Review on Superconducting Materials for Energy Storage Applications

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ABSTRACT

In direct electrical energy storage systems, the technology for development of Superconducting magnetic energy storage (SMES) system has attracted the researchers due to its high power density, ultra-fast response and high efficiency in energy conversion. Hence, SMES is potentially suitable for short discharge time and high power applications. In the present chapter, a detailed description on construction and working of SMES is presented. Moreover, the superconducting wires and tapes used for the construction of superconducting magnets are described. In addition, the future application of the SMES in the electrical power grid is explained in detail.

INTRODUCTION

In present scenario, the demand for power requirements are increasing drastically. Due to electrical power losses from power generation to usage, the power requirements can't able to meet demand. During the power distribution, because of heat losses ($\dot{Q} = i^2 R$) the power losses are approximated as 40%. So, new developments in technology is needed to make power more qualitative during transmission and distribution. ***Superconductivity*** is better technology with fewer losses compared to traditional transmission and power distribution system.

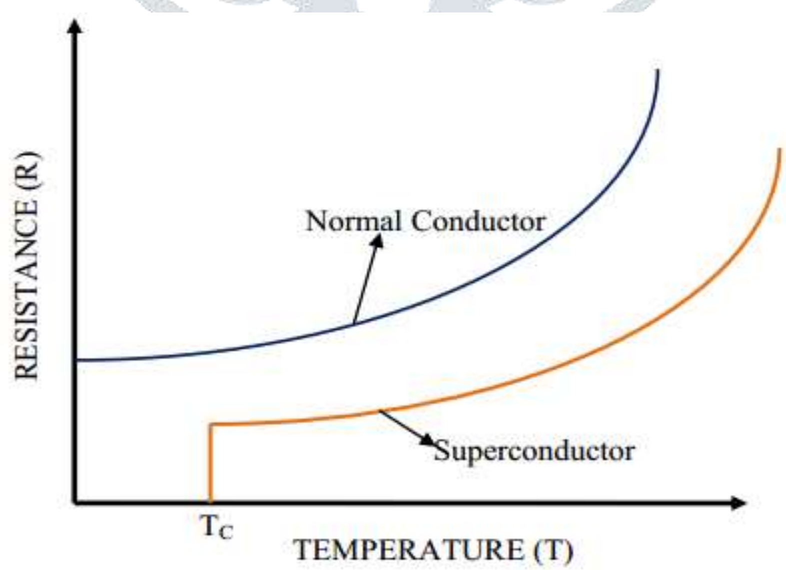

Figure 1 Resistance Vs Temperature comparison for normal and Superconductor

H Kammerlingh Onnes is a Dutch Physicist, discussed about a concept called Superconductivity in 1911. Superconductivity is "the zero resistance offered by any conductor while the flow of electrons through it at *zero absolute temperature." Onnes conducted experiment with decreasing pure Mercury temperature below to its critical temperature. At 4.2K resistance of Mercury became zero and Superconductivity is attained.*

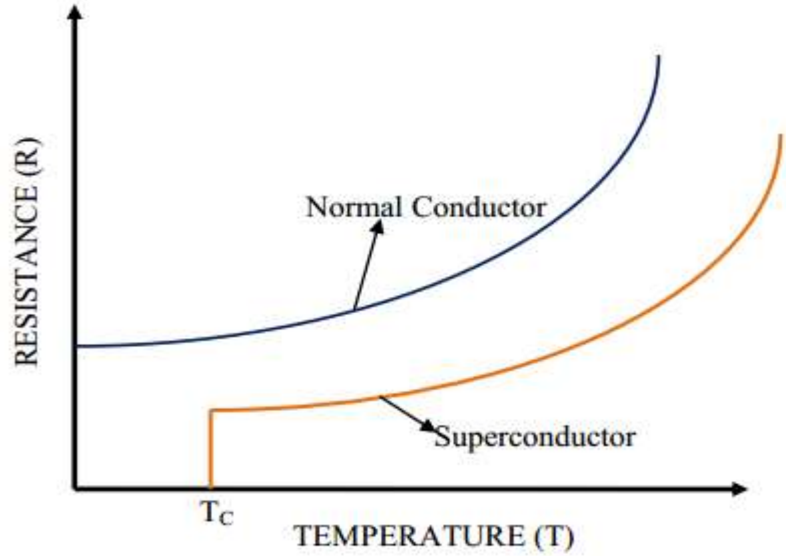

Figure 1 shows Temperature and Resistance comparison for normal conductor and Superconductor. From the figure the resistivity at critical temperature of Superconductor became zero.

Superconductivity is the phenomenon where the material/conductor starts expelling the magnetic field. In other words, it is also defined as state of almost zero electrical resistance of the material. This phenomenon can be observed when the material is maintained at extremely low temperature, also called as Cryogenic temperature, by coolants or cryogenic fluids.

Superconductivity is associated with three basic characteristic properties which are critical temperature, critical current and critical magnetic field. Critical Temperature is the temperature till the material exhibits state of superconductivity. Critical current is the maximum current carried by the material maintaining superconductivity.

Materials exhibiting superconductivity expels the magnetic lines of forces. However, when the value of magnetic field is increased beyond a certain limit, the magnetic field starts to penetrate inside the material. This phenomenon is called as pinning and the maximum value of magnetic field expelled by the superconductor is the critical magnetic field.

