ISSN: 2278 – 7798
International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 2, Issue 10, October 2013

A REVIEW ON ADVANCE ENERGY STORAGE TECHNOLOGY FOR MICROGRID AND SMARTGRID

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***Abstract*: In case of Microgrid (MG) and Smart Grid (SG) having problems like fluctuation and intermittence resulted from unstable micro-sources and nonlinear loads will execute considerable impacts on normal operation of the MG and SG. Energy storage technology presents a preferable solution to the above issue. The paper gives a full scope review of the principal energy storage technologies being developed so far, and the features and benefits of energy storage systems (ESSs)**

In this paper the future trends and challenges of ESS are also fully accounted and gives a existing overview of EESs a view to proposing smart ESS as the promising technology in the future for MG and smart grid. Electrical energy storage technologies for stationary applications are reviewed. Particular attention is paid to solar fuel, superconducting magnetic energy storage, flywheel, capacitor/supercapacitor, Comparison is made among these technologies in terms of technical characteristics, applications and deployment status.

I. INTRODUCTION

The concept of Microgrid (MG) is proposed by the Consortium for Electric Reliability Technology Solutions (CERTSs) so as to enhance the local reliability and flexibility of electric power systems, which may consist of multiple distributed energy resources (DERs), customers, energy storage units, and can be further defined as a small electric power system being able to operate physically Islanded or interconnected with the utility girds.

The renewable energy sources (RESs) such as wind and solar power, are becoming the most important DERs nowadays and EES will contributes remarkably for their reliable operations. The distributed and renewable energy sources will see a remarkably increasing portion in the whole electric power generation. For example, RES generation is compulsorily required to occupy 20% by 2017 in California,USA, while a 15% proportion of the RES generation will be achieved by 2020 in China according to the government report, and in Germany the wind power generation will amount to 60% by 2020

This paper gives a thorough review of the advancement of MG and SG oriented energy storage technologies. Key technologies and principles associated with energy storage, benefits of MG-based applications, power electronic interfaces, and control strategies including charging and discharging control as well as power flow control, are fully elucidated with a view to proposing future trends and research challenges of ES technologies in MG and SG fields. Electrical Energy Storage (EES) refers to a process of converting electrical energy from a power network into a form that can be stored for converting back to electrical energy when needed Such a system operates electricity to be generates at times of either low demand, low generation cost or from intermittent energy sources and to be used at times of high demand, high generation cost or when no other generation means is available.

II. CLASSIFICATION

The various EES are used in Microgrids and Smartgrids are follows and having two criteria to categorize the various EESs:function and form. In terms of the function, EES technologies can be categorised into those that are intended firstly for high power ratings with a relatively small energy content making them suitable for power quality or UPS; and those designed for energy management, as shown in Fig. 1. PHS, CAES, TES, large-scale batteries, flow batteries, fuel cells, solar fuel and TES fall into the category of energy management, whereas capacitors/supercapacitors, SMES, flywheels and batteries are in the category of power quality and reliability. This simple classification glosses over the wide range of technical parameters of energy storage devices. For example, several flywheel manufacturers are developing flywheels with higher energy to power ratios, and advanced batteries often show good characteristics for pulse power; as in this paper represents the detail overview of EES based on their form of storage as further.

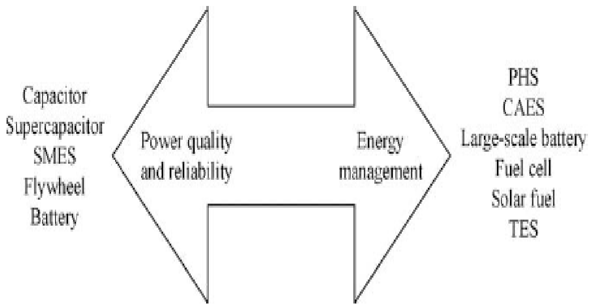


Fig.1 Energy Storage Classification with respect to Function

Although electricity is not easy to be directly stored cheaply, it can be easily stored in other forms and converted back to electricity when needed. Storage technologies for electricity can also be classified by the form of storage into the following:

(1) Electrical energy storage: (i) Electrostatic energy storage including capacitors and supercapacitors; (ii) Magnetic/current energy storage including SMES.

