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A Detailed Study of Energy Storage Systems

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ABSTRACT
India is one of the five fast developing countries. India has made rapid strides towards economic self-reliance over the last few years. On the energy demand and supply side, India is facing severe shortages. To overcome energy crisis, India has developed many projects related to different energy sources. But driven by global concerns about the climate and the environment, the world is opting for renewable energy sources (RESs). However, RESs suffer from the discredit of intermittency, for which energy storage systems (ESSs) are gaining popularity worldwide. The idea of utilizing and storing excess renewable energy is not new, and numerous researches have been conducted to adorn this idea with innovations and improvements. This study is a humble attempt to assemble all the available knowledge on RESs & ESSs. This paper covers all core concepts of ESSs, including its evolution, elaborate classification, their comparison, the current scenario, applications, environmental impacts and future prospects keeping in mind the ever - growing needs, economic feasibility, fungibility and budget constraints. This elaborate discussion on energy & its storage systems will act as a reliable reference and a framework for future development of India in this field.

Keywords - budget constraints, classification, energy storage, renewable energy

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I. Introduction

At COP 21 in Paris in 2015, India made a commitment of meeting 40% of its electricity generation from non-fossil fuels by 2030. This commitment requires a lot of new technologies. The 175 Giga Watts of renewable energy target by 2022 needs to be made bigger with much larger capacity as well as new policies are to be implemented towards low carbon development. The integration of distributed generation resources on the low voltage grid requires the backing of active demand response and energy storage systems to maintain grid stability. In a rapidly changing technological environment, it is necessary to have a clear idea of priorities and to speed up the deployment of renewable energy technologies.

There has been a major increase in the global electricity consumption, which is boosted by technological advancements and stable economic growth worldwide. According to the latest assessment on global energy demand by the International Energy Agency (IEA), the global energy demand increased by 4% or 900 TWh to reach more than 26,700 TWh in 2018. Global energy demand increased by 0.9% in 2019 and approximately 64% of the annual global energy consumption was met by fossil fuels in 2018, which escalated the energy related CO2 emission by 1.7 % to 33 Gigatonnes.

India was the 3rd biggest consumer of crude oil and petroleum products after the USA and China in 2019. India had more than 370 gigawatts of utility-based installed electricity generating capacity connected to the national network by June 2020, according to India’s Central Electricity Authority (CEA). Coal contributed the highest about 55%. Renewable energy contributed a good amount of share of India’s electricity capacity including hydropower projects and other renewables and grew in share size over the past several years. Natural gas, diesel fuel, and nuclear power accounted for much smaller shares. Even though fossil fuel still accounts for majority of energy demand, India is gradually moving towards clean energy for the betterment of the environment.

The integration of RESs with the grid is not only beneficial for the environment, but also has enough economic benefits. Nevertheless, these RESs are intermittent in nature and cause power fluctuations, which seriously affect the reliability and stability of the power. Many types of research have been conducted for finding out potential solutions to minimize these intermittencies such as shifting the load through demand management, interconnecting external grid, electrical energy storage (EES), etc.

Recently many countries have started utilizing the multiple applications and facilities that EES has to offer by building large scale storage systems. Therefore, it is an ideal time for India to review and summarize the recently conducted research works on this field, as variable renewables grow to substantial levels, electricity systems will require greater flexibility. By providing these essential services, electricity storage can drive serious electricity decarbonization and help transform the whole energy sector, which will aid further research and proliferate the implementation and deployment of EES in practical applications.

II. Present Day ESS Technologies

An advantage of mechanical energy is that it can be stored easily and also it is very flexible in the sense that it can be easily converted into and from other energy forms. The two forms of mechanical energy are kinetic and potential energy. Pressurized gas and forced spring are two variations of potential energy, whereas kinetic energy can be stored within motion on a body. The widely used forms of mechanical energy storages are mentioned here. Pumped Hydro Storage popularly known as PHS and Compressed Air Energy Storage known as CAES stores potential energy whereas the flywheel energy storage system stores kinetic energy.

2.1 Pumped Hydro Storage (PHS)

Pumped hydro storage (PHS) is one of the most popular storage techniques due to its simplicity and large storage capacity in the range of 1 to 3000 MW. PHS is a mature and robust technology with high efficiency of 76–85%, low capital cost per unit energy, long storage period, and a very long life of 50 years or more [1]. The PHS is a reflection of the conventional hydroelectric power plant but functions in reverse manner. The schematic of PHS is represented in Fig. 1. Similar to hydroelectric power plant, water from the upper reservoir is used to generate electricity by releasing it to the turbine of the generator. This water is stored in the lower reservoir and pumped to the upper reservoir using the turbine during the low peak hours. This water is again released in the high peak hours when demand is high to produce electricity. Hence, water can be used multiple times which makes the system more efficient. The energy produced from a given quantity of water depends on the head, which is the distance between the turbines and the upper reservoir. The larger the head, the greater the energy generated for a given volume of water will be.

