Overview of Energy Storage Technologies for Micro Grid

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Abstract— **The access of Renewable Energy Resources into the utility grid is progressively increasing. This inclusion can bring problems onto the power quality issues and dynamics of the utility grid due to the lack of controllability over the Renewable Energy Resources such as wind and solar. In this paper various Energy storage schemes used to mitigate these issues are discussed. Mainly energy storage schemes are proposed to achieve voltage control, frequency control and active power stabilizations. Implementation of Energy storage schemes helps to increase the effectiveness, consistency and safety of the power scheme.**

Keywords— storage, energy ,battery ,pumped storage, super capacitor

I. Introduction

Power demand around world is increasing nowadays due to technological and Economical developments. As fossil fuels are exhausting day by day, other alternative generation sources such as renewable energy resources (RES) needs to be utilized to meet power demand. As the level of penetration of renewable energy resources increases, problems related to voltage and frequency stability as well as consistency of utility network becomes a concern. under any circumstances, the voltage and frequency of local bus needs to be operated within the approved limits as mentioned by the respective country grid code [1] A key shortcoming of renewable energy resources is the issue of intermittency which can create a risk to the safety of power supply. Energy storage schemes thus becomes necessary in order to address the variance between energy demand and supply. This need can be fulfilled by the appropriate handling of energy storage schemes.[2][3]. Energy storage scheme is defined as the transfer of electrical energy from a utility network into a form in which it can be stored until changed back to electrical energy. It is necessary to include the high power density and high energy density based energy schemes into this scenario which will not only meet the need of effective incorporation of renewable energy resources into the grid but also improve the power quality aspects. Energy storage devices (ESD) are used as provisional power units to absorb or supply power by controlling the references to the dc -dc converters. These devices need to be operated within its safe state of charge (*SoC*) limits.[4][5].

There are different types of energy storage schemes available based on the functionality and the form of energy storage. Some are capacity-Oriented energy storage schemes does not have quick response time. It is are used for long-run energy balancing to buffer low frequency oscillations of distributed generators output power and compensate intermittency of renewable energy resources in microgrid. Some energy storage schemes are access oriented storage schemes have fast response time and to provide transient response in microgrid, by providing the high frequency component of power[4][5].

II. Classification of Energy Storage devices

Energy storage schemes can be classified into two different types, based on their application and form of energy stored.

A. Depending on Application

Based on application, energy storage schemes are classified as short-run response energy storage schemes and long-run response energy storage schemes. Long-run response energy storage schemes used for power system applications can usually sink and supply electrical energy during minutes or hours and can particularly contribute on the energy management, frequency regulation and grid congestion management[6][7]. Short-run response energy storage devices are usually applied to improve power quality, principally to maintain the constant voltage in power systems, throughout a contribution during transients that exists few seconds or minutes. [7].

B. Depending on form of energy storage

Based on the form of electrical energy stored , energy storage scheme are classified in to five main types such as mechanical, chemical ,electrochemical, electrical, and thermal energy storage [8] as shown in figure1.

III. Energy Storage Systems

Long run and short run power response energy storage schemes will be covered under the five categories of electrical, chemical, electrochemical, mechanical and thermal energy storage Systems.

A. Chemical Storage

Electrical energy stored in the form of chemical energy in chemical storage system. Fuel cell is a chemical energy scheme that converts the chemical energy from a fuel into electricity. Fuel cells are devices that convert chemical energy directly into electrical energy, without the discharge of polluting gases or noise. Fuel cells hydrogen and oxygen in separate electrodes, anode and cathode correspondingly, generating electrical energy and water. Main advantage of this technology, it is possible to emphasize low emission of carbon dioxide and sulphur dioxide, high efficiency when compared to conventional thermal technology and high-power density [9-11]. Operation of fuel cell is shown in Figure:2

There are different types of fuel cells presented, based on the composition of its electrolyte, the working temperature and the type of fuel used. taking into account these characteristics, six main types of fuel cells are the mainly studied such as proton exchange membrane fuel cells (PAFC), alkaline fuel cells, phosphoric acid fuel cells, solid oxide fuel cells(SOFC),