(2) Mechanical energy storage: (i) Kinetic energy storage (flywheels); (ii) Potential energy storage (PHS and CAES).

(3) Chemical energy storage: (i) Electrochemical energy storage (conventional batteries such as lead-acid, nickel (solar hydrogen, solar metal, solar ammonia dissociation–recombination and solar methane dissociation–recombination). metal hydride, lithium ion and flow-cell batteries such as zinc bromine and vanadium redox); (ii) chemical energy storage (fuel cells, molten-carbonate fuel cells – MCFCs and Metal-Air batteries); (iii) thermo chemical energy storage

As PHP and CAES technologies are already used in various power stations so in this paper we focused on recent technologies such as supercapacitor and solar based innovations as under.

III.SUPERCAPACITOR

The most direct and literal way of storing electrical energy is with a capacitor. In its simplest form, a capacitor consists of two metal plates separated by a nonconducting layer called a dielectric. When one plate is charged with electricity from a direct-current source, the other plate will have induced in it a charge of the opposite sign as shown in Fig. 2

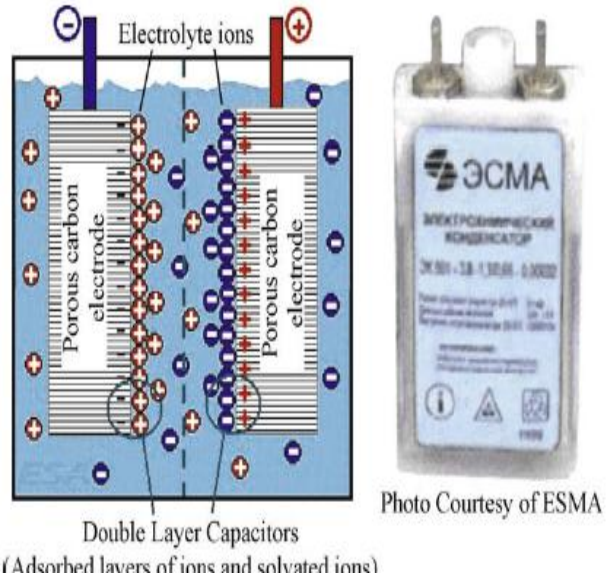


Fig.2 Capacitor / Super Capacitor

[1-2].Capacitors can be charged substantially faster than conventional batteries and cycled tens of thousands of times with a high efficiency. Conventional capacitors have been developed for daily peak load in summer for less than 1 h with small capacities (_kW). However, the main problem presented by conventional capacitors is the low energy density. If a large capacity is required, the area of the dielectric must be very large. This fact makes the use of large capacitors uneconomical and often cumbersome. This is particularly true in stationary EES applications [3-4]. Recent progress in the electrochemical capacitors/supercapacitors could lead to much greater capacitance and energy density than conventional capacitors, thus enabling compact designs. The supercapacitors store energy by means of an electrolyte solution between two solid conductors rather than the more common arrangement of a solid dielectric between the electrodes. The electrodes are often made from porous carbon or another high surface area material as the conductor with an aqueous or non-aqueous electrolyte. Since the surface area of activated carbons is very high, i.e. up to 2000 m2 per gram, and since the distance between the plates is very small (less than 1 nm), very large capacitances and stored energy are possible using supercapacitors. The energy storage capabilities of supercapacitors are substantially greater than that of conventional capacitors, by approximately two orders of magnitude (10–100 s kW) [3-4].

