EERA
European Energy Research Alliance

EERA Joint Program SP4 - Mechanical Storage

Fact Sheet 2 – Nov 2016

Kinetic Energy Storage (Flywheels)

Principle

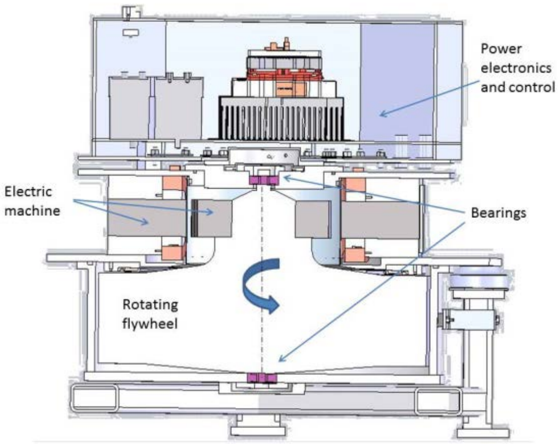

Figure 1. Basic Scheme of a Kinetic Energy Storage device based on Flywheel

A kinetic energy storage system is composed simply by a flywheel driven by an electrical machine (different types of technologies are considered, mainly permanent magnets, asynchronous and reluctance machines), able to work as a motor or a generator, and some power electronics to drive the machine, connecting to the electric grid or the load [1]. When the electric machine (acting as a motor) exerts a positive torque T to the flywheel with moment of inertia J, it increases its rotation speed at a rate T/J, until it reaches maximum velocity, storing a given kinetic energy and getting power from the grid or the load through the power electronics converter. At this stage the energy can be maintained constant at the flywheel by just supplying the idle losses in the machine. For releasing the energy, the electrical machine (acting as a generator) applies a negative torque –T to the flywheel, braking it at a rate – (T/J) and pumping the energy back to the grid or the load where it is connected.

Characteristics

A Kinetic Energy Storage System based on Flywheels is considered as a fast energy storage technology with the main characteristics of high power and energy density, the possibility to decouple power and energy in the design stage, a large number of life-cycles, the possibility to be installed in any location (even on board applications are being considered) and high power but usually low energy compared with some other energy storage devices, are other important characteristics [2][3]. Moreover, flywheels operation is less dependent of the temperature than other storage technologies such as batteries. State of charge (SoC) is also easy to determine since it is directly related to the rotational speed. Finally, the dynamic response is fast and not temperature dependent.

Two main groups of technologies are being developed for flywheels: metallic and compound materials. The first are relatively slow (below 10,000 rpm). The wheel is metallic and often has magnetic levitation systems which offset its weight. These slow storage systems are, in theory, simpler in a technological sense and their main use is in stationary applications, where their weight is not an obstacle. There is also another family of flywheels, rapid ones, whose velocity can achieve 50,000 rpm and which use wheels made of composite materials such as carbon fibers, which offer high levels of mechanical resistance and low density. The elevated cost of the wheel and the difficulty of manufacture mean that its use is restricted in general to applications of limited energy in which the system price is not a critical issue. The greater densities per mass unit are achieved using compound materials (ideally carbon fiber). But if the concern is to achieve energy per volume unit, metals such as steel can be as effective as fibers, remaining much more economical.

Flywheels are better used for higher power levels than batteries and for higher energy levels than supercapacitors. The most common applications

General performance

Typical Power: 100 to 1500 kW

Energy capacity: 10 -100 kWh

Speed range: 5000 -30000 rpm

Cycle efficiency: 80%

Discharge time: secs-minutes

Response time: milliseconds

Technical lifetime: 20 y

Energy to Power ratio: flexible

Main applications

- Transportation: to reduce CO_2 emissions, increase efficiency, reduce consumption peaks, energy savings and power line voltage stabilization.
    - Electric and hybrid automobiles (cars and busses)
    - Light trains and underground transportation [4]
    - Ferries
- Renewable energy generation: to ensure the grid stability, frequency regulation and voltage support.
    - Wind energy [5]
    - Solar PV energy
    - Wave and tidal energy
    - Smart Grids
- Industry applications: to ensure uninterrupted power supply, increase efficiency and reduce load peaks.
    - UPS [6]
    - Cranes and elevators

are: energy saving in transportation, frequency regulation and stability in electric grids and micro grids, elimination of power fluctuations in renewable generation and increase of efficiency or reduction of load peaks in industry applications.

Maturity Level

Flywheel is a mature technology completely introduced in the industrial market. More than 20 manufacturers have been identified and many research centres are focused on this technology as well developing prototypes. However, some technological aspects need to be improved both in manufacturing and equipment cost in order to be competitive with other energy storage solutions. Technology Readiness Level (TRL) has reached the maximum level 9 in some commercial products. However it can be found many alternative solutions or prototypes in the range of TRL from 3 to 8, still in development. The costs varies depending on the power and energy level, being mainly in the ranges of 200-700 €/kW and 1000-3000€/kWh.