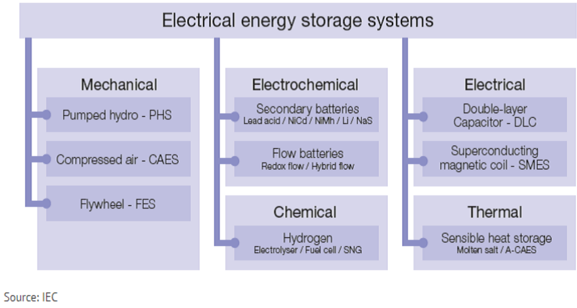

Fig 1 Classification of Energy Storage systems.[IEC]

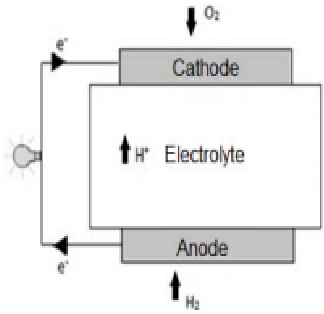

Fig 2 Operation of Fuel Cell

molten carbonate fuel cells(MCFC) and microbial fuel cell. Among these cells SOFC, MCFC and PAFC, are appropriate for cogeneration cycles. This happens due to the fact that the temperature of their operation is appropriate to be used in cycles with cogeneration.[13].

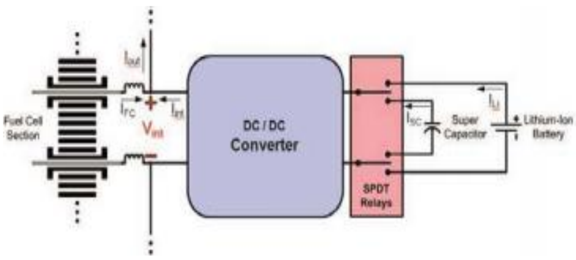

Fig 3 Hybrid connection of Fuel cell with Li-ion.[14]

Fuel cells can also be used as hybrid energy scheme in combination with super capacitor ,lithium-ion battery[14] as shown in figure3.This hybrid connection of fuel cell with battery/ultra capacitor has the advantages such as maximises system life times and extended sustainability time and higher system boosted current carrying capabilities(upto360%).

B. Electrochemical Energy Storage

Electrochemical energy storage schemes covers all types of secondary batteries. Batteries convert the chemical energy enclosed in its active material into electric energy by an electrochemical oxidation-reduction reverse reaction. Batteries are electrochemical energy storage technologies, each with different characteristics. Below is an summary of the technologies of battery system.

Lithium-ion (Li-ion) : In Lithium Manganese Oxide ($LiMnO_2$) batteries ,lithium manganese oxide is used as the cathode material. The design of the batteries such that it generates a 3-dimensional spinel structure that offers better flow of ions on the electrode. Its structure offers higher thermal constancy, as well as better security, which makes Li-manganese batteries highly appropriate for applications with high loads, such as electric vehicles and power tools. Major disadvantages are their comparatively low storage capacity and low life, as they can typically attain up to 700 cycles. Li-manganese batteries can provide between 3 - 4.2V, while their specific energy density varies between 100 and 150 Wh/kg. Lithium Nickel Manganese Cobalt Oxide (NMC) batteries are one of the majorly booming systems as the combination of nickel-manganese cobalt at the cathode ,makes it easy to be used in custom-made applications for energy density (higher capacity, lower current) or power density. Its flexibility makes the battery ideal for a range of applications, from electric vehicles (EVs) to medical and industrial applications. An additional advantage is its reduced *cost* compared to other Li-ion technologies due to the (partial) replacement of cobalt with nickel at the cathode, which is cheaper. Like other Li-ion technologies, NMC effectively operate in the range between 3 and 4.2V. Its specific energy density varies between 150 and 220 Wh/kg, and batteries can reach up to 2 000 cycles. Li-ion Batteries make use of a cathode (positive electrode) which is metal oxide, an anode (negative electrode) which is porous carbon, and an electrolyte. When the circuit is closed, during discharge the ions flow from the anode to the cathode during generating electric power. During charging ion flow direction is reversed. Many types of Li-ion batteries are presently available such as Lithium Cobalt Oxide ($LiCoO2$), Lithium Iron Phosphate (LFP - $LiFePO4$), Lithium Nickel Cobalt Aluminium Oxide ($LiNiCoAlO2$, NCA), Lithium Titanate.[15][16]. Charging and discharging of Li-ion battery is shown in figure 4.