The major problems with capacitors, similar to flywheels, are the short durations and high energy dissipations due to self-discharge loss. Therefore, similar to flywheel, capacitors are mainly used in power quality applications such as ride-through and bridging, as well as for energy recovery in mass transit systems [1]. On the other hand, although the small electrochemical capacitors are well developed, large units with energy densities over 20 kWh/m3 are still in the development stage. There are a large number of developers of capacitors/ supercapacitors. The leading companies include SAFT (France), NESS (Korea), ESMA (Russia), PowerCache (Maxwell, USA), ELIT (Russia), PowerSystem Co. (Japan) and Chubu Electric Power (Japan), etc. [2].

IV. SMES

SMES is the only known technology to store electrical energy directly into electric current [5]. It stores electric energy as direct electric current passing through an inductor (coil) made from a superconducting material and circular so that current can circulate indefinitely with almost zero loss. SMES can also be used for storing energy as the magnetic field created by the flow of electric current. To maintain the inductor in its superconducting state, it is immersed in liquid helium contained in a vacuum-insulated cryostat. Typically, the conductor is made of niobium- titanium, and the coolant can be liquid helium at 4.2 K, or super fluid helium at 1.8 K. The SMES system normally consists of three major components, as shown in Fig. 3, a superconducting unit, a cryostat system (a cryogenic refrigerator and a vacuum-insulated vessel),and a power conversion system. The energy stored in the SMES coil can be calculated by E = 0.5LI2, where L is the inductance of the coil and I is the current passing through it. SMES exhibits a very high energy storage efficiency (typically >_97%) and a rapid response (within a few milliseconds) in comparison with other energy storage systems, but only for short periods of time. The energy output of an SMES system is much less dependent on the discharge rate compared with batteries. SMES also has a high cycle life and, as a result, is suitable for applications

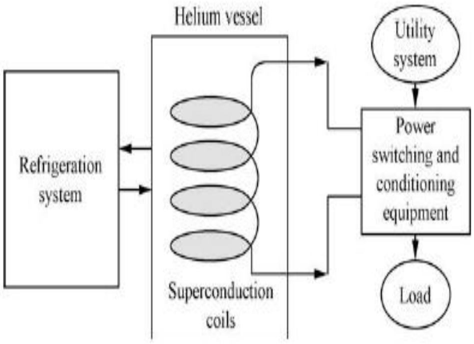
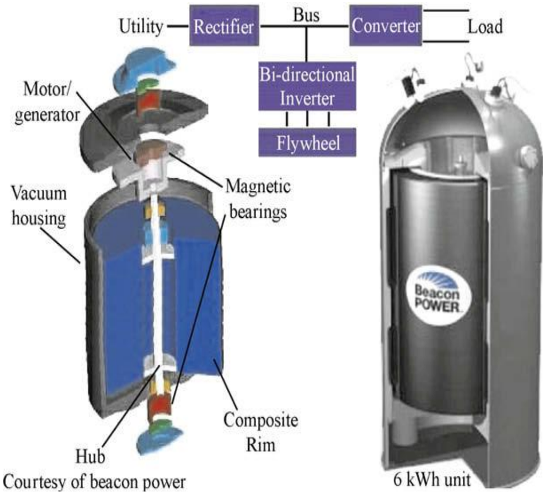


