Overview of Alternative Energy Storage Systems

K.A.L. Udayanga
Faculty of Computing and Technology, University of Kelaniya

Udara S.P.R. Arachchige
Faculty of Technology, University of Sri Jayewardenepura

Abstract — This article presents an overview of alternative energy storage systems in different energy systems. Alternative energy storage is a crucial factor in the integration of energy sources and plays a credible role in maintaining a modern electrical system. It can reduce power fluctuations, increase the flexibility of the power system, and store and transmit electricity generated by variable alternative energy sources. Various alternative energy storage technologies are used in electrical power systems. That can be categorized as chemical, electrochemical, mechanical, electrical or thermal. The alternative energy storage facility consists of a storage medium, a power conversion system, and a power plant balance. This overview report focuses on Redox flow battery, Flywheel energy storage, Compressed air energy storage, pumped hydroelectric storage, Hydrogen, Super-capacitors and Batteries used in energy systems. It involves studying certain economic aspects of different alternative energy storage technologies and concluded the best alternative energy storage systems and techniques in the modern world. Also, the best few alternative energy storage systems exist nowadays.

Index Terms — Alternative Energy Storage System, Compressed Air Energy Storage, Flywheel Energy Storage, Hydrogen, Photovoltaics, Pumped Hydro Energy Storage, Redox Flow Battery, Super Capacitor.

1 Introduction

One of the most widely discussed research topics is considered as energy management since man began to use a variety of energy for his own comfort and needs. The term energy management refers to energy production and energy-efficient use and storage of energy for future consumption. Alternative energy can be used effectively by incorporating proper storage methods.

Fossil fuels have been the dominant source of electricity generation over the past decade. However, environmental pollutions and the scarcity of the available resources tend to search for alternative fuel resources. The widely speaking renewable energy sources are solar, hydro, wind and biomass. However, totally adapted with renewable energy also not a feasible option due to various issues including weather conditions, cost, the difficulty of the storing produced energy for future requirement.

These problems can be avoided by implementing proper alternative energy storage technologies. Alternative energy storage can meet the grid requirements of many countries to bridge the gap between generation and consumer weights as a system resource at the peak of the system and on the customer side of the meter.

This article discusses alternative energy storage systems such as Redox flow batteries, Flywheel energy storage, Compressed air energy storage, pumped hydropower storage, Super capacitors and Hydrogen [1].

2 Process Description

2.1 General Classification of Alternative Energy Storage Systems

Alternative-energy-storage technologies are involved in the conversion of energy that is difficult to store more easily or economically. The efficiency of the system depends on several factors, such as storage capacity, cost, reliability, size and lifetime. The environmental impact of the proposed system also plays a major role in the selection process. Depending on the storage time, the energy storage system can be classified as follows,

- **Long-term energy storage system,**
    1) Compressed air energy storage
    2) Redox Flow Battery
    3) Hydrogen storage
    4) Pumped Hydro power storage

- **Short-term energy storage system,**
    5) Super capacitor
    6) Flywheel energy storage

Each of the technologies has its attributes regarding storage capacity, power, response time and cost [1].

2.2 Alternative Energy Storage Systems

1) Compressed air energy storage (CAE)

The development and use of renewable energy are an important remedy for the worldwide fossil energy crisis and pollution prevention. Due to the volatility and randomness of renewable energy such as wind and solar, the integration into the power grid poses serious challenges to the safety and efficiency of modern energy systems. There has been increasing concern about process optimization of renewable energy in a safe, efficient, and economical way [2]. The main drawback of renewable energy, which is storing capability for future requirements, is become a prominent factor for implementation.

One of the best methods for store energy as compressed air. It uses caverns and large spaces among rock layers underground. The three main types of caverns are salt dome, hard rock and aquifers.

Aquifers are usually hollow underground areas with sandstones or broken rocks used to store water, oil and natural gas. A salt pond is a cavity created by salt excavation, where water is pumped into the rock and dissolved in salt. The water is then pumped out, leaving a space in the layers of rock formation which is available to be used for storing compressed air. Finally, the cavern is the hard rock-cave which is created by using traditional mining tools such as a drill, picks and mining carts [1].

CAES refers to the storage of high-pressure compressed air in the form of a Various form of energy converted from compressed air. In order to support power network operation, the storage of compressed air is operated by pressurizing the air using compressors. The stored compressed air is released for running an amplifier for power generation during the low power generation periods to meet heavy load demand during peak periods. The sketch of the operating process is shown in Fig. 1.