Ni-based batteries: Ni-based batteries makes use of a porous nickel electrode for the deposit of active materials. Since their discovery at the end of the 19th century, numerous improvements have been introduced. Nickel Cadmium (NiCd) was the first type of Ni-based battery. It is highly long-lasting, and can reach more than 1000 cycles with proper maintenance. In addition, it charges fast, performs well in low temperatures, and also offer lower costs per cycle. Due to these characteristics, Ni-Cd batteries became the option for the aviation industry, and it also been used in stabilising wind energy conversion systems. Because of the toxic nature of the cadmium, disposal of these batteries leads to soil pollution and been replaced by other battery technologies. NiCd also has a comparatively low specific energy density of 45 – 80 Wh/kg and has a memory effect. Nickel-metal-hydride (NiMH) is a newer Ni-based technology, and provides ~40% higher energy density than typical NiCd systems. It is mainly used as rechargeable batteries for end user electronics. Its main advantage is it can be used in wider range of temperature and ease of recycling.[16]

Flow Batteries: Flow Batteries are a type of electrochemical cell which is a mix between a conventional battery and a fuel cell. The energy is provided when two liquid electrolytes are circulated through a common core that consists of a negative and a positive electrode and separated by a membrane circulation electrolyte generates an ion exchange between the catholyte and anolyte, which generates a flow current, and ii turn generate electric power. To charge the battery the reverse of this process is used. The Major difference between flow batteries

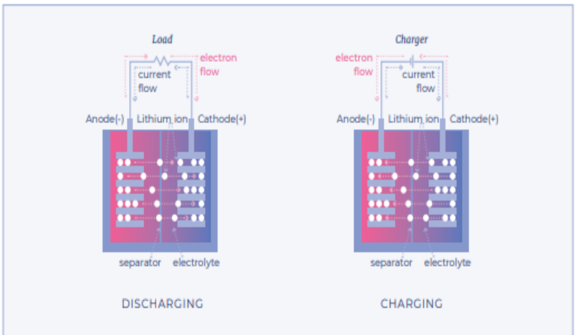

Fig 4 Charging and Discharging of Li-ion battery[16]

and conventional battery is energy is been stored in the electrolyte compared to electrodes in case of conventional batteries. Battery's capacity is decided by the volume of the battery [17] .There are several types of flow batteries available such as Redox flow batteries are the most commonly used flow batteries, where electricity is generated due to the difference in potential of the two tanks. When discharged, both tanks hold the same electrolyte solution – a mixture of positively and negatively charged ions. Materials commonly used in redox flow batteries are Vanadium-Polyamide, Vanadium, Bromine-Polysulfide, Iron Chromium, and Hydrogen-Bromium4. In hybrid flow batteries, one or more electro active components are stored as a solid layer. The electrochemical cell contains one battery electrode and one fuel cell electrode (fig 5). Typical materials used are Zinc-Bromine, Zinc-Cerium, and Lead-Acid. Flow batteries without membrane make use of laminar flow of electrolytes to ensure separation of the two electrolytes in the common core, eliminating the need for a membrane. [17]-18].

