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Using MRI devices for the energy storage purposes

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Využitie MRI zariadení pre účely úschovy elektrickej energie

It is well known, that the electrical energy storage in the large scale is basically a difficult process. Such a process is connected with energy losses, as most frequently it is the conversion of electrical energy into another form, for example mechanical, and then back to the primal electrical form. Though, the SMES technology offers the energy storage in an unchanged form, which is advantageous primarily in the achieved efficiency. The magnetic resonance imaging (MRI) devices, commonly used in the medical facilities are based on the basis of superconducting magnet. After its rejection from operation, (basically caused only by its „software fustiness“ and not by functional faults), there is a possibility of using such devices for the energy storage purposes. Additionally, such a technology of storage is also ecological. A research project is running at the Faculty of Mining, Ecology, Process Control and Geotechnologies (F BERG), the Department of Business and Management, in the field of using rejected MRI for energy storage purposes.

Key words*: cryogenics, energy storage, MRI, renewable energy, SMES, superconducting magnet*

Introduction

Energy storage technologies are strategic and necessary component for the efficient utilization of renewable energy sources and energy conservation. We can categorize the energy storage technologies by the technology type as:

- Electrical (capacitors, SMES),
- Mechanical (flywheels, compressed air),
- Electro-chemical (batteries),
- Chemical (FC),
- Thermal (steam etc.).

The technical capability and the commercial availability of energy storage types is shown in Fig. 1.

The electric energy may be stored in a number of ways. As an electric charge in capacitor; as the chemical energy in accumulators and explosives, the nuclear energy in reactor, the kinetic energy in mechanical systems and as the potential energy in compressed gases [1].

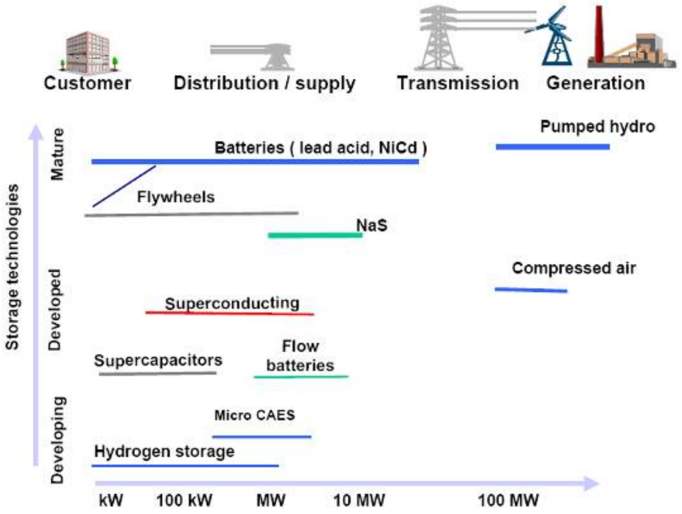

Fig. 1. Technical capability and commercial availability of energy storage types [8].

Energy is extracted from natural resources such as coal, oil, natural gases, hydraulic powerplants, fusion of atomic nuclei, etc. Since it is not feasible to generalize the most perfect method of energy storage, regions in which particular forms of energy storage are suitable must be defined [1].

One of the major issues to be considered in evaluating energy storage options, is the amount of energy that is lost in the storage process. Below are estimates of the typical energy efficiency of four energy storage technologies:

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- Batteries ~75 %
- Compressed air ~80 %
- Flywheel ~ 80 %
- SMES ~ 90 %

MRI devices

Magnetic resonance imaging (MRI), is a method used to visualize the inside of living organisms as well as to detect the amount of bound water in geological structures. It is primarily used to demonstrate pathological or other physiological alterations of living tissues and is a commonly used form of medical imaging. The devices used in medicine are expensive, costing approximately $1 million USD per Tesla for each unit, with several hundred thousand dollars per year upkeep costs. Common magnetic field strengths range from 0.3 to 3 Tesla, although research instruments range as high as 20 Tesla. One of the advantages of an MRI scan is that, according to a current medical knowledge, it is harmless to the patient. It utilizes strong magnetic fields and non-ionizing radiation in the radio frequency range [12].

Generally, the MRI devices are working on the basis of superconducting magnet. This fact means that every MRI device can be used as a SMES with some modifications. In the Fig. 2, 3 and 4 there are illustrated some MRI devices suitable for SMES.

Fig. 2. Typical MRI device[10].

Fig. 3. MRI device at the F BERG laboratory.

Fig. 4. MRI device with charging unit and liquid He dewars at the F BERG laboratory.

