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FLYWHEEL ENERGY STORAGE SYSTEMS, ITS APPLICATIONS AND RECENT TECHNOLOGICAL ADVANCES: A REVIEW

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Abstract*— Energy storage systems have a essential role in recent years. Flywheel energy storage system is catching a eye of many researchers these days, since it has certain advantages over other existing energy storage systems. Flywheels' attribute consists of high lifespan, very low maintenance, higher operation life, very low effect on nature and atmosphere, quick charge-discharge cycle, increased power-density and the ability to hold huge quantity of energy. The principal factors of FES technology includes material properties of flywheel, detailed geometrical specification, and bearing system supporting every elements, through which energy storing capacity and the energy per unit mass of flywheel are diametrically affected. Despite of rigorous research going on, Flywheel energy storage technology is not fully developed. With the help of new advances, the cost of Flywheel energy storage will significantly drop and the technology will play a noteworthy part in achieving global energy sustainability. The uses of Flywheel energy storage system have a broad-spectrum beginning from very tiny purpose and go as far as large space applications. This paper presents a compendious review of different existing energy storage systems, flywheel energy storage system, its components and its applications.

Keywords: Energy storage systems, Flywheel energy storage systems, Magnetic bearings.

I. INTRODUCTION

A flywheel is a mechanical component particularly designed to effectively store kinetic energy due to its rotation. Due to moment of inertia of flywheel, it tends to resist variation in its rotational speed. In Flywheel energy storage system, firstly the Flywheel is given acceleration to raise its rotational speed very high and then the energy is sustained in the system as kinetic energy. The quantity of energy stored by a flywheel is in direct relation with its rotational speed[1]. It is in fact directly proportional to square flywheel's rotational speed. One can easily vary flywheel's stored energy by accelerating or decelerating it. With regards to Principle of conservation of energy, Flywheel's speed decreases whenever energy is withdrawn from the system, while if energy is incorporated to the system correspondingly it accelerates the flywheel. A FES system paradigm is typically a flywheel whole shaft is buttressed by special (mechanical roller or magnetic) bearings and is coupled to a motor and/or generator. Special attention are given to bearings selection to minimize bearing losses. Also complete setup may be enclosed by a vacuum tight vessel as shown in figure 1 to reduce air resistance loss.

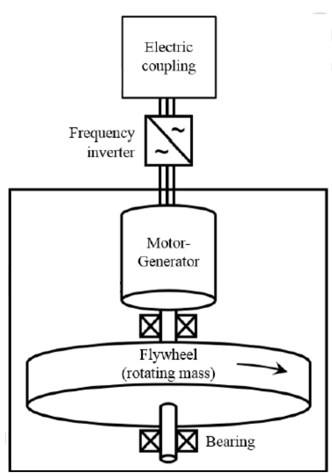

Fig. 1 Diagram of flywheel energy storage system[1]

First generation FES systems employed huge steel flywheel and mechanical bearings disregarding the fact of benefits of using composite materials. Present-day systems incorporates carbon-fibre composite rotors that have properties such as higher tensile strength than steel and which for the same amount of mass, have the capacity to store greatly more energy [2]. To minimise frictional losses, instead of mechanical bearings, magnetic bearings are utilized. Highly developed FES systems have magnetic bearings suspension of the shaft and rotors made composites such as carbon-fiber or glass fibre, which can spin at speed from twenty thousand to over sixty thousand rpm in a vacuum chamber. In Contrast to some other forms of storage, these flywheels can reach their capacity limit very quickly by escalating to a high speed in a few minutes only. The peculiar attribute of flywheel energy storage systems (FESS) is that for a huge number of charge–discharge cycles, at high power, they can be charged and discharged quite easily.

This paper is arranged as follows: Section 2 presents a brief synopsis of different existing Energy storage systems; Section 3 shows different types of bearings to be used in flywheel wheel energy storage system; Section 4 Shows various features and limitations of flywheel energy storage systems; Section 5 shows different applications of Flywheel energy storage system.

