimal. The battery device embedded in the grid shown in Figure 5 below [2][5].

5. Conventional Battery System
There are three major battery types produced which function as traditional but large-scale batteries and have a long service life and low temperature capacity [1][2].

a. Lead-Acid (LA) Battery

Lead acid batteries can be used for various purposes, for long or short storage times of second to hour. Lead-acid batteries are of two types. The first is flooded platinum acid (FLA), that contains two plate electrodes submerged in a chemical mix, which generate a current due to a chemical reaction and the second is valve-regulated lead-acid batteries (VRLA). For its low cost, high responsiveness, low self-delivery rate and lighter weight, lead acid battery is the most common energy storage used in wind power storage systems. The most widely used types are wind and sun applications with these types of batteries seen below Figure 6, higher initial costs and shorter life but with less weight, less capacities and lower operating costs of 24. [1][3]

![Figure 6. Lead acid battery a) Charging b) Discharging c) Structure](image)

Batteries of plum acid have a brief life span and need to be replaced from time to time with short or long-term variance reimbursement.

b. Nickel-Cadmium (NiCd) Battery

A battery is composed of a nickel-oxy-oxydioxide-positive electrode and a nickel-splitting metallic-cadmium electrode. Potassium hydroxide is the electrolyte liquid. In Figure 7 (a), one battery is sealed and in Figure 7, the other batteries are vented. there are two kinds of NICD batteries (b). Sealed batteries are widely used with batteries not releasing gas until they burst, but ventilated batteries emit such gasses as they are discharged or overburdened quickly.

![Figure 7. Sealed nickel cadmium battery a) Internal Structure b) Working](image)
Even if the strong and dangerous Cadmium metal is comparatively inexpensive and has a number of disposal issues, it is suitable for applications in small wind turbines, compensating for shorter wind speed. In Figure 8 below you can see the operating configuration of the NiCd battery.

![Operational Diagram of NiCd Battery](image)

**Figure 8.** Sealed nickel cadmium battery working structure

c. **Sodium-Sulphur (NaS) Battery**

Sodium Sulphur batteries are an electrochemical cell composed of the negative electrode Sodium, with the positive electrode Sulfur and solid β-alumina as an electrolyte.

![NaS Battery Structure](image)

**Figure 9.** Sodium Sulphur NaS Battery structure

Chemical reactions occur during charge when the sodium ions move the electrolyte through a reaction in the positive electrode, to create the sodium polysulfide. The inner configuration of the battery is shown by Figure 9 above and Figure 10 illustrates how the NaS battery operates.

![NaS Battery Working Structure](image)

**Figure 10.** Sodium Sulphur NaS Battery Working structure

Reverse reaction is needed in order that the sodium polysulfide disappears and the sodium ions in the positive electrode become sodium, with the electrolyte maintaining a proper conductivity from 320°C to 340°C (340°C). NaS has a better energy density, a longer life and a lower service life cycle, depending on the depth of the output, from 2500 to 40000.

6. **Flow Batteries System**
Another type of battery energy storage device is known as flow battery energy storage (FBES) based on electrochemical power storage. These types of batteries have two electrodes submerged in an electrolyte that cause a chemical reaction to create a current. The charging ratio, the load depth and the terminology of the memory effect are the three main types of these kinds of batteries.

**a. Vanadium-Redox (VR) Battery**

The flow battery for Vanadium Redox (VR) consists of two reservoirs, cell stacks, and electrolyte pumping pumps as seen in Figure 11.

![Figure 11. Vanadium Redox flow battery working structure](image1)

![Figure 12. Vanadium Redox flow battery structure](image2)

Complete internal configuration and charge and discharging of the battery are seen in Figure 12. It has to be reliably manufactured and has low maintenance because the cell stacks can be built on site and only after the cycle ends must alter and the electrolyte lives forever. For a long and short period, VR batteries are a strong wind variability storage.

**b. Polysulphide-Bromide (PSB) Battery**

The battery arrangement of the PSB is the same as that of the VR battery.

![Figure 13. Polysulphide Bromide flow battery Design](image3)

![Figure 14. Working (Charging and Discharging) Polysulphide Bromide flow battery](image4)
The components are, as seen in Figure 13, a battery, electrolyte and controller pump systems. The mechanism of charging seen in figure 14 has to be reversed.

![Figure 15. Polysulphide Bromide flow battery working (a) Charging (b) Discharging)](image)

The battery discharge ratio is 1:1, it operates at less temperatures (20°C-40°C) and it is calculated that the life cycle is 2000 cycles depending on the use. The polysulfide flow battery process Bromide (charging and discharge) shows in Figure 15.

c. **Zinc-Bromine (ZnBr) Battery**

ZBB flow batteries are significantly different from VR and PSB flow batteries, but do not function in the same way as seen in Figure 16.