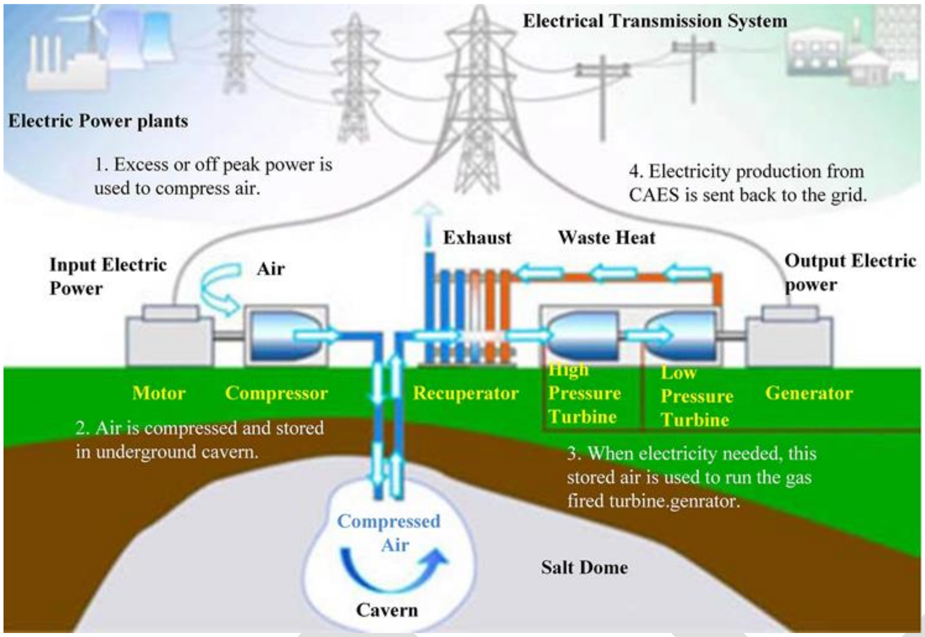


Fig. 1. Illustration of a compressed air energy storage

CAES technology is based on the principle of conventional gas turbine power plants. A gas turbine plant using air and gas as the working medium consists mainly of three parts Gas Turbine, compressor and combustion (Fig. 2). In the combustion chamber, high temperature and pressured gas react with the compressed air. Gas with high temperature and high pressure is combining compressed air and fuel in the combustion chamber drives the turbine and thus, Generator to generate electricity.

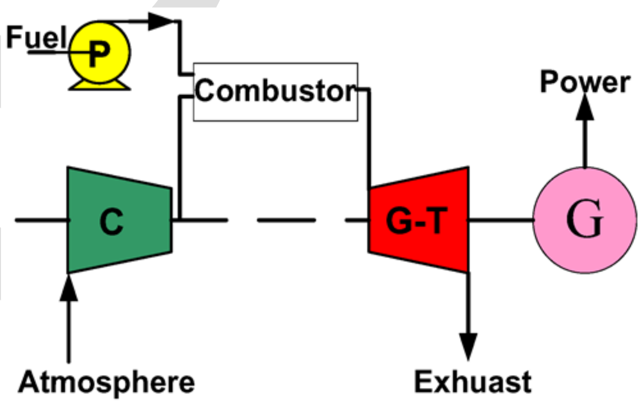


Fig. 2. Schematic diagram of gas turbine plant (C—Compressor, G-T—Gas turbine, G—Generator, P—Pump)

Compressors and expanders are designed, according to the applications and the designed storage pressure of the air. The pressure used for a large scale CAES system is about 8 MPa, for which multi-stage compressors are used, and normally combined axial flow compressors and centrifugal compressors are selected. Similarly, the steam turbines in Huntorf are used for the first-level expansion from 4.6MPa to 1.1 MPa; and gas turbines are utilized for the second-level expansion from 1.1MPa to atmospheric pressure, in which the working medium is a flue gas generated from the combustion of the air and fuel. [3]

2) Redox Flow Battery (RFB)

A rechargeable battery is an electric battery made of vertical electrochemical cells. Rechargeable batteries have a higher starting cost but can be recharged and reused at a low price. Batteries are modular and non-polluting and have a less environmental impact during the operating period. The power conversion of the secondary battery is reversible.

The energy flow of a battery energy storage system is based on the charge and discharge process. Grid power storage applications are used for rechargeable battery weight levels. Batteries are stored in unused surplus power during low demand periods and are supplied to the grid during peak load periods such as storing power generated by photovoltaic. Some available battery technologies include lead-acid batteries, nickel-cadmium, sodium-ion batteries, sodium-sulfur batteries, lithium-ion batteries, and hydrogen vanadium Redox and reagent Redox [1].