II. Energy storage systems

Energy storage is to hold the energy generated previously to utilize it later. Energy is available in many forms which include increased temperature, in the form of radiation, as height potential, chemical form, electrical potential, latent heat and kinetic energy [3]. Energy storages can be classified as direct and indirect storage as shown in the hierarchy below. The most common conventional energy storage used today are Fossil fuel. Energy can be stored mechanically by storing water at higher elevation constructing dams on rivers or by using pumps to store water at height. Other well-known mechanical methods consists of compressing air and running generator, and utilizing flywheels that process electric energy to rotational kinetic energy. Electricity can also be generated using hydrogen fuel cell. Losses due to electrolysis of water and losses due to compression of the hydrogen gas to liquefy it, and conversion to electricity are key hindrance of utilizing hydrogen storage cycle.

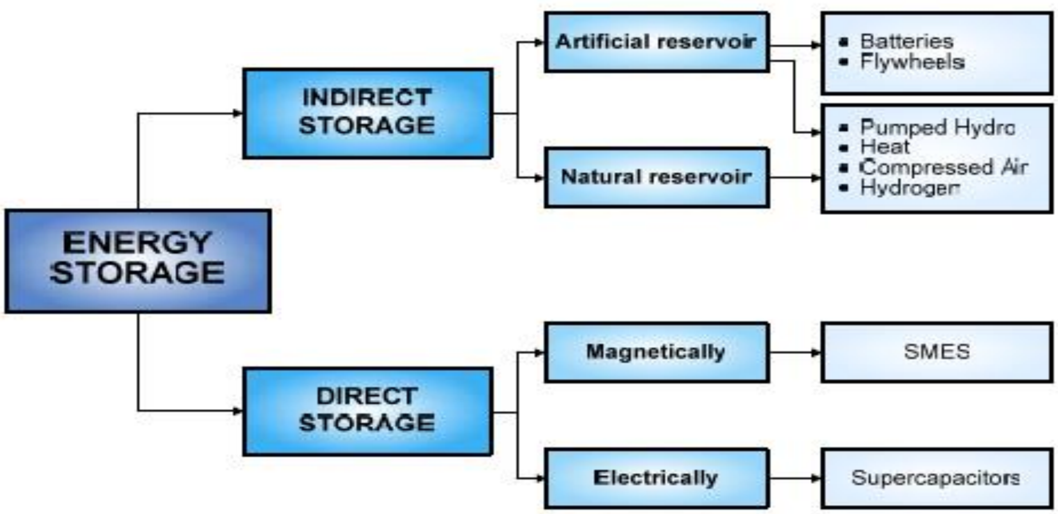

Fig. 2 Types Of Energy Storage systems[3]

Energy can also be stored in a magnetic field. Superconducting magnetic energy storage systems does the same work. The magnetic field is generated by the allowing DC current to flow in a coil of superconducting material. The system is cryogenically protected so the coil's temperature remain within its superconducting critical temperature limits. A Superconducting magnetic energy storage system's paradigm incorporates a superconducting material coil, power adjusting system and cryogenic chamber. The current does not undergo decaying process after the superconducting material coil is fully charged, and thus one can store the magnetic energy for infinite time interval. Super-capacitors have specific energy and energy densities that are near about to ten percent of batteries while their power density is many times higher which provide the advantage of charge-discharge cycles of very small time intervals. Above all, they can withstand greater amount of charge-discharge cycles compared to what batteries can. Batteries growingly subjugate on other energy storage systems[4], but their impact on nature and atmosphere is only insignificantly debated[5]. The reason behind pursuing Flywheel energy storage are first it is a non-toxic and low maintenance system. Second, it has a potential for high power density (W/kg) and high energy density (W-Hr/kg) refer figure below. It also has a tendency to quickly charge/discharge and a cycle life times of greater than 25 years. And above all, it also has a broad operating temperature range.