Fig.3 SMES System

V. FLYWHEEL

Flywheels have been used to store energy for thousands of years [5,6-7]. They store energy in the angular momentum of a spinning mass. During charge, the flywheel is spun up by a motor; during discharge, the same motor acts as a generator producing electricity from the rotational energy of the flywheel. The total energy of a flywheel system is dependent on the size and speed of the rotor, and the power rating is dependent on the motor-generator. Fig.4 shows a typical flywheel storage device which consists of a flywheel that spins at a very high velocity to achieve maximum storage of rotational kinetic energy within the given constraints, a containment system that provides a high vacuum environment (10_6–10_8 atmospheric pressure) to minimize windage losses and to protect the rotor assembly from external disturbances, a bearing assembly providing a very low loss support mechanism for the flywheel rotor, and a power conversion and control system for operating the flywheel to store energy or generate the electricity on demand [5-7]. The major advantage of flywheel over batteries is that they have a long life capable of providing several hundreds of thousands of full charge–discharge cycles. The efficiency of flywheels is high and typically in the range of 90–95%. The applications of flywheels are principally on high power/short duration applications (e.g. 100 s of kW/10 s of seconds). The most common application is to act as a power quality device to provide ride-through of interruptions up to 15 s long or to bridge the shift from one power source to another. Such systems may be implemented in a hybrid configuration with stand-by generators (e.g. diesel generators). Flywheels have also been used for demand reduction and energy recovery in electrically powered mass transit systems. MW scale flywheels can also be used for reactive power support, spinning reserve and voltage regulation by power-quality-sensitive customers such as communications facilities and computer server centres, the duration could be up to tens of minutes with a magnetic levitation bearing. Urenco Power Technologies (UPT) has recently demonstrated the application of flywheel to the smoothing of the output of wind turbine systems and the associated stabilisation of small-scale island power supply networks [7]. The rail traction industry represents another significant and high added value application for flywheel storage, particularly for trackside voltage support [5]. Compared with other EESs, the relatively short duration, high frictional loss (windage) and low energy density restrain the flywheel systems from the application in energy management.



Courtesy of beacon power

Fig.4 Flywheel System

The flywheel systems can be categorised into two groups, conventional metal rotor systems and high speed composite systems. The conventional metal rotor systems, with low speed metal rotor, lack the necessary energy and have relatively large standby losses. They are therefore typically used for short-term (_10–100 s) and medium/high load applications. The leading commercial suppliers of such flywheels are Piller (Germany), Active Power (US), Satcon (US) and Caterpillar (US). Much of the current R&D on flywheel EES is directed towards high speed composite machines, running at 10,000s RPM and utilising fabric composite materials [8]. The high directional strength properties of such composites, in combination with their relatively low density, allow the designers freedom in optimizing the overall configuration hence specific energy and specific power. Units have already been supplied on a commercial basis by UPT and with further systems being developed by AFS-Trinity, Beacon Power, Piller, etc. Typical products are rated at 100–250 kWe with 3.3–25 kWh stored energy.

VI. FLOW BATTERY

A flow battery, as shown in Fig.5, is a form of a battery in which the electrolyte contains one or more dissolved electroactive species flowing through a power cell/reactor in which the chemical energy is converted to electricity. Additional electrolyte is stored externally, generally in tanks, and is usually pumped through the cell (or cells) of the reactor. The reaction is reversible allowing the battery to be charged, discharged and recharged. In contrast to conventional batteries, flow batteries store energy in the electrolyte solutions. The power and energy ratings are independent of the storage capacity determined by the quantity of electrolyte used and the power rating by the active area of the cell stack. Flow batteries can release energy continuously at a high rate of discharge for up to 10 h. In contrast to fuel cells in which only the electroactive chemicals (e.g. hydrogen, methanol, and oxygen) flow through the reactor, and the electrolyte remains at all times within the reactor, flow batteries drive the electrolyte (generally the majority in weight and volume terms) flows through the reactor. Flow batteries are also distinguished from fuel cells by the fact that the chemical reaction involved is often reversible, i.e. they are generally of the secondary battery type and so they can be recharged without replacing the electroactive material. There are three different electrolytes that form the basis of the existing designs of flow batteries currently in demonstration or in large-scale project development.