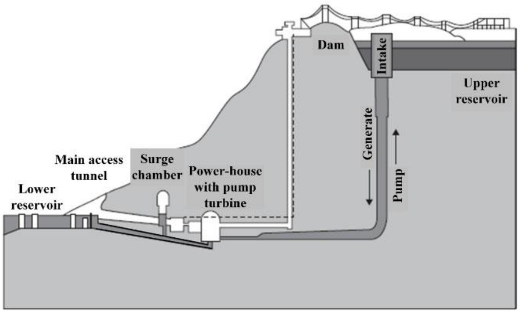

Figure 1: Schematic diagram of PHS

The analysis carried out is as follows:

Table 1: $K_{fitting}$ Values

Fitting Items	Quantity	$K_{Fitting}$ Value	Item Total
Pipe entry projecting	1	0.78	0.78
Pipe exit container	1	1	1
Elbow 45^o	30	0.19	5.7
Total $K_{Fitting}$ Value			7.48

The above Table shows the calculation of K fittings that have been assumed. From the Table, the total $KFitting$value has been calculated and it equals to 7.48

We Find the Reynold number at rated capacity. Where the kinematic varicosity of water is $\upsilon = 1.0 * 10^{-6}\ m^2/s$

$Re = \nu D/\ \upsilon = 5.8\ m/s * 2.1m/\ 1.0 * 10-6\ m2/s = 121.8 \times 105\ turbelnt$

Now substitute the value of Reynold number in equation:

$f = 0.25/\ [\log \{\varepsilon/\ (3.7*D) + 5.74/\ Re^{0.9}\}]^2 = 0.25\ [\log \{4.6\times10^{-6} / (3.7*2.1) + 5.74 / (121.8\times105)\ 0.9\}]^2 = 0.00969$

$KPipe$ can be calculated by substituting the value of (f)
$K_{Pipe} = f*L\ D = 0.00969 \times 1500m\ 2.1m = 6.9282$
Then, the total K value for the system is:
$K = K_{Pipe} + K_{Fitting} = 6.92 + 7.48 = 14.4$
Now the dynamic head can be calculated as follows:
$Hd = Kv^2 /2g = 14.4 \times 5.8^2 /2 \times 9.8 = 24.7\ m$.
Finally, the total pump head is calculated for 1st scenario when the $L_{Upper.r}$ is maximum.
$P_H = Hs + Hd + (L_{Upper.r} - L_{Lower.r}) = 335\ m + 24.7\ m + (14\ m - 4\ m) = 369.7\ m$
For 2nd scenario when the $L_{Upper.r}$ is between the minimum and maximum level.
$P_H = Hs + Hd + (L_{Upper.r} - L_{Lower.r}) = 335\ m + 24.7\ m + (7\ m - 4\ m) = 362.7$ m
The total-frictional pressure drop in the system is the sum of the pressure drops caused by the piping and fittings, and control valve.
Estimated pressure loss for control valve is 0.7 bar and for pipeline we can calculate as follows
$P_{loss} = 4.53 * L * [(Q/C)^{1.852} / D^{4.587}] = 4.53 * 335 * [(18.85/150)^{1.852} / 78.74^{4.587}] = 6.532 * 10^{-8}$ Pa
Pump Sizing:
$W = (g/g_c) * (z_1 - z_2) + (p_1 - p_2)/\rho - (Es + E_D) = (9.81/1) * (335\text{-}4) + (3387675\text{-}101325)/1000 - (6.532*10^{-8} + 0.7 * 10^5) = -63466.54$ N.m./kg
*The negative sign indicates that work is done on the system.
The area is assumed to be 7000 m^2 and the maximum height in upper reservoir for water is considered to be 14m. Thus, the Volume for upper reservoir is 98000 m^3.
Considering Pumps to be operated continuously for 8 hours during off grid electricity supply we calculate required flow rate as follows:
$V = Q * t$
where V= Volume of reservoir; Q= Volumetric flow rate; t= time in Hour
Thus, $Q = V/t = 98000/8 = 12250\ m^3/hr = 3.4\ m^3/s$
In chemical industries a centrifugal pump is used.
So, considering centrifugal pump:
Pump Power $= mW/\dot{\eta} = 3.4*1000*63466.54/0.45 = 480$ MW

Scenario 1:
Total stored energy is given by
$E_t\ (J) = m*g*h = V_u *\rho*g*h = 98000 * 1000 * 9.81 * 369.7 = 3.55 * 10^{11}$ J
Energy density is the energy per unit volume of the stored water given by
$e_v\ (J/m^3) = E_t / V_u = \rho*g*h = 3.55 * 10^{11} / 98000 = 3.62\ MJ/m^3 = 3.62 / 3600 = 1006.24\ W.hr/m^3$ =1.006 W.hr/lt.