Superconducting magnetic energy storage (SMES)

Energy can be stored in the magnetic field of a coil. A reasonable field generated by a superconducting coil (~15 T) gives an energy density of ~ 90 J.cm^{-3}. Energies in the order of MJ to GJ can be discharged suitably in miliseconds to several seconds depending on the choice of the load, the switching mechanism and the superconductor used in the storage coil. A combination of inductive storage coils and rectifier inverters is suitable for the energy pumping in electrical networks [1].

SMES stands for the Superconducting Magnetic Energy Storage. It is technique used to store an electrical energy. It is using magnetic field to store energy by the effect of superconductivity. Magnetic field is generated by DC current flowing through the cooled superconducting wire. Block diagram of the energy storage system is shown in Fig. 5.

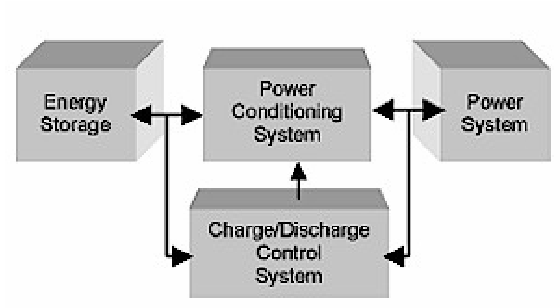

Fig. 5. Block diagram of the energy storage system [9].

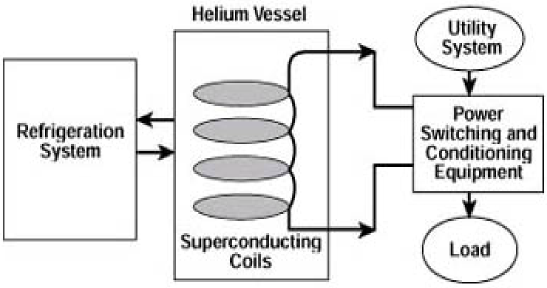

Fig. 6. SMES scheme [6].

Generally, SMES systems are composed from 4 main parts:

- Superconducting magnet,
- Refrigeration system,
- Power conditioning system (PCS),
- Controller.

In Fig. 6, a simple block diagram of the SMES system is shown.

The coil of superconducting magnet is made from asuperconducting wire (alloy of Niobium and Titanium). It can be made out as a solenoidal coil or a toroidal coil. The coil is cryogenically cooled by liquid Helium in LTS (low temperature superconductivity) applications, or by liquid Nitrogen in HTS (high temperature superconductivity) applications. In Fig. 7, the crossection of the solenoidal superconducting magnet is shown.

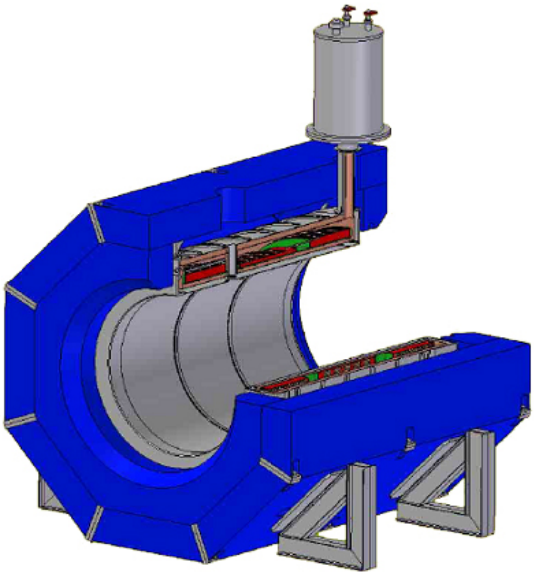

Fig. 7. The crossection of the superconducting magnet [3].

Simply, the energy stored in the coil is given by the equation:

$$E = \frac{1}{2}.L.I^2, \qquad (1)$$

where E – energy [W.s],
L – inductance [H],
I – DC current [A].

The refrigeration system is responsible for cooling the coil to a required temperature (LTS or HTS temperatures) to make it superconducting. The cooling medium is liquid Helium or liquid Nitrogen.

The power conditioning system (PCS) is responsible for transforming the DC energy from the coil into the required 3 phase AC energy, and also for charging the SMES. PCS cost is significant and it can be greater than 25 % of the overall energy storage system. In the case of SMES, there are several topologies available as the Current Source Inverter topology (CSI) or the Voltage source Inverter topology (VSI).

The second major design decision is the use of either a parallel or series configuration for the PCS. The basic topologies are shown in Fig. 8.