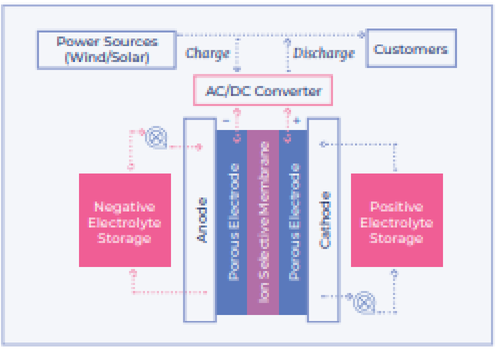

Fig 5 Generation of Electricity in Flow batteries[17]

Lead -Acid Batteries: Lead-Acid batteries comprises of flat lead plates which are engrossed in a pool of electrolyte. One of its plates is covered with a paste of lead dioxide, as the positive, and the other is made of sponge lead, serving as the negative. A separator is placed between the two plates. A key difference for lead-acid systems compared to other batteries is their very long charging times, compared to discharge, which is connected to the formation of lead sulphate on the negative electrode. To avoid water loss in lead -acid batteries ,water is added to electrolyte ,excess electrons will lead to hydrogen generation ,which in turn cause water loss. Lead-acid batteries are low maintenance, and its typical applications are back-up for UPS,emergency power, and automotive and traction. Energy density varies between 30 to 50 Wh/kg, cell voltage is 2V, and systems can go up to 300 cycles. [15][16][5]

Sodium Sulphur (NaS)batteries : Sodium sulphur (NaS) batteries NaS batteries are a type of molten-salt battery technology which use molten sulphur as the positive electrode, and molten sodium as the negative. The two electrodes are separated by a solid ceramic sodium alumina, which acts as the electrolyte as well. During discharge, electrons are released from the sodium metal atoms, leading to the formation of sodium ions which move through the electrolyte to the positive electrode, generating electricity. NaS batteries operate at high temperatures, typically >300°C, so in many cases external heaters are required. They have a high round-trip efficiency of ~90%, and specific energy is 150 Wh/kg or higher. They are often used for peak shaving and generally for stabilising renewable energy output and providing ancillary services.[15][16]

Metal-Air Batteries: Metal-Air batteries consists of anode made up of pure metal , an air cathode, a separator, and the electrolyte. The separator acts as an insulator which only allows transformation of ions. During the discharge process, oxidation reaction

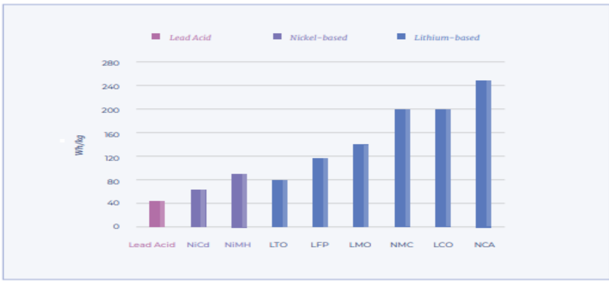

Fig 6 Specific Energy for different batteries[16]

occur to the metal anode with metal dissolved in the liquid electrolyte and an oxygen reduction reaction is induced in the air cathode. Due to the open battery arrangement that uses air as the reactant, metal–air batteries have much higher energy capacity (up to ~12 000 Wh/kg, which is comparable to that of petrol), which has made it very attractive to the automotive industry. Metal -air batteries not been commercialized yet, since there many technical challenges that needs to be resolved..[15]

C .Mechanical Storage

Mechanical energy storage schemes are one of most efficient and sustainable energy storage scheme. There are three main types of mechanical energy storage schemes; flywheel, pumped hydro and compressed air.

Pumped Hydro Storage Systems :Pumped hydro storage systems are flexible, dynamic, efficient and green way to store and deliver large quantities of electric power, pumped-storage hydro plants store and generate energy by moving water between two reservoirs at different heights. During times of low electric power demand, such as at night or on weekends, excess energy is used to pump water to an upper reservoir.(fig 7) The turbine acts as a pump, moving water back uphill. During periods of high electric power demand, the stored water is released through turbines. Conventional hydroelectricity has a limited future as an additional energy source due to challenges with resource availability and concerns regarding interruption of natural river flows. However, pumped hydro energy storage (PHES) is a major opportunity. As variable solar PV and wind electricity generation rises into the range of 50-100% of total electricity production, large amount of additional storage is required [23]. PHES is, by far, the leading energy storage technology [21,22], representing 97% of global storage power (160 GW) and more than 99% of stored energy. PHES is a mature off the-shelf technology and is much cheaper than alternatives for large-scale energy storage. solar PV , wind, PHES and high voltage DC and AC transmission together represent mature technologies, each with more than 100 GW of global deployment, that can support 100% renewable electricity at modest cost [24], allowing large greenhouse gas emissions reductions.