In RFB, soluble Redox couples of electrolytes are used, storing and releasing energy during battery charge and discharge, respectively. Fig. 3a shows a typical Redox flow cell, Positive and negative electrodes are separated by an ion transfer membrane. The membrane transport ions and it helps to prevent the mixing of the two cellular electrolytes store in separate tanks and circulate using batteries pump. Fig. 3b shows a membrane-free system.

It is currently in the early stages of developing practical applications that require high current Voltage. To achieve this, several unit cells can be placed vertically. There may be electrical grades and stocks that increase Voltage electrically connected in parallel to provide high current.

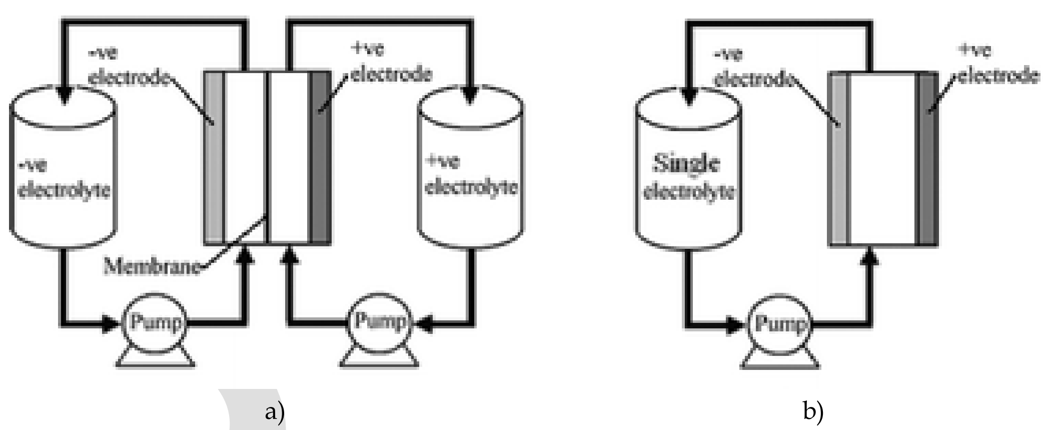


Fig. 3. The principle of (a) a divided and (b) an undivided Redox flow battery.

In order to reduce weight, volume, and cost, bipolar electrodes are often used. In many reactor designs, cells are nourished Diffusion of the electrolyte into each cell. Fig. 4 is representing a Redox bipolar electrode carrying Four-unit cells.

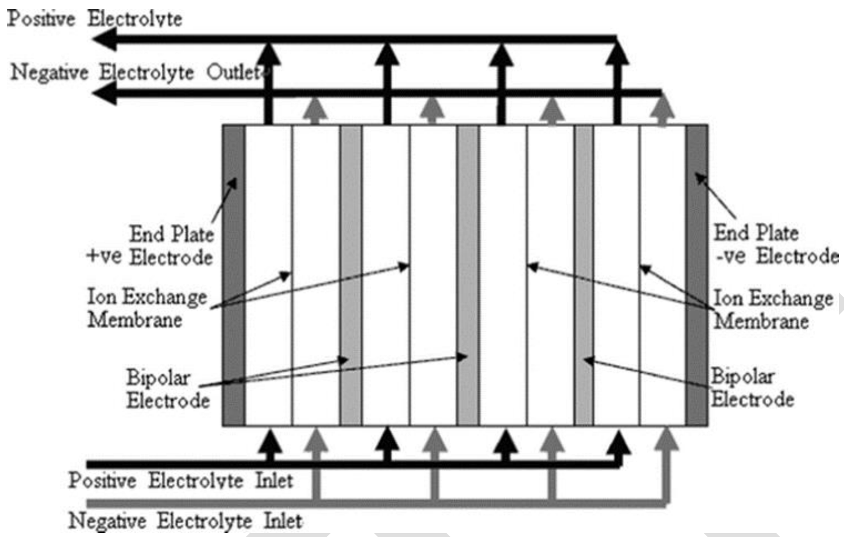


Fig. 4. A stack design for a four-cell stack with bipolar connection of electrodes

The benefits of RFB can be considered as the relatively low cost, multi-functionality, flexibility while compared with the lead-acid batteries. As a result of the modular design and long-term performance, RFB tends to build and maintain the lowest cost among all other energy storage systems. Also, in many cases, flow batteries can be disposed of without damaging the electrodes [4].

