SMES MRI Device – Alternative for Ecological Energy Storage

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ABSTRACT

It is well known, that the electrical energy storage in the large scale is basically difficult process. Such a process is marked by the energy losses, as the conversion of electrical energy into another form is most frequently.

Though, the superconducting magnetic energy storage (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, there is possibility of using such ecological devices for energy storage purposes, after its rejection from operation.

The paper gives a short review of current UPS and energy storage technologies, SMES applications and short section about a research project running at the Faculty of Mining, Ecology, Process control and Geotechnologies at Technical University in Košice, Slovakia, which deals with using rejected MRI for electrical energy storage and backup power supply purposes.

Keywords: SMES, UPS, MRI, superconducting magnet, energy storage

1 INTRODUCTION

Energy storage is important process, where the key question in the technology type selection is the overall efficiency, response time, investment and operational costs. SMES technology provides power conditioning, as well as possibility of energy storage without the need of conversion into the other form.

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

- Electrical (capacitors, SMES)
- Mechanical (flywheels, compressed air)
- Electro-chemical (batteries)
- Chemical (fuel cells)
- Thermal (steam)

Electrical energy may be stored in a number of ways such as an electric charge in capacitor, chemical energy in accumulators and explosives, kinetic energy in mechanical systems and a potential energy in compressed gases. Energy is extracted from natural resources like coal, oil, natural gas, 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 the four energy storage technologies:

- Batteries ~75%
- Compressed air ~80%
- Flywheel ~80%
- SMES ~95%

2 SUPERCONDUCTING MAGNETIC ENERGY STORAGE (SMES)

The most frequent superconducting devices are superconducting magnets, which are used to generate very high magnetic fields. The main advantage of superconducting magnet comparing to electromagnets with conventional winding is its low energy consumption, small size and weight

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 research began in the US at the University of Wisconsin to understand the fundamental interaction between an energy storage unit and an electric utility system through a multiphase bridge. This led to the construction of the first SMES devices.

Later, 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 transmission line stability. In 1998, a 100 kW.h 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.

Various SMES devices use very similar technologies, but have different use. Basically, the difference is in the stored energy amount and in the use of system such as:

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

There are two main options of using superconducting magnets, the first is to release stored energy rapidly into the resistive load (lower stored energies) or slowly into the grid (higher stored energies). The releasing of energy is controlled by high-current superconducting switches.

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 the inductive storage coils and rectifier inverters is suitable for energy pumping in electrical networks [2].

Magnetic field is generated by DC current flowing through the cooled superconducting wire. Block diagram of the energy storage system is shown in Figure 1.

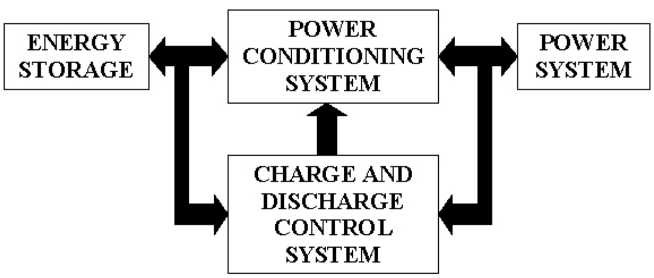

Figure 1: Block diagram of the energy storage system.

Generally, SMES systems are composed of 4 main parts:

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

In Figure 2. is shownn the simple scheme of the SMES system

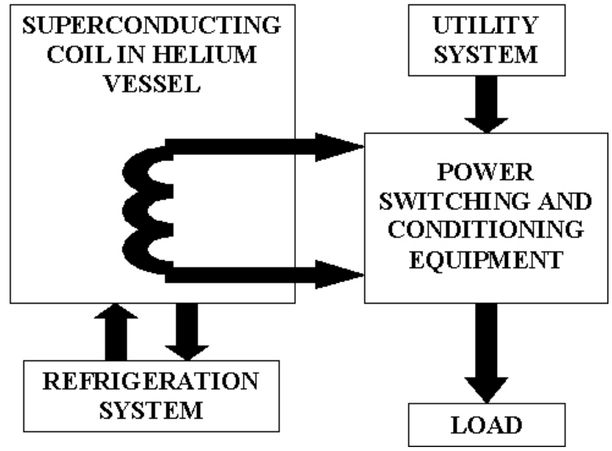

Figure 2: SMES scheme.

Coil of superconducting magnet is made from superconducting wire (alloy of Niobium and Titanium). It can be made out as solenoidal coil or toroidal coil. Coil is cryogenically cooled by liquid helium in LTS (low temperature superconductivity) applications, or by liquid nitrogen in HTS (high temperature superconductivity) applications.

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].

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

Power conditioning system (PCS) is responsible for transforming the DC energy from coil into the required 3 phase AC energy or other and also for charging the SMES. PCS cost is significant and it can be greater than 25% cost of the overall energy storage system.

There are two basic topologies available to choose from as Current Source Inverter topology (CSI) or Voltage Source Inverter topology (VSI) for PCS. The second major design decision is the use of either a parallel or series configuration for the PCS. The basic topologies are shown in Figures 3 and 4.

