Overview of Four Energy Storage Techniques.

C. Chukwuka*, K.A. Folly**

*Electrical Engineering, University of Cape Town, South Africa, Oluchux@yahoo.com

**Electrical Engineering, University of Cape Town, South Africa, Komla.Folly@uct.ac.za

ABSTRACT

Renewable Energy has gained a significant attention in recent years due to high energy cost and adverse environmental impacts of conventional fossil fuels. One of the major challenges for the renewable energy systems remains matching the intermittent energy supply with the dynamic power demand. This problem can be solved by grid-tie solar system. However for the stand alone systems certain energy storage devices must be added into the system so as to provide power- on- demand. The energy storage devices which include molten salts, superconducting magnets, supercapacitors and underground thermal energy storage must store energy in excess of electricity supply and subsequently meet demand in shortage of supply.

Keywords; molten salt, superconducting magnets, supercapacitors, underground thermal energy storage

1 INTRODUCTION

Engineers and scientists all over the world have worked tirelessly towards the development of clean energy. This has led to the development of even cleaner ways of storing the energy produced. In this paper, we shall be presenting possible and economical ways to store harnessed energy for future use. These include; molten salt, superconducting magnetic (SMES), supercapacitors and underground thermal energy storage (UTES)

2 MOLTEN SALT ENERGY STORAGE

The molten salt energy storage is used in Eskom 100MW solar Concentrating Thermal Turbine project located in Upington, Northern Cape, South Africa. This project is poised to be completed in 2014 as part of Eskom's commitment to renewable energy. As illustrated in the figure above, it is made of 200m high tower surrounded by 6000 heliostats which are arranged in elliptical formation around the focal point. The central receiver is situated on top of the central tower which in essence is a heat exchanger consisting of thin walled tubing which absorbs the concentrated beam radiation and transfers the heat to the working fluid(the molten salt circulated through it) which in turn is used to generate superheated steam. Electrical power is generated through a Rankine cycle (steam turbine process)[2]The salt melts at 221 °C (430 °F). It is kept liquid at 288 °C (550 °F) in an insulated "cold" storage tank. The liquid salt is pumped through panels in a solar collector where the focused sun heats it to 566 °C (1,051 °F). It is then sent to a hot storage tank. This is so well insulated that the thermal energy can be usefully stored for up to a week.

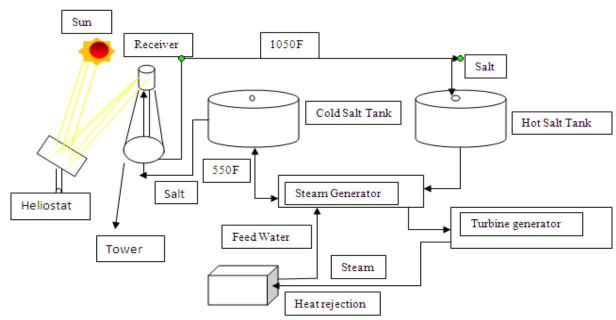

Fig 1 Solar Thermal Turbine using the molten salt storage [1]

When electricity is needed, the hot salt is pumped to a conventional steam-generator to produce superheated steam for a turbine/generator as used in any conventional coal, oil or nuclear power plant. A 100-megawatt turbine would need tanks of about 30 feet (9.1 m) tall and 80 feet (24 m) in diameter to drive it for four hours by this design. The main disadvantage of molten salt energy storage is low energy densities compared to ordinary lithium batteries [3].

3 SUPERCONDUCTING MAGNETIC ENERGY STORAGE

Superconducting magnetic energy storage (SMES) system is a device for storing and instantaneously discharging large quantities of power. It stores energy in the magnetic field created by the flow of DC in a coil of superconducting material that has been cryogenically cooled. The SMES recharges within minutes and can repeat the charge/discharge sequence thousands of times without any degradation of the magnet. Recharge time can be accelerated to meet specific requirements, depending on system capacity.

3.1 Superconductivity

A superconducting material enhances storage capacity. In low-temperature superconducting materials, electric currents encounter almost no resistance. The challenge is to maintain that characteristic without having to keep the systems quite so cold. However the applications of superconductors have been limited by the conditions of low transition temperature, critical magnetic field and critical current density.

It stores electric energy in the magnetic field generated by DC current flowing through a coiled wire. If the coil were wound using a conventional wire such as copper, the magnetic energy would be dissipated as heat due to the wire's resistance to the flow of current. However, if the wire is superconducting (no resistance), then energy can be stored in a ``persistent" mode, virtually indefinitely, until required. Superconductors have zero resistance to DC electrical current at low temperatures so that ohmic heat dissipation is eliminated; hence the refrigerator is needed in the SMES to cool the coil. For both DC and AC applications, energy savings will be significant. The current carrying capacity of the wire is dependent on temperature and the local magnetic field. The optimal operating temperature for most of the devices will be 50-77 K. The energy stored within the coil is given by

$$E = \frac{1}{2} L I^2 \quad \text{------- (1)}$$

Where L is the inductance of the coil, and I is the current passing through it. The volumetric energy density is given by

$$U_D = \frac{B^2}{2\mu_0} \quad \text{-------------- (2)}$$

SMES coils vary in size depending on the energy they store. The superconductor of choice for this application is a niobium-titanium alloy which needs to be kept at liquid helium temperature in order to superconduct.