The power and energy capacity of RFBs can be easily changed. Hence, the flexibility of the energy storage is enhanced. A scale-up of the battery storage can be achieved by increasing the electrode size or by adding more electrodes in each stack with either mono-polar or bipolar connections. The energy storage capacity depends on the concentration of electro active species and the volume of the electrolytes [4].

3) Hydrogen storage

Hydrogen based energy storage systems are the best electronic energy storage medium. The hydrogen energy system can be easily integrated with renewable energy sources such as solar and wind. Although the efficiency of hydrogen energy is not very high, their required storage space is less compared to other energy storage systems. Therefore, hydrogen energy is economically preferable when the total amount of energy stored is worth more than efficiency.

Their essential components include a hydrogen energy conversion system such as an electrolytic unit for converting electrical energy into hydrogen, a reservoir of chemical energy stored, and a fuel cell for converting stored chemical energy into electrical energy. The produced hydrogen compressed or melted, stored and converted back into electrical energy or thermal energy. The main advantage of hydrogen is that it can replace all fossil fuel inputs without emitting harmful gases. The various hydrogen storage mechanisms are as follows.

a) Liquid hydrogen storage

The liquid hydrogen storage system is one of the bulk storing mechanism. However, the expensive cryogenic storage has become the issue with implementing.

b) Compressed and stored in a pressure tank

Compressed-gaseous hydrogen storage is suitable for long-term storage applications to avoid the failures of the expensive liquid process.

c) Physical adsorption in carbon

Through the adsorption process, hydrogen can be stored in gaseous carbon. Gaseous hydrogen can be adsorbed onto the carbon surface to achieve a more volumetric densities' appearance than liquid hydrogen. Carbon nanofibers are used as an adsorbent surface to enhance the storing capacity.

d) Complex compounds - Micro sphere hydrogen storage

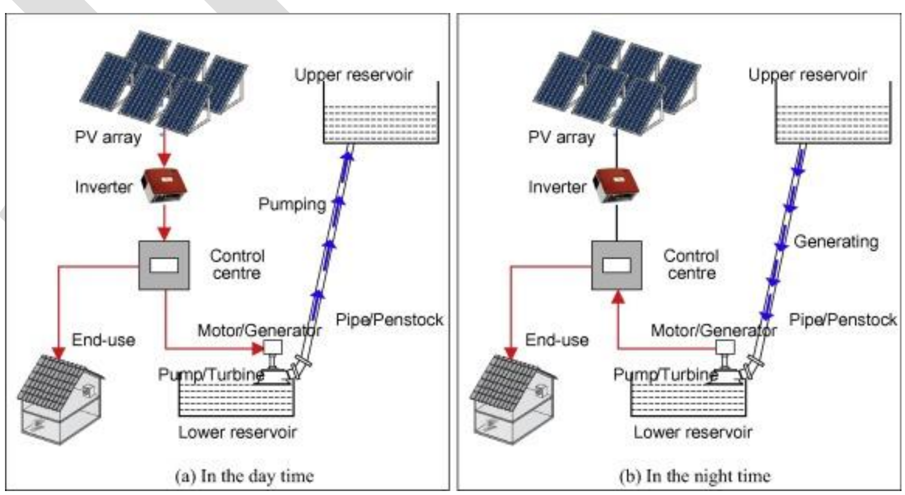
Micro sphere Hydrogen Storage is well suited for automobile applications. The system consists of the hollow glass spheres which are charged with hydrogen and released by heating and reduction of pressure.

e) Metal hydrides

Metal hydride generates by reacting with metal or alloy with hydrogen. Formation of metal hydride is an external heating process. When enough heat is provided, hydrogen is releasing back from the metal hydride. Metal hydride is having higher safety precautions and having high storage density [1].

4) Pumped Hydro power storage

Combining renewable resources with energy storage becomes an advanced energy storage solution. The pumped hydropower station is one of the best available energy storage mechanism. It consists of two water storage reservoirs in the two different elevations. The excess solar energy generated during the sunlight is used to operate the pumps to pump water from the lower reservoir to upper-level reservoir. During nighttime, water from the upper reservoir is using as a normal hydropower plant to generate energy. After generating hydropower, that water collected in the lower reservoir for nighttime pumping back (Fig. 5).



(a) In the day time (b) In the night time

Fig. 5. Operation of pumped hydro electric energy storage with photovoltaics power system

5) Super Capacitor (SC)

Super Capacitor (SC) is one of the emerging technology currently discussing as an energy storage device which can be used to store higher energy compared to traditional storage devices.