Efficiency of pumping operation is given by
$\dot{\eta} = (E_s / E_{in}) * 100\%$
$E_{in} = E_s * \dot{\eta}_{trans} * \dot{\eta}_{motor} * \dot{\eta}_{pump} * \dot{\eta}_{pipe,\ p} = 3.55 * 10^{11} * 1.685 = 5.98 * 10^{11}$ J
The pumping mode efficiency is given as
$\dot{\eta}_p = (E_s/E_{in}) * 100 = (3.55 * 10^{11}/5.98 * 10^{11}) * 100 = 59.36\%$
Efficiency of generating operation is given by
$\dot{\eta} = (E_{out} / E_s) * 100\%$

After generator and step up transformer losses from Fig 2, energy output to the grid is
$E_{out} = E_s * \dot{\eta}_{pioe,\ g} * \dot{\eta}_t * \dot{\eta}_{gen} * \dot{\eta}_{trans} = 3.55 * 10^{11} * 0.89 = 3.16 * 10^{11}$ J
Generating mode efficiency is
$\dot{\eta}_g = (E_{out} / E_s) * 100 = (3.16 * 10^{11} / 3.55 * 10^{11}) * 100 = 89\%$
The overall round-trip efficiency is therefore
$\dot{\eta}_{rt} = (E_{out} / E_{in}) * 100 = \dot{\eta}_p * \dot{\eta}_g = (3.16 * 10^{11} / 5.98 * 10^{11}) = 52.8\%$
Charging (pumping) time:
$t_p = (E_{in} /P_{in}) = (E_s /\dot{\eta}_p * P_{in})$
$t_p = (V_u *\rho*g*h/ \dot{\eta}_p * P_{in}) = (3.55 * 10^{11} / 24 * 6 * 0.6 * 480 * 10^6) = 8.5$ hours
Discharging (generating) time:
$t_g = (E_{out} /P_{out}) = (E_s * \dot{\eta}_g /P_{out})$
$t_g = (V_u *\rho*g*h*\dot{\eta}_g/ P_{out}) = (3.55 * 10^{11} * 0.89 / 24 * 6 * 480 * 10^6) = 5.5$ hours

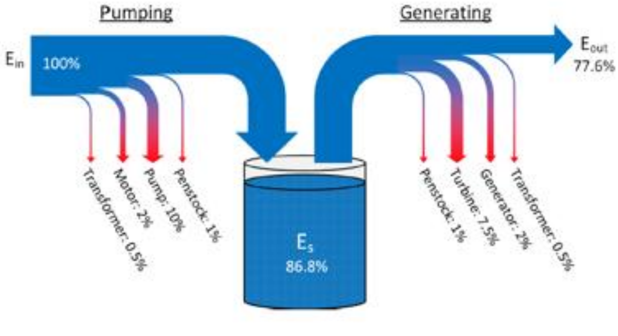

Figure 2: Typical Losses for PHS

Scenario 2:
Total stored energy is given by
$E_t\ (J) = E_s = m*g*h = V_u *\rho*g*h = 49000 * 1000 * 9.81 * 362.7 = 1.74 * 10^{11}$ J
Energy density is the energy per unit volume of the stored water given by
$e_v\ (J/m^3) = E_t / V_u = \rho*g*h = 1.74 * 10^{11} / 49000 = 3.52\ MJ/m^3 = 3.55 / 3600 = 988.35\ W.hr/m^3$ = 0.988 W.hr/lt.
Efficiency of pumping operation is given by
$\dot{\eta} = (E_s / E_{in}) * 100\%$

$E_{in} = E_s * \eta_{trans} * \eta_{motor} * \eta_{pump} * \eta_{pipe,\ p} = 1.74 * 10^{11} * 1.685 = 2.93 * 10^{11}$ J

The pumping mode efficiency is given as

$\eta_{p} = (E_s/E_{in}) * 100 = (1.74 * 10^{11} / 2.93 * 10^{11}) * 100 = 59.8\%$

Efficiency of generating operation is given by

$\eta = (E_{out} / E_s) * 100\%$

After generator and step up transformer losses from Fig 2, energy output to the grid is

$E_{out} = E_s * \eta_{pioe,\ g} * \eta_t * \eta_{gen} * \eta_{trans} = 1.74 * 10^{11} * 0.89 = 1.55 * 10^{11}$ J

Generating mode efficiency is

$\eta_g = (E_{out} / E_s) * 100 = (1.55 * 10^{11} / 1.74 * 10^{11}) * 100 = 89\%$

The overall round-trip efficiency is therefore

$\eta_{rt} = (E_{out} / E_{in}) * 100 = \eta_p * \eta_g = (1.55 * 10^{11}/2.93 * 10^{11}) = 52.9\%$