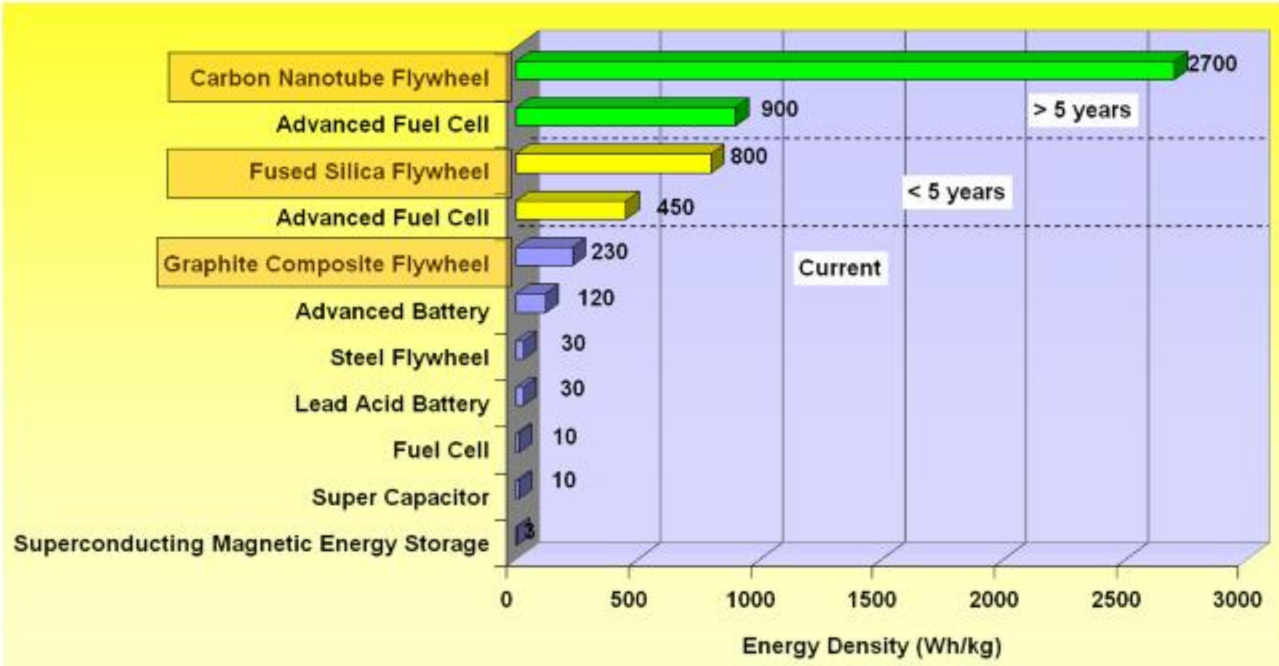

Figure 3 : Comparision of different energy storage systems

III. Bearings in FESS

Bearings are necessary to maintain the flywheel in one place while it is rotating minimizing friction, and to bestow a support mechanism for the shaft on which flywheel is supported. The bearing system can be mechanical or magnetic, depending on the weight, lifecycle life, and lower losses [6]. Gas bearings cannot be used due to the vacuum within the enclosure. Traditionally used mechanical ball have problems like lubricant deterioration over time and greater friction, which is why they were needed to be replaced occasionally and thus now magnetic bearing are being utilized in place of them [7]. There are no losses due to friction in case of magnetic bearings and they don’t even require lubrication of any kind. Active magnetic bearing only require power for energizing themselves and work. There are three main types of magnetic bearings namely Active magnetic bearings (AMB), Passive magnetic bearings (PMB), and Superconducting magnetic bearings (SMB) [7]. A PMB has high stiffness, low cost, and low losses, due to lack of a current. However, it has limitations in providing stability and is usually considered as an auxiliary bearing system [7], [8]. An AMB is operated by the magnetic field produced from current carrying coils controlling the rotor position. It positions the rotor through a feedback system by applying variable forces which are determined based on the deviation of the rotor position, due to external forces. Summing up, system losses are increased in case of Active magnetic bearings considering their cost, enigmatic control system and requirement of energy to work[8]. AMB mass also has a part in FESS standby loss[9]. In order to make sure a superior efficiency of the whole system, a trade-off between speed