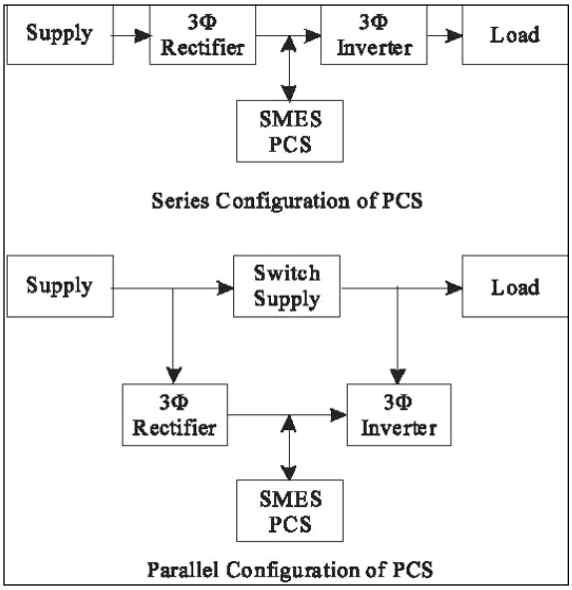

Fig. 8. Series and Parallel configuration block diagrams of a PCS [2].

The advantages and disadvantages of each system is much more self-evident than that of the inverter choice. The parallel configuration benefits from the fact that the SMES system sits idle for long periods between events. Hence the devices used for the rectifier and inverter need to only be rated to perform during the event time (<1s). It can also be attached to an existing main supply, without the need to disturb the already installed equipment. However, the fault detection and switch control system required for this configuration is very complex. The control algorithm almost needs to pre-empt a fault to effectively mitigate it. The series configuration does not require the complex fault detection, and needs only to maintain the voltage on the DC bus. It also provides the advantage that the main supply is passed through the inverter so that any distortion of the supply up-line can be removed by the system [2].

The controller is the part responsible for controlling all other parts of the system as:

- measuring the parameters of utility grid,
- controlling the PCS,
- controlling the charging of the SMES,
- controlling the cryogenic system.

In case of need, it gives a signal to discharge the stored energy into the grid. The application of the SMES systems is following:

- Back-up power supply,
- Grid parameter adjusting (voltage sags, variations in frequency),
- Power system stability.

Advantages of SMES technology are:

- SMES is environmentally friendly.
- Superconductivity does not produce chemical reaction.
- No toxins produced in the process.
- High efficiency (cca 90 %).
- High capacity (it depends on the magnet and load needs).
- Short charging time (few minutes).
- Very fast response (tens of miliseconds).
- Long lifetime of the system.
- Minimal need of maintenance.
- Low operational costs (actually only for the cryosystem maintenance).

On the other hand, the disadvantages of SMES technology are:

- High investment costs because of superconducting magnet with the cryosystem and the power conditioning system.
- Short carryover time (but it depends on load).
- Need of permanent cooling.
- Size issues in the case of high capacity system.
- Lorentz forces issue (“earth supported” coil could be the solution for large scale systems).
- Possible health effects because of high magnetic field (in the case of large systems).

In Fig. 9 possible applications of SMES technology are shown.

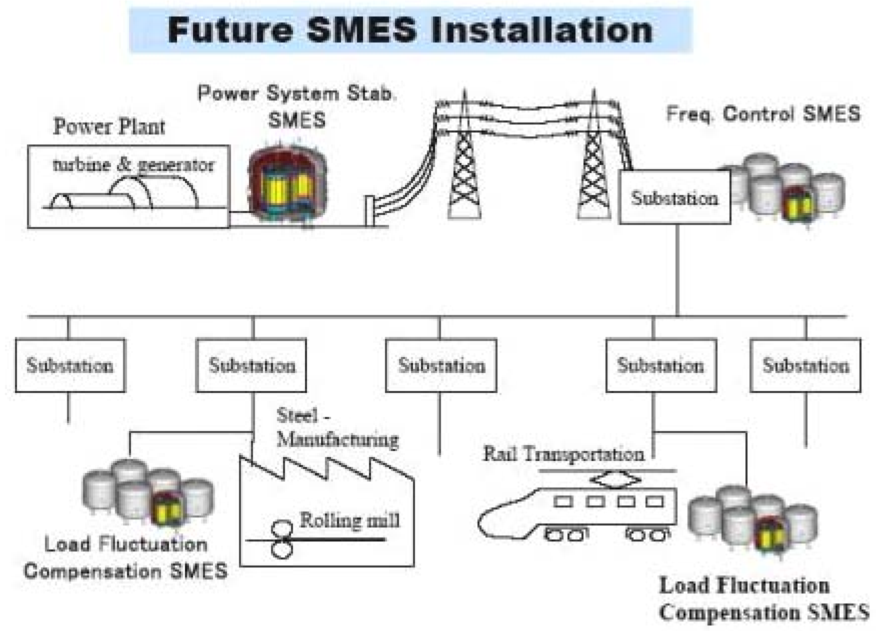

Fig. 9. Example of SMES application [7].