Charging (pumping) time:

$t_p = (E_s /\eta_p * P_{in})$

$t_p = (1.74 * 10^{11} / 24 * 6 * 480 * 10^6 * 0.598)$

$= 4.3$ hours

Discharging (generating) time:

$t_g = (E_s * \eta_g /P_{out})$

$t_g = (1.74 * 10^{11} * 0.89 / 24 * 6 * 480 * 10^6)$

$= 3.25$ hours

Table 2: Comparison of PHES energy density with other energy storage/sources

	Energy Density (W.hr/lt.)
PHS (h = 362.7)	0.988
PHS (h = 369.7)	1.006
PHS (h = 500)	1.36
PHS (h = 1000)	2.73
Natural Gas	10.1

From the above Table we can see that, even at high heads, PHES has very low energy density hence large reservoirs are required for high energy density.

2.2 Flywheel Energy Storage (FES)

Flywheel Energy Storage (FES) possesses high energy and power density, high energy efficiency, and its power ranges from KW to GW range [2]. Also, its energy storing capacity is around 500MJ. These qualities make Flywheel energystorage systems useful for variety of applications such as satellites, transportation, etc. In comparison with the batteries, they have longer cycle and the response time is also higher. In addition, the depth of discharge (DoD) of these systems are low thus they are suitable for UPS applications. The FES also has applications, where energy is stored during the off- peak time and this stored energy is used during the off- peak time. The fundamental parts of the flywheel system are represented in Fig 3.

To minimize frictional losses and disturbance, the entire flywheel is placed in low pressure or in a vacuum state. It stores and releases kinetic energy according to the energy demand. During the charging stage, by means of a motor, the flywheel system rotates at a very high speed and stores the kinetic energy while, in the discharging state, this stored kinetic energy is used to rotate the motor, which acts as a generator and produces electric energy. In the load leveling and peak shaving applications, by means of appropriate control systems and converters, the FES stores the kinetic energy during the off- peak time, when the demand is low and this stored energy is used during the peak time when the demand is high. They also can be used to reduce the intermittencies of the renewable energy systems by supplying real power to the system when necessary.

Based on the rotational speed ω, the FES can be categorized into two types: low- speed FES and high- speed FES. The low- speed FESs has a rotational speed of less than 6000 rpm, whereas high-speed FESs has a rotational speed of about 104 -106 rpm. The low- speed conventional FES is highly suitable for uninterrupted power supply and power reliability applications and its cost is also low. On the other hand, the high- speed FESs are particularly suitable for traction and aerospace applications and can be partially or fully integrated with electrical machines. However, the cost of high- speed FES is almost five times higher than the cost of conventional low- speed FES. The characteristics of low- and high- speed FES.

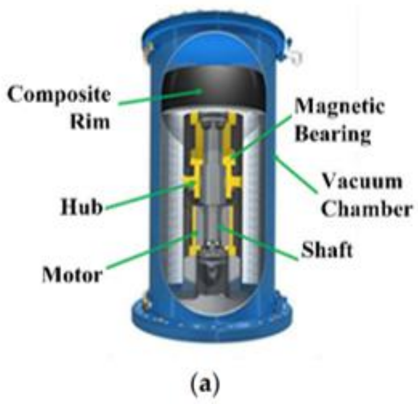

Figure 3: (a) Flywheel energy storage system

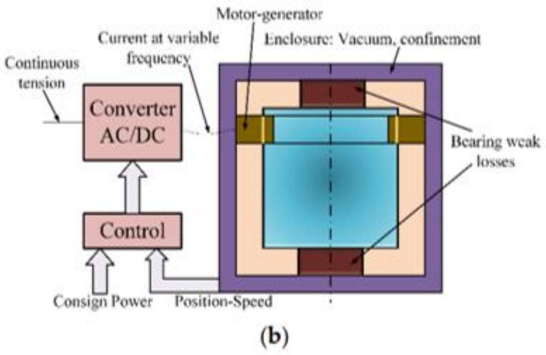

Figure 3: (b) Schematic diagram of flywheel energy storage (FES), also called accumulator

The maximum specific energy will be,

$$\frac{E}{m} = K\frac{\sigma_{max}}{\rho} \text{ [J/kg]}$$

and the maximum energy density will be

$$\frac{E}{V} = K\,\sigma_{max} \text{ [J/m3]}$$

Where K is the shape factor and can be described as a measure of how efficient the material of the flywheel is used. For a detailed derivation of the shape factor see. Fig 4 which shows the most common types of flywheel geometries [3].