and losses is necessary. The merits of SMB includes devoid of friction, high speed, longer life, minimal size, and steady working. It can be categorize finest magnetic bearing for application that require high speed as it has the capacity of stabilizing the rotor without external power or a orientation system[10]. While apart from the aforementioned benefits of SMBs; it works at a very low temperature and hence, a cryogenic cooling system is necessary for its operation. This problem has been recently overcome by utilizing high temperature superconductors. However, its very high cost becomes the main demerit [6], [7], [10]. Approximately five percent of the total storage capacity per hour are the parasitic losses one have to incur by using mechanical bearings, for electromagnetic bearings the loss is about one percent [11] and can be further lowered to 0.1% by using HTS bearings [12]. The use of hybrid bearings will reduce the losses and complexity of the control system and also provide a stable and cost effective solution [10]. A close-packed flywheel energy storage system supported with bearings consisting of both mechanical and magnetic was suggested in literature [10]. The levitation required for translation and rotation is handled by mechanical bearing while the levitation required for vertical orientation is retained by the magnetic bearing. In,[9] in order to minimize the expenditure of the cryogenic system required, a hybrid use of SMB and PMB also has been suggested in literature to acquire the benefits of both . The SMB benefits by suppressing the vibrations of rotor while PMB manages the position of the rotor. However, the capability of PMB of hampering the system at higher speeds is still an interest of many researchers.

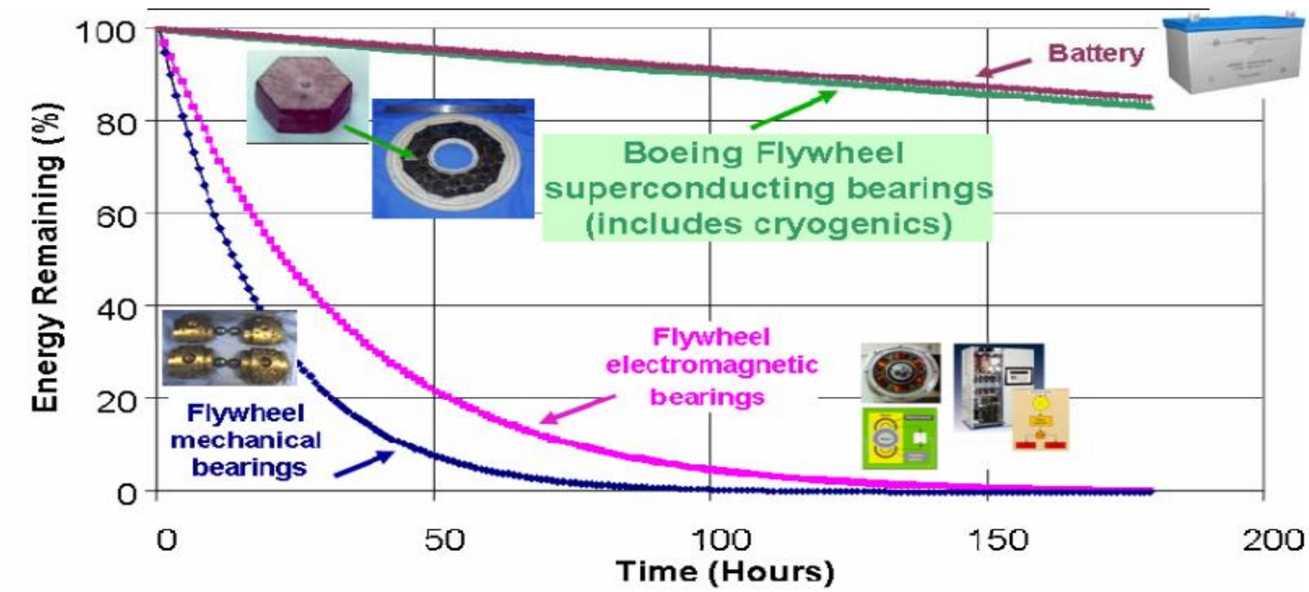

Figure 4: Comparison of FESS with different types of bearings[12]