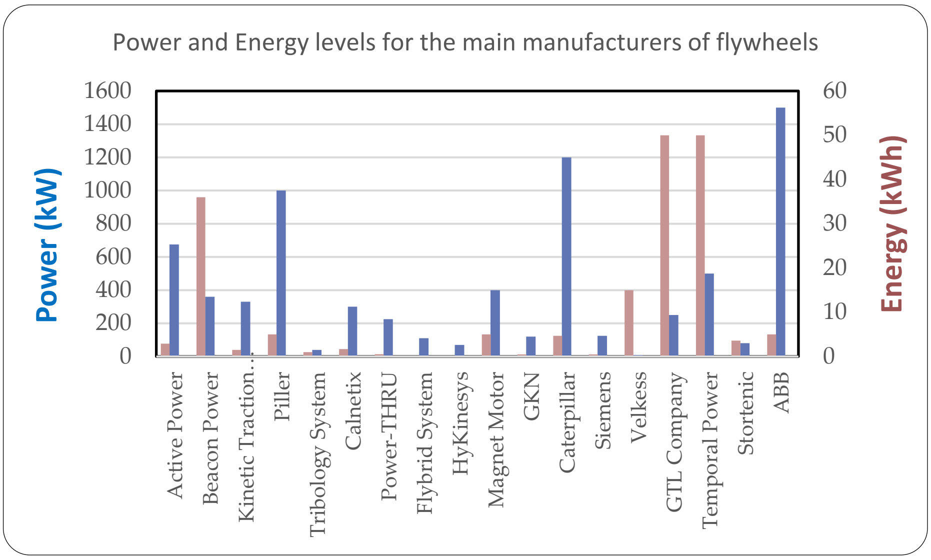

Figure 2. Main Flywheel manufacturers in the market.

Potential, barriers and challenges

The technology of flywheels present several advantages compared with other conventional energy storage alternatives, such as: a fast power response, high power density, high number of operation cycles during its life, higher than other fast energy storage devices (supercapacitors), flexible power/energy ration since they depend on machine and flywheel dimensions, and high efficiency when storing and releasing power.

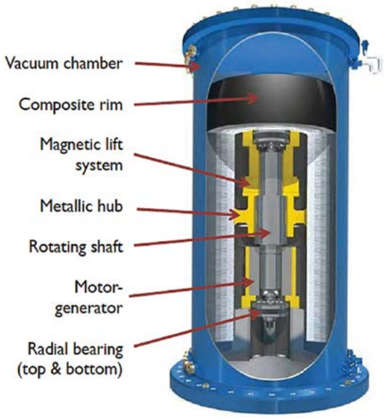

Figure 3. Beacon Power flywheel.

The main barriers of this technology are the cost of the flywheel materials, specially carbon composite and glass fiber; the self-discharge power losses released while the system is not exchanging power with the grid, higher than in other storage alternatives; and the mechanical complexity that is very critical especially in high performance flywheels.

The main challenges in a kinetic energy storage are:

- Flywheels with a higher energy density at a lower cost by improving the manufacturing procedure (especially carbon composite and glass fiber flywheels but also metallic)
- Electrical machines more reliable, with a high quality torque to reduce the bearings requirements and lower power losses to ensure continuous operation with a simple cooling system
- Research on electromagnetic bearings to achieve higher rotational speeds to ensure robustness and stable operation in this application.
- Improve the power electronics performance in terms of higher switching frequency and lower power losses. Faster digital control devices are also required.

Potential

Fast power response
High life-cycles
Flexible power/energy ratio
High efficiency

Barriers

Flywheel materials cost
Mechanical complexity
Self discharge power losses

Challenges

Increase energy density
Increase electrical machine speed and reliability
Improve power electronics performance
Faster digital control devices

References

[1] Petar J. Grbovic, "Energy Storage Technologies and Devices" Wiley-IEEE Press, 2014.
[2] G. Genta. Kinetic energy storage : theory and practice of advanced flywheel systems. London ; Boston : Butterworths, 1985.
[3] D.Bender . Flywheels: An Overview of Applications and Technology. Technical Report CTO Helix Power Corporation
[4] M.Lafoz; L. García-Tabares; C. Vázquez. Flywheels Store to Save: Improving railway efficiency with energy storage. Electrification Magazine, IEEE. 1 - 2, pp. 13 - 20. Power and Energy Society, 12/2003. ISSN 2325-5897.
[5] H. H. Abdeltawab and Y. A. R. I. Mohamed, "Robust Energy Management of a Hybrid Wind and Flywheel Energy Storage System Considering Flywheel Power Losses Minimization and Grid-Code Constraints," in IEEE Transactions on Industrial Electronics, vol. 63, no. 7, pp. 4242-4254, July 2016.
[6] Frequency regulation in a wind–diesel powered microgrid using flywheels and fuel cells.K. V. Vidyanandan; Nilanjan Senroy. IET Generation, Transmission & Distribution. 2016, Vo.l 10, Issue: 3 Pages: 780 – 788.

Contact

EERA Mechanical Storage
Atle Harby, Coordinator: Atle.Harby@sintef.no
Marcos Lafoz, Flywheels: Marcos.Lafoz@ciemat.es

European Energy Research Alliance (EERA)
Rue de Namur, 72
1000 Brussels | Belgium