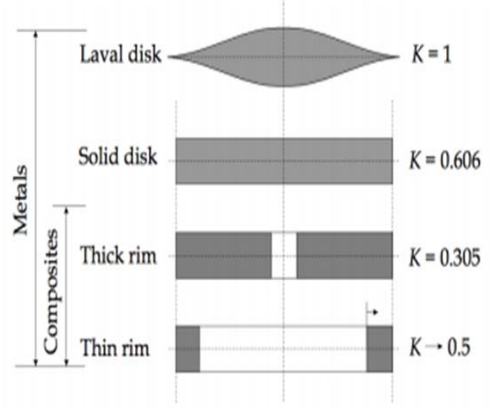

Figure 4: Shape factor of common flywheel shapes

The analysis carried out with certain assumptions is as follows:

The height changes with the radius, so that if the height is 10 cm at the center axis and 3 cm at the outer radius, which is 15 cm. The thickness decreases linearly with r. The flywheel rotates at 16 krpm, and the material has a density of 3000 kg m3. Neglecting energy contributions from elasticity. Instead of assuming that the thickness of a material with constant density changes, we will assume that the density of rotating disk with a constant thickness change. The density changes relative to the thickness so that it has hundred percent of the density at the center (0.1/0.1) and then a relative decrease of 0.1−0.03 / 0.15 - 0.1 times the radius. The density thus becomes $(dE_{kin}/dr) = \lim_{\Delta r \to 0} (1/2) * \{\rho * \pi^3 * h * (2r + \Delta r) * \omega^2 * 4 * [r^2 + 1/2 * r * \Delta r + (\Delta r/2)^2] / 60^2$ $\rho = \rho_0 * \{(0.1/0.1) - [(0.1 - 0.03) / (0.15 - 0.1) * r]\} = \rho * (1 - 4.67 * r)$, where ρ0 is the density of the material itself, 3 000 kg m−3.

By inserting given values

$E_{kin} = [4 * 3000 * \pi^3 * 0.1 * 16000^2 * (0.25 * 0.15^4 - 0.933 * 0.15^5)] / 60^2 = 147 \text{ kJ} = 41 \text{ Whr}$

But 41 Whr is actually not too much energy. That is why this needs to be placed in context of the mass of the flywheel and the conversion time.

$P = \Delta E_{kin} / \Delta t = (41 / 0.00556) = 7.38 \text{ kW}$

Now, 7.38 kW is a significant amount of power. It is almost 10 hp

$$(dE_{kin}/dr) = \lim_{\Delta r \rightarrow 0} (1/2) * \{\rho_0 * (1 - 4.67r) * \pi^3 * h * (2r + \Delta r) * \omega^2 * 4 * [r^2 + 1/2 * r * \Delta r + (\Delta r/2)^2] /60^2$$

$$(dE_{kin}/dr) = [4 * \rho_0 * (1 - 4.67r) * \pi^3 * h * r^3 * \omega^2] /60^2$$

$$E_{kin} = \int_0^{0.15} \{[(4 * \pi_3 * \rho_0 * h * \omega^2) * (r^3 - 4.67r^4)]/ 60^2\} * dr$$

$$m = \int \rho * dV = 2 * \pi * \rho_0 * h \int_0^r r - 4.67r_2 * dr$$

$$= 2 * \pi * h * \rho_0 * [(r^2/2) - (4.67r^3/3)]^{0.15} = 11.3 \text{ kg}$$

In addition to the wheel itself, there are the auxiliary components (electric motor and shaft) of said 20 kg. A mass of 31.3 kg gives a specific power of 0.235 kW kg^{-1}. The specific energy can be calculated to 1.31 Wh kg^{-1}. These two numbers are really important for evaluating suitability in the energy sector. we have assessed a system that has the energy density slightly larger and power density equivalent to that of a typical super capacitor. If considering a 75 kW electric engine of mass 100 kg instead of 20 kg, the energy and power density would drop by almost a factor of five. Thus the auxiliary components are the most important factors for energy and power density in this example.

We are now to change the rotational velocity from 16 to 75 rpm and the density from 3,000 to 1,500 kg m^{-1}. Looking at below equation, we can that as long as the energy is proportional to the square of the rotational velocity and directly proportional to the density, $E_{kin\ r,\ h(r)}\ \alpha\ \rho * \omega^2$. Therefore, finding materials that can rotate faster is a good idea, even though they have lower density. From the proportionality relation we get:

$$E_2 = E_1 * [(\rho_0,2)/(\rho_0,1)] * (\omega_2/ \omega_1)^2 = E_1 * ½ * (75/16)^2 = 11 * E_1$$

$$E_2 = E_1 * [(\rho_0,2)/(\rho_0,1)] * (\omega_2/ \omega_1)^2 = E_1 * ½ * (75/16)^2 = 11 * E_1$$

The energy increases by a factor of eleven. So does the power as long as the discharge time is the same. The specific energy and power increase more because of the reduced weight, a factor of 11 compared to the initial. Therefore, as long as weight matters, reducing the density of the flywheel is irrelevant as long as it can rotate faster.