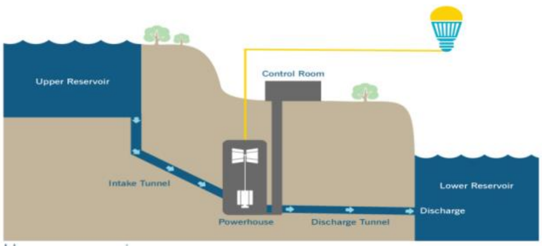

Fig 7 Pumped storage systems[24]

Flywheel Energy Storage Systems : Flywheel energy storage system (FESS) stores electrical power as kinetic energy in a rotating flywheel rotor and discharges the power by transforming the kinetic energy into electrical power via an electrical motor and generator(fig 8). The FESS can stabilize output fluctuation of PV panels due to changes in sunshine by a charge and discharge of storage energy from the FESS. The benefits of the FESS are rapid response, low hazardous waste, and long-life compared to secondary batteries [25]. Other flywheel applications should also be highlighted. The fast response time of flywheels make them suitable for different applications in power systems including in micro grid. Flywheels have been used for harmonic compensation, being able to reduce the harmonics about 50% up to the 11th harmonic [26].Companies from Europe and the USA have developed flywheels with the purpose of keeping the power quality; providing ride through for momentary power outages, reducing harmonic distortions, eliminating voltage sags, etc.[27].

Compressed Air Energy Storage (CAES): is a way to store energy generated at one time for use at another time. At utility scale, energy generated during periods of low energy demand (off-peak) can be released to meet higher demand (peak load) periods. Since the 1870's, CAES systems have been deployed to provide effective, on-demand energy for cities and industries (fig 9). While many smaller applications exist, the first utility-scale CAES system was put in place in the 1970's with over 290 MW nameplate capacity. CAES offers the potential for small-scale micro grid, on-site energy storage solutions as well as larger installations that can provide immense energy reserves for the grid. compressed air energy storage (CAES) plants are largely equivalent to pumped-hydro power plants in terms of their applications. But, instead of pumping water from a lower to an upper pond during periods of excess power, in a CAES plant, ambient air or another gas is compressed and stored under pressure in an underground cavern or container. When electricity is required, the pressurized air is heated and expanded in an expansion turbine driving a generator for power production[28].Depending on the procedure, CAES technologies are separated into, Adiabatic (A), Diabetic (D) and Isothermal (I) CAES concepts. Thus relying on the how heat is handled while compression and prior to expansion of the air helps in their categorization [29]. Compressor, air storage reservoir and expander are the three main components in CAES system [30]

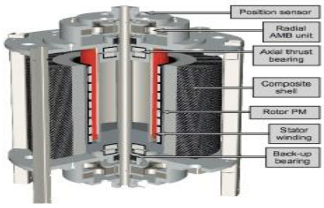

Fig 8 Flywheel Energy Storage[23]

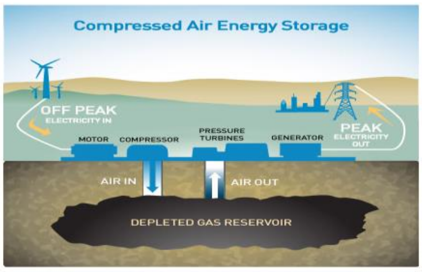

Fig 9 Compressed Air Energy Storage[28]

D.Electrical Energy Storage

Electrical energy storage schemes (EESS) can be categorized as electrostatic energy schemes including capacitors and super capacitor, and magnetic/current energy storage schemes [31]. Electrical energy storage schemes for the utility grid is an developed approach to increase the reliability and improve safety and consistency of utility grids. EESS offers a storage scheme that store energy when there is more generation than the demand, and discharges the stored energy during high demand periods.