![Figure 16. Zinc Bromine flow battery structure](image)

![Figure 17. Zinc Bromine flow battery working structure](image)

Figure 17 demonstrates the working framework and Figure 18 illustrates Zinc Bromine's internal flow structure is shown.

![Figure 18. Zinc Bromine flow battery structure internal flow of electrons](image)
d. Super Capacitor Energy Storage (SCES) Battery

Two parallel metal plates are created by lithium-ion super condensers or high condensers; one is activated carbon coated, the other is lithium doped with carbon and insulator isolated design. The superconductor function form shown in Figure 19, the analytical style in Figure 20 and the SC forms shown in Figure 21 below.

![Figure 19. Super Capacitor Energy Storage (SCES) Battery Types](image1)

![Figure 20. Supercapattery Types and Analysis Design](image2)

![Figure 21. Supercapattery Types](image3)

The inner configuration of the super capacitors is shown in figure 22 below and figure 23 (a) The charging of the super condensers and the discharge of the super capacities. The internal functioning of the super condensers is shown in figure23 (b).

![Figure 22. Super Capacitor Energy Storage (SCES) Battery](image4)

![Figure 23. Super Capacitor Energy Storage (SCES) Battery (a) Charging and Discharging (b) Internal Operation](image5)

Furthermore, because of the deep discharge, super condensers are of limited deterioration without heat dissipation owing to their lack of heat and the production of dangerous substances. While super condensers have relatively low energy densities, the stability and fluctuation can be measured very well for a short period of time and up to 5000F. The Schematic representation of (a) the ELDC, (b) the pseudocapacitor (PC) and (c) the hybrid supercapacitor is shown in Figure 24.
**Figure 24.** Schematic representation of (a) electrical double-layer capacitor (EDLC), (b) pseudocapacitor (PC) and (c) hybrid supercapacitor (HSC) **Figure 25.** Overall graphical Representation of the Super Capacitors

The overall graphic representation of the super capacitors, demonstrating the density of energy and strength during battery charging and releases, is shown in Figure 25. The energies generated by wind turbines is also stored by ultra-condensers and batteries. It stores the energy used to store energy and to help the ramp-rate cap when needed for power shifts. This Super Capacitor Battery Storage Analysis Diagram is seen in Figure 26.

**Figure 26.** Super Capacitor Battery Storage Performance Analysis Diagram

**Figure 27.** Implementation of energy storage system in renewable power generations

Figure 27 shown below illustrates the implementation of energy storage system in renewable power generations. It is often used in energy storage after grid failure, since the electricity produced is lower than the wind power generated and is used to decouple the wind turbine from the grid side and the turbine side produces fluctuated power because voltage and it causes a frequency difference.

| Types of Battery                  | Net Power  | Charging/Discharging Efficiency | Storage Efficiency | Standby Efficiency | Net Efficiency | Losses         |
|-----------------------------------|------------|---------------------------------|--------------------|--------------------|-----------|----------------|
| Lead-Acid (LA)                    | 180W/kg    | 50 – 95%                        | 35–40%             | 80 – 90%           | 80 – 90%  | Minimum        |
| Nickel-Cadmium (NiCd)             | 150W/kg    | 70–90%                          | 40–60%             | 85 – 95%           | 90 – 95%  | Minimum        |
| Sodium -Sulphur (NaS)             | 150W/kg - 170W/kg | 75–95%                          | 45–65%             | 85 – 95%           | 90 – 95%  | Minimum        |
Vanadium Redox (VR) 150W/kg – 170W/kg 75–80% 40–60 % 85 – 95 % 90 – 95 % Minimum

Polysulphide Bromide (PSB) 150W/kg – 180W/kg 75–95% 50–75 % 85 – 95 % 90 – 95 % Less

Zinc-Bromine (ZnBr) 180W/kg - 180W/kg 75–95% 75–85 % 85 – 95 % 90 – 95 % Very Less

Super Capacitor Energy Storage (SCES) 180W/kg – 200W/kg 85–95% 80–90 % 85 – 95 % 90 – 95 % Negligible But Costly

The table 1 represented the Wind Generation Battery Storage Capacity with respect to its range of efficiency and standby power analysis.

7. Conclusion
This chapter gives a quick overview of the most recent energy storage methods to help large-scale wind penetration. That include pumped/hydroelectric energy storage (PHES), underground energy storage pumped/hydroelectric (UPHES), Compressed Air Energy Storage (CAES), battery energy storage (BES), Flow battery energy storage (FBES); Flight Wheel Energy Stockage (FES), super-capacitation energy storage (SCES). The objective for this study is to find the better energy storage device which can regulate both stability and efficiency of the renewable energy system. Basically wind energy battery storage systems are depicted here with their construction, operation and usability. This paper can be effective for the researchers to study and to implement the better energy storage device in the wind or solar system to regulate the power quality. A brief comparison was highlighted in the discussion section for better analysis.

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