Table 3: Comparison of Discharge efficiency

Technology	PHS	Flywheel
Energy Density (Whr/L)	0.5-2	20-80
Power Rating (MW)	30-5000	0.25-20
Lifetime (Years)	40-60	15-20
CO2 (g/kWhr)	127	-
Disharge Efficiency (%)	87	90-93

2.3 Compressed Air Energy Storage (CAES)

CAES is a technology where compressed and pressured air is utilized to store energy. CAES along with PHS is the only large- scale energy storage system at present. With respect to PHS, CAES is much smaller in size, however its construction sites are much more widespread, which means that CAES is capable of offering is a more widely distributed large scale storage network. The capacity of these systems ranges from 35 MW to 300 MW, which makes them suitable in stationary applications such as frequency regulation and load leveling.

With a wide search about CAES projects, this section provides updated information. A detailed comparison of the key operating parameters between the Huntorf and McIntosh CAES plants is listed below in the Table. These are two CAES power plants currently in commercial operation [4]. The common feature of these two power plants is the requirement for fossil fuel (natural gas), which is not desirable for the current clean energy agenda. Low energy conversion efficiency is another key factor heavily criticized. All the current projects and researchers are attempting to avoid using fossil fuel and improve energy efficiency.

Table 4: Information of commercial CAES facilities

Location	Huntorf, Germany	McIntosh, USA
Manufacturer	Browne Boveri	Dresser-Rand
Power Rating (MW)	290	110
Charge/Discharge Time (h)	8/2	40/46
Air Pressure (bars)	46-66	45-74
Heat Sources	Natural Gas	Natural Gas
Efficiency	42%	54%
Year of operation	1978	1991

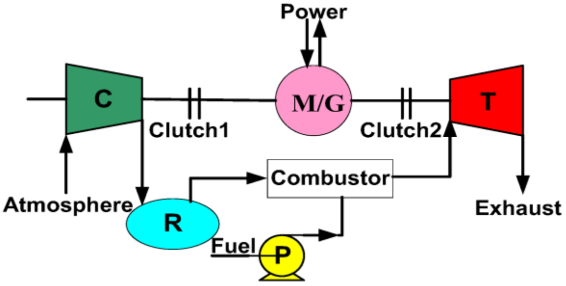

Figure 5: Schematic diagram of CAES system (C-Compressor, G-T – Gas Turbine, M/G- Motor Generator, P-Pump, R- Resevoir)

III. Applications of ESS

In the earlier days, the sole purpose of ESSs was to provide backup power to the system and serve as secondary support for the utility. With the advancement of research and technology, ESS has now become a prominent part of the power system. ESSs are also used in energy applications such as load levelling, peak shaving, etc. They are also being implemented in transmission, and distribution applications. Moreover, with the high penetration of electric vehicles (EV) in market, ESSs are now playing a vital role in the transportation sector. All the ESSs do not perform in the same way for some applications So, it needs to be analyzed beforehand whether or not a particular type of ESS is suitable for a certain application, or whether or not it outperforms its similar types.

Energy storage is a uniquely flexible type of asset in terms of the diverse range of benefits it can provide, locations where it may be sited, and the large number of potential technologies which may be suited to provide value to the grid. Fundamentally, energy storage shifts energy from one-time period to another time period. However, the value of energy stored by a resource varies highly based upon the controllability, dispatch and use of that energy. The electricity system has historically operated on a "just-in-time" basis − with decisions about electricity production based on real-time demand and the availability of transmission system to deliver it. Because of this, generation and load must always be perfectly balanced to ensure high power quality and reliability to end customers. At very high penetrations of variable wind and solar generation, energy storage can be effective for storing excess energy at certain times and moving it to other times, enhancing reliability and providing both economic and environmental benefits

Storage's unique physical characteristics enable it to perform multiple functions on the grid, at the customer level and in transportation sector. The ability to store energy when there is no demand and deploy energy when load is needed can be applied to all aspects of the energy systems. In addition, storage systems can function like a power plant, dispatching electricity. When renewable resources such as solar, wind or hydropower produce excess energy, ESS can store it for later use, reducing energy waste.

Energy storage can play a very important role in grid integration and balancing of variable generation sources. By increasing the system's overall flexibility, it can improve power quality, reduce peak demand, enhance capacity of distribution / transmission grids, avoid/reduce deviation penalties etc. Use of energy storage systems by residential, commercial or industrial consumers, in conjunction with renewable energy has potential to improve power quality and reliability for such consumers. This would also allow for minimization of diesel consumption from back-up power applications. Energy storage is the main component of EVs both in terms of cost and performance determination. The thrust for electric mobility utilizing indigenous modern and reliable energy storage would significantly reduce the country's dependence on imported fossil fuels and energy storage systems.