IV. Features and limitations of flywheel energy storage systems

The essential attributes of flywheels includes their capability to run constantly at high power, and a cycle life of typically of 10^7 cycle [13]. The energy storage is a direct function of its rotational speed which makes quantity of energy storage certain. Sadly flywheels that have a storage of short-term, approximately of some minutes, and a greater quantity of charge–discharge cycles. A crucial advantage of flywheels is that capacity is always clearly known by knowing the rotational speed. Flywheel's minimum and maximum operating speed clearly points out the stored energy or the available capacity of the system.

Steel rotors can store energy per unit mass approximately up to 5 W h/kg, whereas high-speed composite carbon fibre rotors can remarkably store higher energy per unit mass up to about 100 W h/kg [14]. The theoretical maxima for the materials used is much higher than these specific energies. The specific power is directly dependent to the flywheel hub, the specification of motor/generator, and the power electronic interface. However, if one takes the weight of the whole system, considering body, vacuum enclosure and electronic interface into account, then the specific energy and energy of the whole system may be levelled down by at least a factor of 10.

The amount of energy required for its operation is comparatively higher. This is because of the fact that bearing losses and losses in the motor/generator and electric interface losses are prevailing during operation. The higher cycle life of flywheels is one of their important attributes, which does not relay on the rate of charge or discharge. Cycle lifetimes of flywheel typically ranges from of 10^5 up to 10^7. To properly understand the meaning of this, even if the cycling rate is of 1 charge–discharge cycle every 100 minutes; the longest cycling lifetimes will only be over after about twenty years of continuous operation [15]. In most of the application existing now this long life span more than enough.

Figure 5 HIGH SPEED Carbon fibre composite flywheel[2]

In contrast to batteries, Flywheel systems are very environment friendly and create no problems for disposal at end-of-life. Most of the system is made up of steel and other metal materials which comprise of copper and aluminium, which can be recycled and reused utilizing standard established techniques creating no harm to the environment. Composite rotors can also be disposed of in a landfill location without much concern as it do not pollute land. Techniques for reusing composite rotor materials after processing are currently under research, which also include the technique to regain high cost carbon fibre from components whose lifespan is over and scrap from industries.

The major risk during operation is the chance of failure of the rotor due to fatigue, which could be catastrophic because of the sudden and quick outburst of the stored energy in the form of heat and out shooting debris. However, In the case of failure of a composite flywheel rotor, any disaster can be avoided due to the presence of containment chamber, and any gas emissions from the system is just equally harmful as that of the exhaust from an internal combustion engine.

V. Applications of Flywheel energy storage system

The major business area for flywheel systems are uninterruptible power supply systems, power quality improvement technology and traction related applications. According to inspections carried out by Taylor et al. (1999), flywheel energy storage system could generate a cut-throat competition in case of cost with batteries in some UPS applications. Flywheels shares approximately six percent of the 3-phase uninterruptible power supply market. There do exist few uses of flywheel energy storage systems for smoothing the power fluctuations in power generation using wind energy, and new requisites are coming forward for the improvement of stability and safety of wind farms from network voltage dips. Aforementioned applications are particularly compatible with the high-power cycling abilities of flywheels. With on-going research, the duration of energy storage may increase and then ideally flywheels may surpass battries.