SMES types

Various SMES devices use the very same technology, but have a different use. Basically, the difference is in the stored energy amount and in the use of system as:

- Large scale SMES
- Micro SMES
- D-SMES (Distributed SMES)

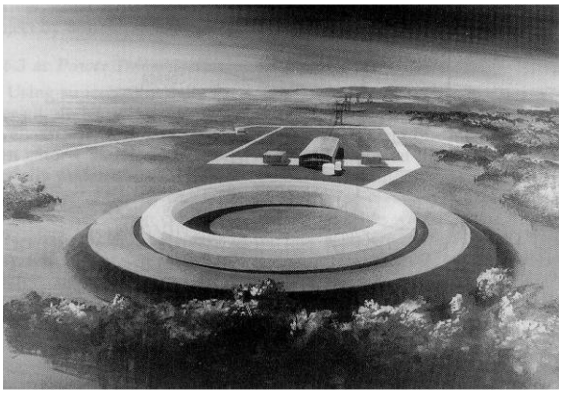

Fig. 10. Large scale SMES [5].

In Fig. 10 is shown the 20 MW.h toroidal large scale system Raytheon Ebasco. In Fig. 11, the 2 MJ micro - SMES system Accel is shown. In Fig. 12, a typical distributed SMES for protecting the power system from instability is shown.

History of SMES

The initial proposal of a SMES was brought up by Ferrier in 1969, who proposed the construction of a large toroidal coil capable of supplying diurnal storage of electrical energy for the whole of France. However, the cost would have been too high and the idea was not pursued. In 1971 a research began in the US at the University of Wisconsin to understand the fundamental interaction between the energy storage unit and the electric utility system through a multiphase bridge. This led to a construction of the first SMES devices. Hitachi built and tested a 5 MJ SMES system in 1986, which was connected to the 6.6 kV power line of the Hitachi Works to evaluate the transmission line stability. In 1998, a 100 kWh SMES was constructed in Japan by the ISTEC program.

It can be seen that SMES systems are improving rapidly. In the future they can be used as an effective way of storing large amounts of energy.

Fig. 11. Micro-SMES Accel [4].

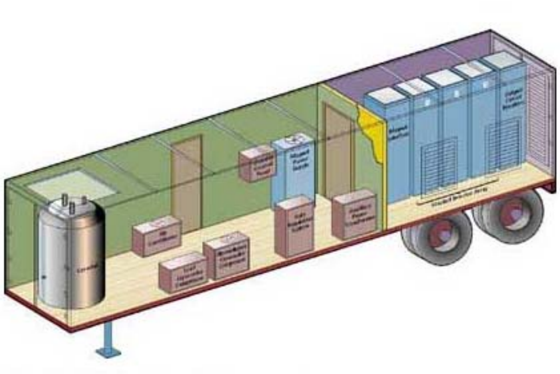

Fig. 12. A typical distributed SMES unit [11].

MRI device stored energy calculation

Fig. 13. Calculated MRI device with liquid helium dewars.

There is an rejected MRI device available at the FBERG laboratory at the Technical University of Košice for research. In Fig. 13, the mentioned MRI device for which the calculations have been made is shown. Below are the approximate possible stored energy calculations:

MRI device specifications are:

- Field = 0,5 T,
- length= 1,8 m,
- d_{outer} = 1,8 m,
- $d_{central}$ = 1,2 m

Then, the possible stored energy according to the equation (1) mentioned above is approximately at least 0,8 MW.s. It means that this device is capable to supply the load with 800 kW power for 1 second, or for example the load with 10 kW power for 80 seconds, etc.

Conclusion

It seems to be a good solution from the investment aspect of obtaining the new SMES system, to use the rejected but still functioning superconducting magnet from common MRI devices used in the medical facilities. This is an advantage over obtaining the whole new SMES system due to the fact that only some modifications has to be done to the system as PCS construction according to the needs of application, etc. In this manner, it is possible to reduce the investment costs paid for such a system significantly.

Resume

Energy storage is an important process, where a key question in the technology type selection is the overall efficiency, response time, investment and operational costs. The SMES technology provides power conditioning, as well as the possibility of energy storage without the need of conversion into other forms. From the view of investment, the usage of rejected but functioning MRI devices appears to be advantageous, with some modifications, due to the absence of real PCS. Although, the SMES systems are still a very good experimental form of energy storage, they hold promise, especially for the power conditioning and the back-up supply. They have an advantage over the conventional energy storage systems in that they do not use hazardous chemicals, which are difficult to dispose of and recycle. However, the SMES still require the liquid helium for an efficient operation at 1.8K- high temperature superconductors (up to 160K) are not yet suitable. There is a possibility, though, as the research on the high temperature superconductors continues, that one day a room temperature SMES becomes available.

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