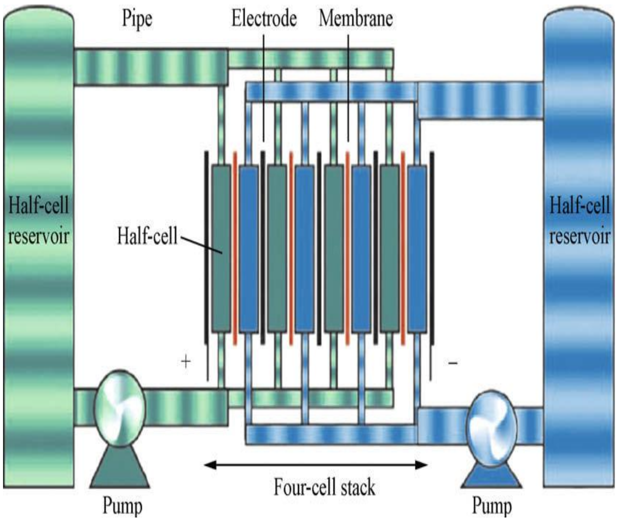


Fig.5 Schematic Of Flow battery

VII. VANADIUM REDOX BATTERY (VRB)

VRB stores energy by employing vanadium redox couples(V2+/V3+ in the negative and V4+/V5+ in the positive half-cells) [2]. These are stored in mild sulphuric acid solutions (electrolytes). During the charge/discharge cycles, H+ ions are exchanged between the two electrolyte tanks through the hydrogen-ion permeable polymer membrane. The reactions can be expressed simply by V4+ M V5+ + e_ at the positive electrode and V3+ + e_M V2+ at the negative electrode. The cell voltage is 1.4–1.6 V and the efficiency can be as high as 85%. VRB is suitable for a wide range of energy storage applications for electricity utilities and industrial end-users. These include enhanced power quality, UPSs, peak shaving, increased security of supply and integration with renewable energy systems. The majority of development work has focused on stationary applications due to the relatively low energy density.VRB was pioneered in the University of New South Wales (UNSW), Australia, in the early 1980s. The Australian Pinnacle VRB bought the basic patents in 1998 and licensed them to Sumitomo Electric Industries (SEI) and VRB Power Systems. VRB storages of up to 500 kW, 10 h (5 MWh) have been installed in Japan by SEI for Kwansei Gakuin University, etc. VRB has also been applied for power quality applications (3 MW, 1.5 s, SEI) for Tottori Sanyo Electric.

VIII. SOLAR FUELS

Solar fuels are at an earlier stage of development but have attracted more attention recently. The principle of solar fuels is shown in Fig.6. By concentrating the diluted sunlight over a small area with the help of parabolic mirrors and then capturing the radiative energy using suitable receivers and reactors, one is able to obtain heat at high temperatures for carrying out an endothermic chemical transformation and producing a storable and transportable fuel [9–10]. The fuels can be stored and/or transported to the customer site for electricity generation. In principle the energy input to a solar fuel could be provided with electricity; however, re-conversion of recovered heat to electricity via a steam Rankine cycle or other ‘‘heat engine” processes would result in a relatively low round trip efficiency. The major competitive advantages of the solar fuel approach are that the change in solar to electric conversion efficiency of a solar energy system with and without storage can be close to zero. The storage becomes an integrated part of the system and replaces components that would have some energy losses anyway. The result is a ‘‘virtual” electricity storage system of close to 100% ‘‘virtual storage efficiency”. Furthermore, the substitution of components plus the ability to downsize the heat engine to run at a higher capacity factor mean that it is conceivable that the cost increment can also be very small [1].A number of fuels can be produced by solar energy. The following are the three key examples:

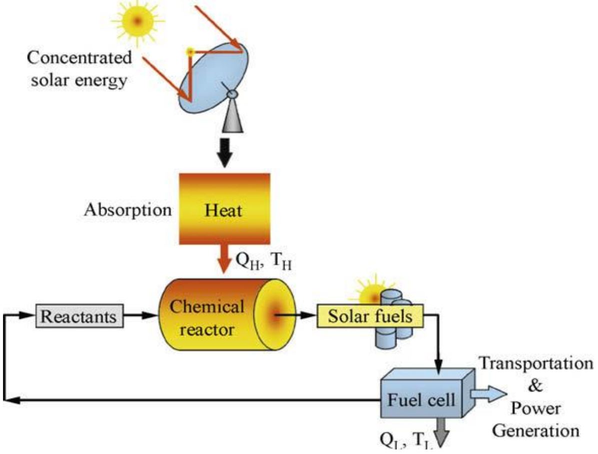
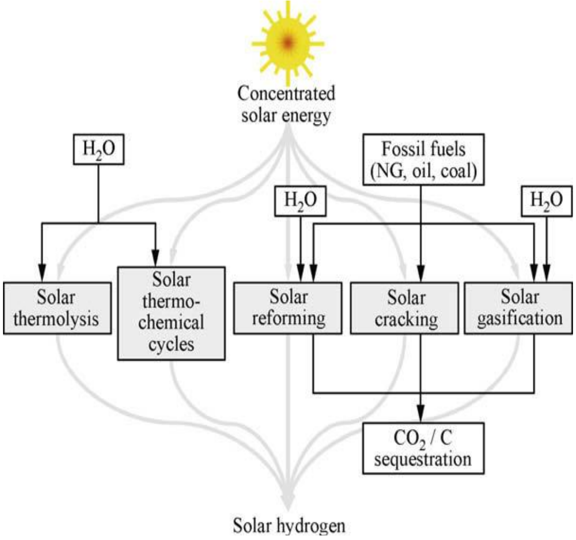


Fig.6 Solar energy conversion into solar fuels

(1) Solar hydrogen: Five thermo-chemical routes for solar hydrogen production are depicted in Fig.7. The figure shows the chemical sources for hydrogen production, including water for the solar thermolysis and solar thermo-chemical cycles, fossil fuels for the solar cracking, and a combination of fossil fuels and H2O for the solar reforming and solar gasification. All of these routes make use of concentrated solar radiation as the energy source of high-temperature process heat [9-10].

(2)Solar metal: Metals are attractive candidates for storage and transport of energy. They may be used to generate either high-temperature heat via combustion or electricity via fuel cells (batteries).

The chemical products from these power generating processes are metal oxides which, in turn, need to be reduced and recycled. The conventional extraction of metals from their oxides by carbothermic and electrolytic processes is characterized by high energy consumption and concomitant environmental pollution. Both the issues can be substantially reduced by using concentrated solar energy as the source of high temperature process heat [11]. The solar thermal dissociation of ZnO is among the most promising metal oxide processes because of relatively low reaction temperature [10].



(3) Solar chemical heat pipe: High temperature solar process heat is used for driving an endothermic reversible reaction in a solar chemical reactor. The products can be stored for a long term and transported over a long range to the customer site where the energy is needed. At that site, the exothermic reverse reaction is effected, yielding process heat in an amount equal to the stored solar energy DHA?B. This high-temperature heat may be applied, for example, to generate electricity. The chemical products for the reverse reaction are the original chemicals; they are returned to the solar reactor and the process is repeated. Two reverse reactions that have been extensively investigated for application in chemical heat pipes are the CH4 reforming methanation and the NH3 dissociation synthesis [12-13].

IX. MAIN TECHNICAL CHARACTERISTICS COMPARISON OF EESS

Technologies	Maximum Power Rating	Discharge Time	Response time	Efficiency
Super Capacitor	<100KW	10 Sec	<5ms	0.90
SMES	10KW-10 MW	1-30 Min	<5ms	0.95
Flywheel	<750KW	<1 Hour	<20ms	0.93
Flow Battery VRB	<1MW	<4 hour	<5ms	0.75
Solar Fuels	W-10MW	---	---	0.60

X. CONCLUSION

Based on review the following conclusions are drawn
EES is ultimately needed for the smart grid and Micro grid connected distributed energy resourses, by using EES, challenges faced by the power industry can be greatly reduced. EESs have numerous applications ranging from large-scale generation and transmission-related systems, to distribution network and even customer/end-user sites. The EES technologies are effectively contributes in power sector functions like of energy management and power quality and reliability.

Energy storage systems (ESSs) play an important role as power buffers in MG and SG. A thorough review is done in this paper to fully account for the state-of-the-art advancements of ESS , covering principles and topologies, power electronics interfaces, control strategies and new emerging issues,especially for hybrid ESS technologies and the promising smart ESS, which forms the research emphasis in the near future.

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