Development of an Innovative Superconducting Magnetic Energy Storage System

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Abstract—The present work is focused on the demonstration of an innovative approach to a superconducting magnetic energy storage system by means of next generation superconducting wires. The device is thought to be integrated in a more complex biomass plant for green energy production which includes an anaerobic digester and a cogenerator for biogas and electrical energy production. Presented technology allows the storage of the green energy produced with a very high efficiency and with a better power quality respect to traditional counterparts.

Keywords—Energy storage; Superconducting coils; Magnesium Diboride, Biomass.

I. INTRODUCTION

Biomass is a renewable energy resource, which can supply human energy needs in a sustainable way. It is defined as the biodegradable fraction of products, waste and residues of biological origin from agriculture (including vegetable and animal substances), forestry and related industries as well as the biodegradable fraction of industrial and municipal waste. Only 13.3% of the energy produced on Earth comes from renewable sources. Fossil products (such as petroleum, coal and natural gas) plus nuclear sources fill 81.6% and 5.1% of worldwide energy needs, respectively. Biomass represents one of the most promising way to re-use natural products; it is also a generic term for all vegetable materials storing solar energy through photosynthesis [1], [2].

The use of biomass to produce energy can be considered advantageous when the growth of the vegetable species is thick and vigorous and/or its availability during the year is sufficiently constant. Especially in Italy, where the agriculture is one of the main sectors in terms of production, the disposal of waste in the supply chain is a substantial problem for local agribusinesses often resulting in serious environmental risks. The most useful way to re-use biomass is to convert it into “green” energy and store the energy with high efficiency and low losses for an easy-to-use consumption when required [3], [4]. Actually, there are two limiting factors in its use:

- Electrical energy is consumed as it is generated. The production have to dynamically meet the varying demand. An imbalance between supply and demand will damage the stability and quality (voltage and frequency) of the power supply.
- Electrical energy is often generated far from where it is consumed. Complex power grids and energy management systems are required for a suitable energy distribution. If a failure on a line occurs (because of congestion or any other reason) the supply of electricity will be interrupted.

Power demand and energy costs vary hourly. During high-energy demand periods, power suppliers have to give a supplement to the base-load power plants with less cost-effective but more flexible forms of generation, such as oil and gasified generators. During the off-peak period when less electricity is consumed, costly types of generation can be stopped. Electrical Energy Storage (EES) is recognized as hot topic with great potential in meeting the optimized energy use criteria, whereby energy is stored according to the technology used, and is efficiently used when needed. There are different technologies which to date represent valid alternatives for energy storage systems, but most of them actually are still in the early stage of developing. In this field plays an important role driving into the market the innovation in order to allow the emergence of business ideas that can give life to a market of innovative storage systems [5], [6].

Superconducting magnetic energy storage systems (SMES) provide complementary features than battery storage systems. In particular the advantages of the SMES are the immediate response time, the high charging and discharging power (power intensive system), the possibility to support a virtually unlimited number of cycles, and the high efficiency of the cycle (round trip efficiency up to 95%). This system allows to drastically reduce the problems of interfacing with the electrical network of sensitive and / or disturbing users (e.g. industrial processes or data centers), especially if it used in combination with systems with high storage capacity (energy intensive) such as batteries [7], [8]. The stored energy is immediately available in the electrical form and can be released by discharging the superconducting coil with an efficiency of the whole cycle of charge and discharge more than 95%. SMES devices allow the rapid release of high power and are particularly suited for compensating brief power outages. Due to their main characteristics which fit mainly low energy needs, the idea is the development of small sized devices able to help small rural enterprises, small villages and/or public government during black out allowing the use of small biomass plant together to high innovative EES. Real scale SMES systems, with rated power in the range 1-10 MW and usable energy up to 30 MJ, have been developed in the past based on liquid-helium cooled low-temperature superconductors and have been...
successful submitted to live grid installation [9]-[11]. The feasibility of SMES technology based on HTS materials has also been investigated more recently [12]-[17]. The use of these materials allows a higher operating temperature, in the range 15-30 K, thus simplifying the cooling system and reducing the cooling losses. Furthermore, the much higher in-field performance of HTS materials also allows achieving high energy density and more compact devices. Several small size SMES prototypes have been built based on 1G HTS materials.