NSTI-Nanotech 2009, www.nsti.org, ISBN 978-1-4398-1784-1 Vol. 3, 2009

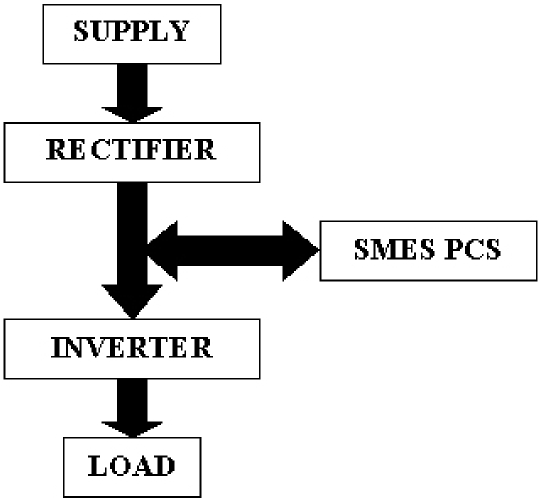

Figure 3: Series configuration diagram of a PCS.

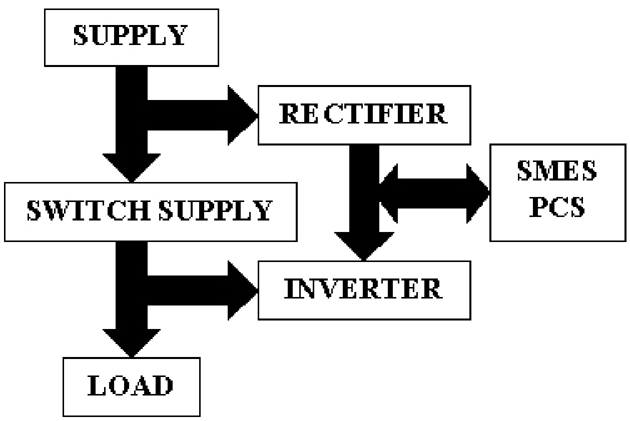

Figure 4: Parallel configuration diagram of a PCS.

The advantages and disadvantages of each system are 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 mains supply is passed through the inverter so any distortion of the supply up-line can be removed by the system.

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 the case of need it gives a signal to discharge the stored energy into the grid. Application of the SMES systems may supply as:

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

In Table 1 possible applications of SMES technology are shown.

Process	**SMES application**
Electrical energy generation	Power system stability
Electrical energy transmission	Frequency control
Electrical energy consumption	Load fluctuation compensation

Table 1: Examples of SMES application.

Advantages of SMES technology are:

- SMES is environmentally friendly
- Superconductivity does not produce chemical reaction
- No toxins produced in process
- High efficiency (95 %)
- High capacity (it depends on magnet and load needs)
- Short charging time (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 cryosystem and power conditioning system
- Short carryover time (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

3 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. The devices used in medicine are very expensive, costing approximately 1 million USD per Tesla. Common magnetic field strengths range from 0.3 to 3 Tesla, although research instruments range as high as 20 Tesla.

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, after its rejection from operation.

In the Figure 5, there is illustrated MRI device from General Electric suitable for SMES, at the Faculty of Mining, Ecology, Process Control and Geotechnologies at Technical University in Košice, Slovak Republic.

Figure 5: SMES MRI device at the F BERG.

4 EXPERIMENTAL RESULTS

The unique SMES system was constructed by using of rejected MRI as an alternative for electrical energy storage.

This system consists of a 1,1 MJ NbTi magnet in the form of solenoidal coil with inductance of 2,2 H. Its helium vapor cooled leads support 1.5 kA. Table 2 contains important data of our equipment.

Inner radius of coil /mm/	600
Outer radius of coil /mm/	1300
Length of coil /mm/	1700
Rated stored energy /MJ/	1,1
Limited stored energy /MJ/	2,5
Inductance /H/	2,2
Limited critical current /A/	1500

Table 2: Data of SMES MRI system.

The simulation of action was carried out with 100 A charging current and next discharging to discharger board /12 halogen bulbs /.

Time dependency of discharging current rundown is shown on Figure 6.

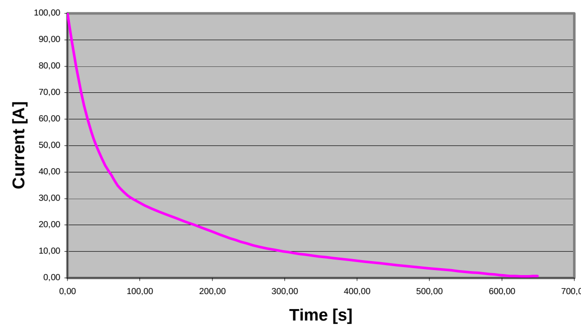

Figure 6: Time dependency of discharging current rundown.

5 CONCLUSION

From the view of investment, the using of rejected but functioning MRI devices from medical facilities appears to be advantageous, with some modifications due to the absence of real PCS. In this manner, it is possible to reduce the investment costs paid for such a system significantly. Although the SMES systems are still very much an experimental form of energy storage, they hold promise, especially for power conditioning and back-up supply. They have the advantage over conventional energy storage systems - they do not use hazardous chemicals, which are difficult to dispose of and recycle. The SMES still can be require in the pumped liquid helium for efficient operation at 1.8 K with about twin critical current or can be used high temperature superconductors. This is a possibility, though, as research on high temperature superconductors continues, that one day a room temperature SMES becomes available.

6 REFERENCES

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NSTI-Nanotech 2009, www.nsti.org, ISBN 978-1-4398-1784-1 Vol. 3, 2009