IV. Environmental Impacts of ESS

Energy storage systems are very green since they promote the use of renewable sources of energy, thereby reducing the emission of greenhouse gases and also protecting the limited fossil fuels. The energy demands of people are exponentially increasing, which resulted in the global CO2 emissions rising by 1.7% to a record high of 33.1 Gigaton. This was the highest growth rate since 2013, and almost 70% higher than the average growth rate since 2010. About 2/3rd of the emissions have arisen from the power sector alone. The extensive use of coal in the power sector exceeded 10 Gt in CO2 emissions in India. The leading countries in the world with the highest energy demands, i.e. USA, India, and China, are responsible for 85% of the overall increase in emissions.

Fig. 6 shows the dreadful amounts of CO2 emissions from combustion of coal for power generation and other uses, and from other fossil fuels from the year 1990 to 2019 which depicts that emissions are ever increasing.

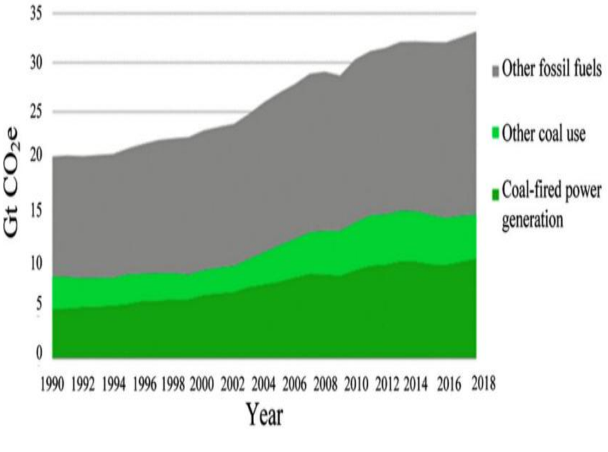

Figure 6: Energy related CO2 emissions by source

As ESSs help fight the climatic vagaries and intermittencies of renewable sources, they can encourage the integration of more renewables in the power grid. Further, ESSs can ensure that the generation system operates at optimal levels and reduce the usage of less efficient generating units, which run only to meet the maxium demands. There can be some possible negative sides of Energy storage systems, but it depends on the type, materials used, and efficiency of the ESSs. Some batteries, such as lithium and lead, are often harmful from an environmental perspective, and can even cause health hazards if not disposed of properly. These toxic materials need to be recycled effectively to ensure that ESSs remain a safe option. The storage process involves the conversion of energy, which can also lead to loss of energy.

The carbon footprint of the ESS should be kept as minimum as possible for benefit of the environment. There are various benefits of ESS when it comes to the environment such as making the adoption of ESSs an excellent choice for meeting the sustainable development goals. ESSs are capable of improving the overall efficiency of power grids. ESS is completely free from any sort of emission that might harm the atmosphere. Solar photovoltaics and ESS are a great duo, together paving way towards a greenhouse gas free, clean, and profitable power generation system.

V. Future Prospects

5.1 Future of CAES

CAES has demonstrated its unique merits but it has weakness in terms of low round trip efficiency. The future technology development is currently focusing on improving its efficiency. Such technology developments are presented here around 95 % of the compressor power are transferred into heat. Not only that heat is lost during normal air compression to the surrounding, the air must be heated before and during the expansion in a turbine, because warmer air means more volume means more turbine work. According the first law of thermodynamic, energy can't be lost in a closed system, the heat which is required to reach initial conditions after the turbine, is exactly the same amount of heat that has to be removed during compression. Isothermal compression is theoretically the best way to compress air, because the compression volume does not increase during compression - which is an exothermal state change of ideal gases. Isothermal means, that the heat has to be carried away as soon as it appears, which makes it impossible to cool over the surrounding surfaces. According to the second law of thermodynamics, temperature gradients are required which are not allowed in the definition of isothermal. The most promising way is to spray water mist directly into the compression chamber, because water will then evaporate, which is an endothermic process. This technique has already been discussed and tested in 1927, but has been dismissed because of technical problems during the grinding parts.

Today there are two examples of isothermal or quasi isothermal processes, the compressor of LightSail and the carmaker BMW which injects water in the combustion chamber in its M4 safety car. One indirect system is also present which reaches a quasi-isothermal process because it works extreme slow. These systems seem technically very good, but the complexity is relative high. Also the costs of such an installation should be relative high. It is always important to have a good balanced between technological advance, robustness and price. The future will show if they can establish successful in the market. Another possibility is Advanced Adiabatic - CAES which is thermodynamically researched. Adiabatic means that no exchange of with the surrounding. Because the compressor has to be cooled, the waste heat has to be transferred into a special heat storage. A standard scuba compressor with 2,2 kW nominal power, three compression stages and inter-cooling is used to compress air up to 300 bar. A circulating water heat storage stores heat until 100 ◦C. Pressurized air is stored in standard gas bottles.According to actual studies, the efficiency of AA-CAES systems is between 50 and 70 %

Integration with Solid Oxide Fuel Cells (SOFCs)- The integration of SOFCs (to provide base-load power) and a CAES system (to follow peaking demand) with zero direct CO2 emissions was proposed by Nease and Adams [5]. It was found that the integrated system could provide satisfying load-following capabilities with relatively small penalties to efficiencies and levelized electricity costs. To solve the limitation of SOFC output and the finite of CAES storage capacity, a two-level rolling horizon optimization scheme was also presented.