A project was started at University of Magna Grecia with the main goal of demonstrating the viability of SMES storage systems based on next generation of superconducting materials through the implementation of a reduced scale demonstrator. The present work describes the progress of the project and the main characteristics of the SMES system under development.

II. SMES SYSTEM

The innovative elements of the project are the use of Magnesium Diboride (MgB\textsubscript{2}) for the realization of the superconducting coil and the contextual use of a conduction cooling system. The Magnesium Diboride is a well-known low-cost material whose superconductivity, with a critical temperature of 39 K, was discovered in 2001. Today, Columbus Superconductors (Genova, Italy), which is one of the most important player in the world for the production of this material, can supply long length of MgB\textsubscript{2} superconducting strands with a cost of about 1 Euro/kAm. The MgB\textsubscript{2} superconducting strands can be used to realize superconducting magnets operating in the temperature range of 10-20 K. The efficiency of the cooling system is then significantly higher with respect to the case of conventional low temperature superconductors (NbTi, Nb\textsubscript{3}Sn) which operates at the liquid helium temperature (4.2 K). In this project the MgB\textsubscript{2}-coil of the SMES will be cooled by a cryogen free system by means of thermal conduction.

The main components of the system under development are:

- Cryogenic system
- Superconducting coil
- Power conditioning system

A. Cryogenic system

The cryogenic system of the SMES is based on the cryogen-free test facility of the University of Bologna. This facility was realized by Alca Technology (Schio, Italy) and is in operation since 2012. The facility utilizes a 4 K Gifford-McMahon regenerative heat exchanger (RDK-408D by Sumitomo) with nominal heat loads of 35 W at 40 K from the 1st stage and 1 W at 4 K from the 2nd stage. The high temperature stage (also referred to as first stage) of the cryocoolers is connected to the current leads and to the thermal shield with the aim to reduce heat invasion due to radiation. The low temperature stage (second stage) is connected to the device under test which can be cooled down to 10 K. The current leads, thermal shield and the device under test are located in a cryostat where a void of 10\textsuperscript{-5} mbar is obtained by means of a rotary vane pump which acts in series with a turbomolecular pump.

B. Superconducting coil

The superconducting coil is of the solenoid type and will be manufactured by Ansaldo Superconductors (Genova, Italy) utilizing an MgB\textsubscript{2} strand produced by Columbus Superconductors (Genova, Italy). The main parameters of the strand are reported in Table I.

| Nominal Radius | 1.13 mm |
| Number of filaments | 36 |
| Filling factor | 0.14 |
| Composition | Ni 70%, Cu 20% |
| Tensile strength | 300 MPa |
| Critical Current @ 22 K | 550 A |

Fig. 1 shows the critical current of the strand vs. the magnetic flux density field in correspondence to different values of the temperature of operation.

Fig. 2 shows the inductance of the coil (a), the maximum current (b) and the required length of superconducting strand (c) vs. the number of layers of the solenoid, assuming an operational temperature of 16 K, and a voltage of the d.c. bus of 200 V. In order to store 30 kJ of energy 8 layers are required; a lower value of the stored energy, and hence a lower lent of superconductor, can be considered for the purposes of this project in order to reduce the cost.

C. Power conditioning system

Fig. 3 shows the main scheme of the power conditioning system which connects the SMES to the electric power network/load. A d.c. bus is connected to the superconducting...
coil by means of a chopper and with the power network with a three phases full bridge inverter; a transformer is also used for adapting the output ac voltage with the voltage of the grid. Both the inverter and the chopper are controlled in order to control the power flow between the SMES and the network.

![Image of inductance vs number of layers](Figure 2)

Fig. 2: Inductance (a), current (b) and length of the conductor (c) vs. the number of layer of the superconducting MgB$_2$ solenoid

Superconducting coil and a cryogen free closed-cycle cooling. The operating temperature of the superconducting coil is 16 K and the stored energy is in the order of few kJ. The output power is in the order of the few kW. Such energy storage systems can be applied to installations of production of renewable energy by an anaerobic digester increasing the efficiency and the reliability of the power supply.

**REFERENCES**


**CONCLUSION**

The present paper discusses the progress on the fabrication of a demonstrative SMES system based on MgB$_2$...