3.2. Operation of an SMES system

The basic operation of a complete SMES system is very simple. The transmission voltage (from the AC network) is first stepped down from a few hundred kV to several hundred volts using a step-down transformer. This is then converted into DC which is fed into the superconducting coil. Hence when the power flows from the system to the coil, the DC voltage will charge up the superconducting coil and the energy is stored in the coil. The maximum energy stored depends on the design of the device.[6]

When the AC networks requires a power boost, say when there are sags, spikes, voltage and frequency instabilities, the coil discharges and acts as a source of energy. The DC voltage is converted back into AC voltage through the converter.

An SMES system includes a superconducting coil, a power conditioning system, a cryogenically cooled refrigerator and a cryostat/vacuum vessel. SMES are highly efficient at storing electricity (greater than 97% efficiency), and provide both real and reactive power. These facilities are used to provide grid stability in a distribution system and power quality at manufacturing plants requiring ultra-clean power, such as microchip fabrication facilities [5].

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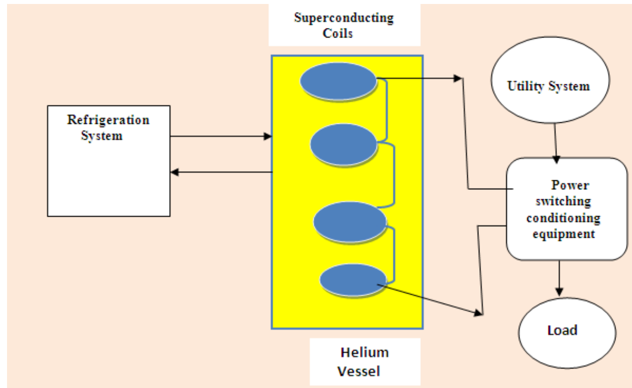

Fig 2: Operation of a superconducting magnetic energy storage system

3.3 Energy capacity of SMES

Energy is stored directly in a superconducting magnetic energy storage system. It is able to store energy with a loss of only 0.1% per hour (this is required for the cooling system), compared to a loss of about 1% per hour loss for flywheels. It is claimed that SMES is 97-98% efficient and it is much better at providing reactive power on demand.

At this point SMES systems are able to store up to about 10 MW. Some research groups have achieved much higher capacities of hundreds of MW, but only for a second. However, some researchers believe SMES can potentially store up to 2000 MW. Theoretically, a coil of around 150-500 m radius would be able to support a load of 5000 MWh, at 1000 MW; depending on the peak field and ratio of the coil's height and diameter.

Recent developments have tried to use silicone-based three-phase adjustable speed motor drives (ASDs), which bring down the scale of SMES to fit into lorry trailers. Storing energy in the range of 1-10 MWs, they are aimed at the power quality market. [7]

4 SUPERCAPACITORS

Supercapacitors are a type of electrochemical capacitors that have very high power densities. They are also known as ultracapacitors, Electric double-layer capacitors, supercondenser and pseudocapacitors. The following are various classes of capacitors which evolved to supercapacitors

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4.1 Electrostatic capacitors;

Tables and illustrations can appear within columns or span both columns. If two column figures or tables are required, place them at the top or at the bottom a page. They should have a self-contained caption and be center justified. Figures must be 600 dpi resolution or equivalent. All lettering should be 10-point type or larger. Figures must not extend into the margins.

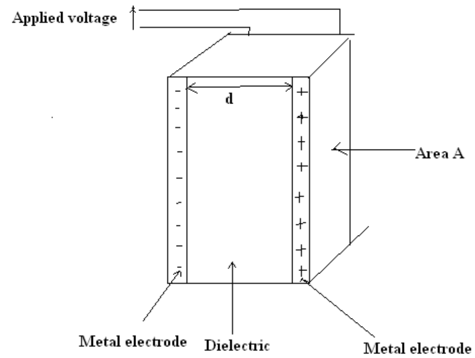

Figure 4 : The principle of capacitors[8]

These are the normal capacitors made of the dielectric which is sand wished by two plates or electrodes. Energy is stored by the removal of the charge carriers typically electrons from one metal plate and depositing them on another. This charge separation creates a potential between the two plates. The amount of charge stored per unit voltage is essentially a function of size, the distance, and the material properties of the plates and the dielectric, while the potential between the plates is limited by the dielectric break down. Optimizing the material leads to a higher energy densities for any given size of capacitor

The formula for capacitance is given by the capacitance is defined as

$$C = \frac{A}{d}\epsilon_r \epsilon_0 \quad \text{-------------------- (3)}$$

where A is the area of the parallel plates, d is the distance between them, εr is the relative permittivity or dielectric constant and ε0 is the permittivity of free space (8.854x10-12F/m). The energy stored by the capacitor is given by

$$E = \frac{1}{2}CV^2 \quad \text{--------------------} \quad (4)$$

Where V is the voltage applied across the parallel plates. The energy can be increased many ways. One can increase the voltage applied V , but this is limited by the maximum Energy Field strength Eb at which the dielectric breaks down to failure and starts conducting electricity, resulting in external component damage.