5.2 Future of PHS

Gravity-based energy storage is an evolution of PHS technologies, which can store large quantities of energy using the mass of water at different levels. PHS systems are only economically feasible due to installation costs. For instance, the cost of a PHS tunnel doubles when the diameter doubles. However, a tunnel twice the width quadruples the quantity of water that can pass through it, boosting the storage capacity of the system. Rather than a series of tunnels and pumps, the Gravity-based energy storage system is based on a vertical shaft up to 1500 meters deep with weight configurations ranging from 500 to 5000 tonnes. Raising the weight charges the system while lowering the weight discharges the electricity back to the grid. The weight system is guided with a network of thick and tensioned wires that keep the weights from swinging into the sides of the shaft. The winch structure has also been designed to keep the weights stable. The Gravity-based energy storage system is designed to last at least 50 years without cycle limits or degradation. This system is said to have an efficiency of 80 to 90%, with costs below that of a comparable lithium battery system [6].

ESSs are in the plans of the scientific community for quite a long time. It is, in fact, difficult to trace back to when the idea of energy storage first came up in human minds. However, it is true that the necessity of ESSs will keep on increasing with the growth of renewable sources of energy, distributed energy resources (DERs), distributed generation (DG), microgrids, and the overall utility grid. ESSs are useful not only to tackle the intermittency of renewables, but also in numerous grid- scale applications. The most important advantage of using ESSs lies in its ability to save costs, in the form of several applications, such as demand side management, reduction of demand charges, etc. As climate changes are drastically hampering the quality of life on our planet, it is imperative for humans to cut down on conventional sources of energy generation that emit greenhouse gases and threaten the environment. In such a dire situation, in the future, it will be crucial to switch to a 100% renewable- energy- dependent electricity generation system. Due to the intermittent nature of renewables, together with the ever- increasing demand for energy, there will be no way out other than adopting energy storage systems.

VI. The outcome of this Study

This is a comprehensive study on energy storage systems that is aimed at encompassing everything one needs to know before initiating research in this field. This project has been formatted in such a way that some necessary information about ESSs from a chemical engineering point of view is included in a single place. To summarize, the outcomes of this study are presented below:

i. A brief introduction to energy storage systems is provided, which reassures the necessity of ESSs to tackle the problem of intermittence of RESs, whose penetration into utility grid is of importance in today's world due to the depletion of fossil fuels and deteriorating condition of our planet.

ii. Energy can be stored in numerous forms. Various types of energy storage systems are discussed here, including their detailed concept, related diagrams, and equations.

iii. The comparison among ESSs is the major subject of analysis before the practical deployment of an ESS.

iv. At present, the use of ESSs is increasing, as more countries are trying to install increased capacities of ESSs.

v. The environmental impacts of ESSs are narrated, with reflections on how ESSs are helping the environment.

vi. ESSs are a promising technology, with vast possibilities to upgrade the global energy scenario. The prospects for the future are outlined.

VII. Conclusion

This critical study focuses in the realm of energy storage technology with reference to its main components. Bulk Energy Storage is a mitigating step for bringing quality, cheap energy to consumers and as more strain on the grid gets prevalent with the drive towards renewable energy sources, the world is set to be drawn more towards ESS, which will require a complete understanding of this technology. This study encompasses a substantial information on energy storage systems. Most of this study has been dedicated to elaborately describing all the different types of energy storage systems.

Pumped storage has provided a mechanically simple and reliable means to achieve the market need. Compressed air, through its innovative advances, becomes a competitive design in roundtrip efficiency and also in competitive in areas that do not have the geographic advantage for pumped storage.

Today, compressed air technologies, like Advanced Adiabatic CAES, gain ground in design and produce a round trip efficiency of 71% in the design evaluated in this study. Advantages in CAES are just beginning to match the efficiencies of PHES. However as geographic and economic limitations become more prevalent in pump storage, the window of opportunity becomes available to CAES storage plants.

For wind energy, the technology is often unused due to operation at night and unpredictable generation. Since many wind farms operate in favorable geological locations for CAES, the CAES technology can ultimately be built at wind farm sites and provide further recoverable losses.

It is true that there still remains a huge, unexplored part in energy storage that has not been covered in this paper. The future works will be to study and find effective ways for controlling ESS and to find newer and better applications of energy storage systems.

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