The energy storage mechanism for SC having the functional properties, such as low energy density to unit weight, handle very high current rates, extremely high price for unit energy [6].

MODEL OF SUPER CAPACITORS

- Electrical double layer model
- Porous electrode model
- Equivalent Circuit Model
    i. Simple Model of Super capacitors
    ii. Model based on kinetic parameters
    iii. Transmission Line Model
    iv. Model based on the structure features
- Intelligent Model [7].

6) Flywheel energy storage

The concept of a flywheel energy storage system (FES) is to store electrical energy as kinetic energy by rotating a mass that is mechanically connected to the motor/generator combination. When there is excess energy in the grid, the motor is forced to rotate at a high-speed. When the stored energy is needed, the motor/generator operates by rotating mass, as a generator. In this way, the kinetic energy is converted back into electrical energy, and the flying wheel acts as a mechanical battery. Often, the mass used in the flywheel is shaped like a hollow cylinder [8].

Fig. 6 shows the configuration of the prototype FES using a conventional induction motor and ball bearings. In this system, the kinetic energy of 3.0 MJ can be stored at 2900 r/min. In such a low rotational speed zone, a normal ball-bearing and general-purpose motor can be used. Besides, the flywheel vacuum case and the motor are separated by magnetic coupling. Therefore, the vacuum pump can reduce the pressure in a vacuum case, thus greatly reducing wind loss.

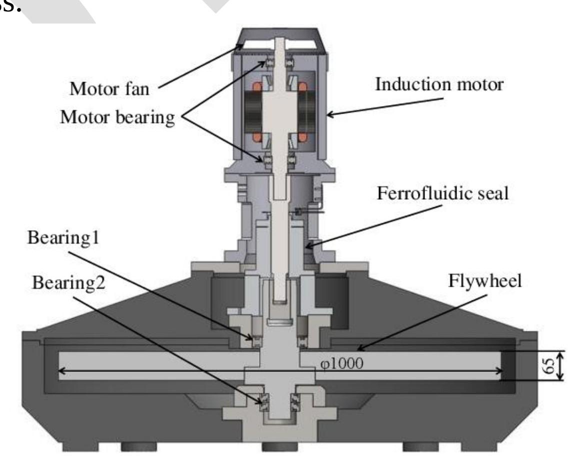


Fig. 6. Configuration of a flywheel system that employs an induction motor and ball bearings

Also, the vacuum in the vacuum case does not affect the thermal vapor of the motor. Therefore, a general-purpose motor can be used to operate the flywheel without adding a special cooling mechanism. In the flywheel system, the actuator-motor acts as a generator during degradation; Kinetic energy is converted to electrical energy. On the other hand, electrical energy is stored as kinetic energy during acceleration. This system therefore uses a regenerative converter. Also, the high temperature of the bearings and mortar can be prevented by the oil cooler [9]. Flywheel batteries can be used as a replacement. Although the initial cost of installing the flywheel is high. It has no environmental impacts such as battery power storage [1].

3 CONCLUSION

The efficient storage of energy produced can be improved by implementing a proper alternative energy storage system. Several alternative energy storage systems have been discussed and the summary is given below. Table 1 shows the general characteristics of the alternative energy storage system discussed. Alternative Energy storage systems can be properly used to select the best one for the specific application. It is clear from the table that the Super Capacitors and Redox Flow Battery are suitable for small-scale alternative energy storage applications and the Fly wheels are suitable for large-scale alternative energy storage applications. Compressed air energy storage and pumped water energy storage are well suited for central alternative energy storage due to their high energy storage capacity. Hydrogen energy storage systems are best suited for distributed energy storage. Batteries today are a long-term energy storage system that is widely used due to its low maintenance and efficiency.

Table 1. Comparison of different alternative energy storage technologies [1]

Energy Storage System	Power Rating	Discharge Time	Deployment time	Lifetime Efficiency
Compressed air energy storage	50-300 MW	1hr - 24hr	30 Years	70-80%
Redox flow Battery	<50 MW	Sec-hours	5-10 years	80-90%
Hydrogen storage	<250 KW	14hr - 24hr	10-20 Years	20-50%
Pumped hydro energy storage	100-4000 MW	1hr - 24hr	30 years	70-85%
Supercapacitor	<100 KW	Milliseconds to minute	10,000 Cycles	90-95%
Flywheel energy storage	<750 KW	milliseconds to 40 Min	20 years	90-95%

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