4.2 Electrolytic capacitors

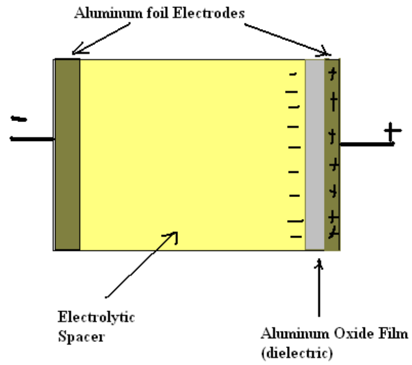

Fig 5 electrolytic capacitors [9]

These have the advantage of very high capacities 47000uf. Electrolytic capacitors use an aluminum or tantalum plate with an oxide dielectric layer. The second electrode is a liquid electrolyte, connected to the circuit by another foil plate

4.3 Electrochemical capacitors

Supercapacitors store large amounts of energy. Supercapacitors made from carbon aerogel, carbon nanotubes, or highly porous electrode materials offer extremely high capacitance (up to 5 kF as of 2010 and can be used in some applications instead of rechargeable batteries. Alternating current capacitors are specifically designed to work on line (mains) voltage AC power circuits. They are commonly used in electric motor circuits and for smaller applications like home solar enery system where extremely fast charging is a valuable and are often designed to handle large currents, so they tend to be physically large. They are usually ruggedly packaged, often in metal cases that can be easily grounded/earthed. They also are designed with direct current breakdown voltages of at least five times the maximum AC voltage

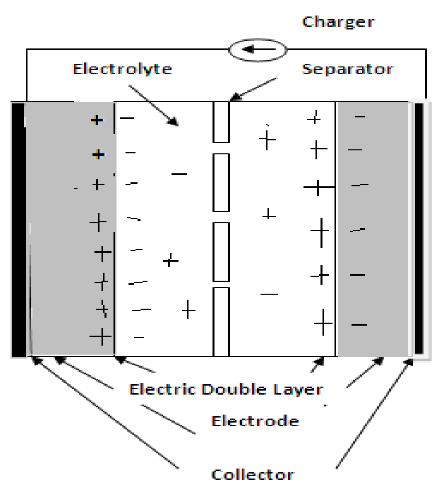

Fig 6 Ultracapacitors [10]

Ultracapacitors are like batteries except that they have faster in discharge times because even though they are electrochemical In nature but no reaction takes place in them

Carbon nanotubes and polymers are practical for supercapacitors. Carbon nanotubes have excellent nanoporosity properties allowing the polymer tiny spaces to sit in the tube and act as a dielectric. Polymers have redox (reduction-oxidation) storage mechanism along with a high surface area. Advantages include longer life, lower internal resistance and faster charging and discharge times. Disadvantages are lower energy per unit weight, voltage varies with the stored energy for higher voltages ultracapacitors are connected in series, higher energy dielectric absorption, higher self discharge, safety issues due to high discharge and charging. Applications include regenerative braking in hybrid vehicle, cold engine starting,, Load leveling PEM Fuel cell, Ride through backup power systems. Digital electronic devices [10]

5 UNDERGROUND THERMAL ENERGY STORAGE (UTES)

Also known as seasonal thermal storage, interseasonal thermal storage or thermal bank this slightly differs from the other energy storage techniques discussed in the sense that here heat energy is never converted to electricity hence the cheapest method. It is a new concept in that it makes use of the earth as the thermal mass. The basic concept that at dept of 20m below ground, temperature is steady round the year. Energy is collected as heat using solar collectors, stored underground either in underground aquifers (underground water reservoirs) or underground heat bank and then extracted using heat exchangers in winter for space heating. Normally, temperature is usually below 100 degrees celcius [11]. This an efficient and economical way of storing excess heat produced in the summer for use in the winter. In desert it, could also be used for space cooling thereby taking the load of heating and cooling off the grid. Different types of UTES include the duct, aquifer and the borehole thermal energy storage. [12]

CONCLUSION

Energy generated by several different methods needs to be stored however if we need to maintain a cleaner environment, we must stick to methods that release least green house gas such as we discussed in this paper. Not every method is suitable for all purposes, here we insist on applying the best techniques to suit an individual system. For example ultracapacitors are best used for systems. Where a sudden boost of power is needed in a fraction of a second like in automobiles supercapacitors are our candidate. UTES are needed where space cooling and heating are very important like in Europe and middle east to name but few. There are however a host of other methods practiced in different parts of the world today but these are not discussed in this paper

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