Superconductors posses an excellent property of handling larger transport current and hence can be useful in electrical industries as larger currents can be transferred with decrease in overall size of the conductor. Several machines have been developed on this physical phenomenon such as Superconducting Motor, Superconducting Transformer, Superconducting cables and Superconducting Magnetic Energy Storage Devices.

LITERATURE REVIEW

Hayashi et al 2006 [1] investigated on reducing the price of the SMES of 2.9 MJ capacity solenoid at an operating current of 9.6 kA. Further, a line with 6 kV distributions was compensated in 16.6 ms in active as well as reactive powers which can be used in practical large scale SMES.

The thermal run away of the SMES is studied by **Seong et al 2007** [2]. It is observed that for the 4-ply conductor the properties such as mechanical and electrical are increased. There was a slight change in the temperature and the thermal run away is at 400A. The temperature also increased due to the eddy losses by radial slitting. At 600kJ the eddy currents are very high for the conductor.

The new model of PSCAD/EMTDC to increase the voltage sag compensation as well as the currents due to the harmonics in the SMES are studied by **Kim et al 2008** [3]. The power supplied is DC and the coils made of both HTS and LTS are connected to the system. It is observed that response time is increased during the charging and discharging of the SMES.

The stability of SMES is measured by varying the temperature, charging and the discharging is measured by **Kim et al 2009** [4]. Further, the accuracy to decrease the eddy losses during transmission, magnetization losses due to current flow and internal energy due to storage during experimentation is measured.

For the WPGS connected to grid with single, double magnets of SMES fir stabilizing the frequency is studied by **Kim et al 2010** [5]. Dual magnet is better than the single magnet SMES during frequency stabilization. In future by varying the magnets critical currents, no turns of the coil and the superconducting wire length the experimentation is to be done.

The scheme for predicting the power oscillations was studied by **Yao et al 2016** [6]. During the connection between the interconnected grids and smart grids are suppressed. To calculate the optimized control an approach of control constrains in SMES is studied.

Zhao et al., (2017) [7] investigated AC losses for superconducting wire having twists using H formulation in FEM software. In this work, AC losses due to transport current and magnetic field profile was simulated along with the estimation of effect of pitch length on AC losses. It was concluded by the authors that the effect of transverse magnetic field on AC losses is more as compared to effect of longitudinal magnetic field. Also larger the pitch length assumed, larger was the AC losses.

Muzaffer Erdogan (2016) [8] proposed a novel method to estimate propose AC loss for power transmission cables using FEM software Comsol Multiphysics. The cable is assumed to have two layers in which current is equally distributed. Therefore, application of this model where two coaxial cylindrical tubes are there, the AC loss prediction came out to be in good agreement with analytical results by Duoblock model.

Y.D Agassi, (2015) [9] computationally investigated AC losses in superconductor electric field for a slab geometry carrying parallel AC magnetic field. It was reported that the results obtained were in good agreement with BSCCO data and with critical state model

Xu et al., (2015) [10] numerically and computationally investigated the distribution of AC loss for a storage superconducting magnet working on different operating conditions. These conditions are based on commercial Finite Element software as well as on properties of Bi-2223 tape. In this study, using Analytical results, AC loss was estimated which were verified with the computational results obtained.

Otabe et al., (2013**)** [11] numerically estimated AC losses in superconductor wire with ripple current. It was reported by the authors that the value of AC losses increases with the value of direct current for strip superconductor. It was also recommended that cylindrical hollow structure will be ideal for reduction in AC losses.

Amemiya et al., (2013) [12] numerical electromagnetic field analyses were made for two-layer power transmission cables consisting of coated conductors with spiral geometry. The model for numerical electromagnetic field analyses, considering the spiral geometry of coated conductors in a two-layer cable, was validated successfully by comparing the calculated ac losses with the measured ones. The ac loss in a cable distributes along the cable axis, because the relative positions between inner-layer coated conductors and outer-layer ones vary along the axis. The spiral pitches of layers in a cable influence the current distribution between layers, and, hence, influence the ac loss of the cable. It should be noted that the uniform current distribution would not always minimize ac losses.

Zhao et al., (2011) [13] reported AC loss of HTS pancake coil measured by electrical method maintained at liquid nitrogen temperature. Numerical analysis was performed on Matlab and the theoretical and measured results were compared.

Coombs et al., (2010) [14] focused on computational H formulations to calculate AC loss for real life applications. There are several factors such as quality of mesh, order of element, and thickness of the tape, that affect the AC loss calculations and the time required to solve the computational analysis. Therefore the effect all of these factors was evaluated and an optimal settings of the model was determined that provides fast and accurate results. Computational results proved that AC loss increases with increase in the transport current and the applied magnetic field for single tape carrying current as well as for stack of tapes kept in magnetic field.

CONCLUSIONS

There are several prominent issues associated with SMES such as design related issues of superconducting coils, cooling up components of SMES, AC losses in superconducting tapes etc. Therefore, the available literature related to Superconducting Magnetic Energy Storage Devices can be divided among those issues. In this section a typical review on the aforementioned issues is presented and efforts are made to find out a technical gap for further research.

Superconducting coil can be developed in various configurations such as Solenoid type coil, Toroidal type coil, Pancake type coil, Double pancake type coil. Sometimes the solenoid configuration is developed by keeping pancake coil one over another axially. In double pancake coil, two pancake coils are connected to each other make one unit or module. Then these units are placed either in a solenoid configuration or in toroidal configuration depending upon the requirements. Literature Review on AC losses in SMES

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