In the Aerospace Flywheel Development Program of the NASA Glenn Research Centre, research is going on with an objective to acquire a 5 times increase in the energy stored per unit mass in the present spacecraft and to achieve a 2 times increase in lifespan of battery for low-Earth orbit applications. They have develop a flywheel which can operate at a speed high up to sixty thousand revolutions per minute, hence storing a large amount of energy for about 2 hours. Also flywheels are being given consideration for use in hybrid electric vehicle (HEV) by US DOE HEV program. One theory unites a flywheel with a vehicle engine, which will provide aid during acceleration, and absorbing energy release during braking. Another theory is about replacing batteries by flywheel but one hindrance to it is that the energy density of a flywheel system is too low comparitively.

Figure 6 NASA G2 flywheel for space applications[16]

Flywheels may also be utilize in aircraft launch from the carriers. While presently, steam accumulators are being used to store energy for driving these systems but soon in order to decrease the size of power generation system which are currently sized according to peak power load, flywheel might replace them. The flywheel storage is now designed to minimize the dependency on conventional diesel generators by about forty percent. In addition to that, the FESS has been estimated to run for about fifty thousand cycles and might have twenty-five years of life.

Flywheel energy storage system can evolve as of great significance in automobile industry. After extensive research and testing of its flywheel technology, a leading automobile company has declared that the system might raise fuel economy by about twenty-five percent. The company is now trying to incorporate the Flywheel technology into its production line for mass production. The experimental flywheel rotor is made up of carbon fibre that rotates in a vacuum chamber to decrease losses due to friction. During road testing it was found that when combined with a 4-cylinder engine, the technology can reduce fuel consumption up to 25 percent avoiding using turbo 6 cylinder engine. It has also been found that the system can provide an eighty horsepower boost, which accelerates near about to a 6-cylinder in as quick as five point five seconds.

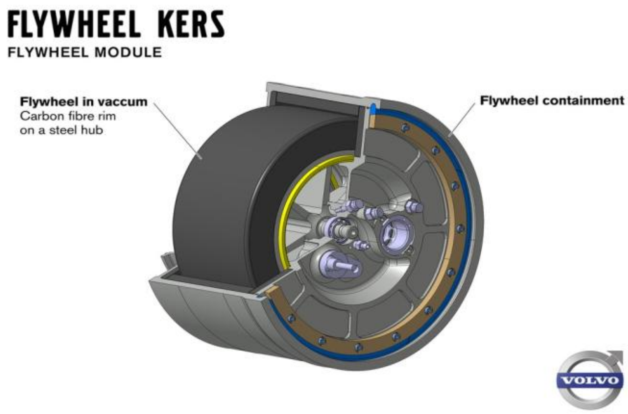

Figure 7 Volvo's flywheel KERS (APPLICATION IN AUTOMOBILE INDUSTRY)

Various funded researches for using the flywheel in renewable energy generation flied such as the smoothing of fluctuations in generated power by wind turbines have been undertaken and some are still on going. The inclusion of flywheel energy storage in a power system with significant penetration of wind power and other intermittent generation has been studied by Nyeng et al. (2008)[17]–[19]. The response to an external fluctuating regulation signal was demonstrated by creating simulation paradigm of a hydropower-plant, flywheel system and power-control system was. In current case, the objective was to use flywheel storage in order to minimize power fluctuations of hydropower-plant, and the demonstration was carried out using simulation. The technology might be further extended and developed to smoothen wind power fluctuations, in the case of a very complicated power system too.

VI. CONCLUSION AND FUTURE PROSPECTS

During the last hundred years, sustainability of energy and safety of environment have led the way for development of Flywheel energy storage system. Due to much research on this technology, it is applicable now, yet the commercialization of this technology is not successful till date, this might be because the technology is still under development process and is not yet mature enough to replace the existing technologies. Also the cost related to it is quite high. Apart from many applications of FESS, the use of this technology in extracting renewable energy such as wind energy is one of the most opportunist topic of research in recent times. Application of flywheel energy storage system such as smoothing of power and balancing of power generation to varied demand yet requires investigation further. The required major development in this technology is to increase the specific energy stored by the flywheel and the time interval for which the energy is stored. Also frictional losses can be further reduced by utilizing levitation technology keeping cost in mind.

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