Super Capacitors : Super capacitors, also called as electrical double-layer capacitor, ultra capacitor, are new energy storage scheme that close the gap between aluminum electrolytic capacitors and batteries in terms of power and energy density[32]. ultra capacitor 's capacity ranges from several farads to tens of thousands farads and its power density is 10 times more than battery's. The storage capacity of super capacitor is more than electrolytic capacitor, and it has wide range of working temperature , fast charging and discharging, extended life cycle , no pollution and emission and so on[33-35]. The energy storage scheme plays major role for improving the power quality of the micro grid. Through the inverter control unit, it can adjust the super capacitor energy storage scheme to provide active and reactive power for users, so as to improve the power quality[36]. As the super capacitor can quickly sink and discharge electric energy with high power, it is very appropriate to resolve some of the transient issues in the power schemes, such as instantaneous outage caused by the system failures, a sudden swell in voltage, and the voltage sag and so on. At this time, the super capacitor can be used to sink or compensate the power scarcity in order to regulate and smooth the voltage fluctuations.

Superconducting magnetic energy storage (SMES): Superconducting magnetic energy storage (SMES) scheme is a technologically improved method of storing energy in a magnetic field.Energy is generated when current flows around coil(fig 10). In order for this to operate SMES scheme resourcefully as an energy storage schemer, the coil should be made of a superconductor with zero electrical resistance to avoid energy losses due to the current circulation.[37]

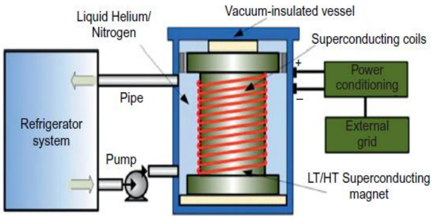

Fig 10 Structural View of SMES[38]

Superconducting magnetic energy storage scheme is an energy storage method that depends on a particular property of some materials, superconductivity. A superconductor has no electrical resistance and so when a current flows through it, there is no heat or energy loss due to resistivity. The top superconducting materials are metal alloys, which can be cooled to close to zero, before it starts super conducting. In cooled state, super conducting coil is charged with electric current, which then creates a strong magnetic field in which energy is stored. Energy will be stored until the temperature is low or Zero. Small superconducting energy storage rings have been used to offer utility grid support services because they are extremely fast acting. But large storage scheme are prohibitively costly. Structural view of superconducting magnetic energy storage system is given in Fig. 10 [38][39].

E. Thermal Energy Storage (TES)

Thermal storage – schemes utilize cold water, hot water or ice storage to store the heat and use for afterward. The efficiencies of the thermal energy storage differ with the material used for thermal energy storage schemes. They are significant for integrating large scale renewable energy resource such as concentrated solar thermal technology and it can be used as a reliable and dispatch able source of energy to balance the power supply and power demand.[40][41] Due to intermittency in accessibility and constant variation in solar radiation, TES found its place in thermodynamic schemes. TES effectively reduces the difference between demand and supply by conserving energy, but also enhances the performance and thermal reliability of the system. Therefore, designing efficient and economical TES schemes is of great significance. However, few solar thermal plants in the world have employed TES at a large scale. in addition, the design of TES systems in a variety of domestic solar applications is presently being investigated [42][43].

IV. Conclusions

An energy storage scheme (ESS) will facilitate Micro grid concepts with renewable energy resources which is one of the upcoming technologies in near future. Eliminating the intermittences related issues of the renewable energy resources with their power generation. ESSs may maintain system reliability and moreover offer some supplementary facilities such as load balancing, spinning reserve, black start capability. Major problems of energy issues such as sustainability and protection of environment are pressing issues requires energy storage schemes and renewable energy resources implementation. The difference of electric energy/ electric power generation amounts due to short and long run fluctuations of renewable resources require some important measurements. Thus, energy storage becomes significantly important to improve the response capacity of the electric grid system due to their easy in manageability, controllability, predictability and flexibility. Effective energy storage would compensate the difference of the levels between electricity generation and consumption in short and long run spans, accurately.

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