Evaluation of Energy Storage Technologies and Applications Pinpointing Renewable Energy Resources Intermittency Removal

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Abstract -- Renewable energy sources (RES), especially wind power plants, have high priority of promotion in the energy policies worldwide. An increasing share of RES and distributed generation (DG), should, as has been assumed, provide improvement in reliability of electricity delivery to the customers. Paper presented here concentrates on electricity storage systems technologies and applications pinpointing renewable energies variability removal. It can be seen from presented issues that there are numerous options to energy storage systems which can assist in generation and load shifting, peak shaving, transmission expansion planning deferral, ancillary services procurement, and power quality issues. Focus of applications is on renewable resources intermittency elimination. Some related issues including relation between electricity markets and storage systems, system expansion and storage systems, and correlation among smart grid issues and storage systems are also presented. As a result, some comparisons are conducted in terms of various interested criterions in the field of energy storage comprising storage capacity, power level, response time, unit investment and operation costs, round trip efficiency, physical dimensions, cycle life time, life time, availability, and environmental impacts.

Index Terms - Ancillary services procurement; electricity market; energy storage systems (ESS); renewable energy resources; smart grid; storage applications..

I. INTRODUCTION

NOWADAYS, in many countries the increase of generating capacity takes place in small units of so-called distributed power industry (distributed generation - DG), and among them in hybrid power (generating) systems (HPS). They use primary energy conventional sources as well as renewable energy sources (RES), and in many cases produce electricity and heat (CHP). Electricity or heat produced from renewable energy shall also include the fraction of energy corresponding to the percentage of fuels used for the production of the electricity or heat. Using of renewable energy sources is one of the crucial components of the sustainable development, giving rationale economic, ecological and social effects. Electrical energy sources can be qualified into two groups: with production dependent on unpredictable external sources of primary energy, and others. The most difficult is to integrate with power system those, production of which depends on renewable energy sources like: hydro energy, the Sun, and wind energy. The idea of electric energy storage with the purpose of meeting the periodically increasing power demand has been known for a long time. The oldest technology commonly employed in long-time electric energy storage is pumped storage hydroelectric power plants. Technological progress has given us a wide range of energy storage devices employed for long as well as short periods of time. The name commonly used for such devices is Energy Storage Systems (ESS). Both well-developed and new ESS technologies can have potential applications in all sectors of the power industry. They can also serve both technological and economical improvement. At present a lot of research institutes concentrate on renewable energy sources (RES) and availability of their Implementation in power systems [1]. One of the ways to achieve this goal is to build a hybrid power plant based on RES and energy storage system. It is commonly known that implementation of RES and distributed generation (DG) within electric power system can eliminated effectively intermittency of generated power.

Energy storage systems installed within an electricity system can be provided by a range of technologies and can add value in a variety of ways. Income may be derived from an energy store by charging it when the local electricity value is low and discharging it when the value is high. If, at some times, the grid at the point of connection of the embedded renewable generation (ERG) cannot absorb the entire output of the generator, then output must be curtailed and the value of

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the excess is effectively zero. If, at other times, demand is high and expensive generators are used to meet that demand, then the price will be high. Another source of income results from supplying ancillary services, for example, reactive power, voltage, and frequency control and emergency power during a power outage [2].

This paper focuses on the various storage technologies and configurations as well as possible applications of them. Various applications including generation and load shifting, peak shaving, transmission expansion planning deferral, ancillary services procurement, and intermittency elimination of renewable resources are considered. Focus of applications is on renewable resources intermittency elimination. Some related issues including relation between electricity markets and storage systems and correlation among smart grid issues and storage systems are also presented. As a result, some comparisons are conducted in terms of various interested criterions in the field of energy storage comprising storage capacity, power level, response time, unit investment and operation costs, round trip efficiency, physical dimensions, cycle life time, life time, availability, and environmental impacts. The data presented in this paper have been derived from conference and journal articles and websites, many from IEEE. The remainder of paper is as fallow: section II review available storage schemes .Section III gives the possible applications of ESS. Section IV states the relation between ESS and smart grid issues. Section V introduces power market regulation effects on storage systems. Section V gives some classification criterions for ESS and offers useful tables in order to analogy between various ESS technologies. Finally, section VII states the conclusions of this work.

II. Energy Storage Systems (ESS) Technologies

This section reviews all available energy storage systems including hydraulic Pumped Energy Storage (HPES), compressed air energy storage (CAES), flywheel energy storage (FWES), super conductor magnetic energy storage (SMES), battery energy storage system (BESS), supercapacitor or ultracapacitor energy storage (SCES), and hydrogen along with fuel cell (FC) storage system.

A. Hydraulic Pumped Energy Storage (HPES)

The only ESS technology that is both technically mature and widely used is hydroelectric pumped energy storage (HPES). These Plants have been in worldwide use for more than 70 years. These large scale energy storage plants are the most wide spread energy storage technology in use today [3]. There are approximately 280 installations of HPES worldwide. They have a combined generation capacity of about 90GW, which is about 3% of the world's generating capacity [4,5]. In a HPES system, pumps are used during off-peak periods, when surplus cheap electricity can be generated elsewhere on the power system, to move water to a reservoir at a higher elevation than the water source. During peak periods, when power is scarce and expensive, the water in the reservoir is released to move backward through the system, where it drives hydraulic turbines to produce electricity [6]. However, there will probably be few opportunities to build more HPES plants worldwide. Two limiting factors are lack of suitable site and high cost. Perhaps even more important than the cost of HPS are the perceived environmental impacts, including flooding of valleys to create reservoirs and damage to wildlife habitats. Environmental objections to HPS are so severe that they have delayed the operation of completed plants. There is however an alternative to avoid the environmental impacts of the large reservoirs by placing them underground. The use of underground pumped hydro plants has been proven to be technically feasible, but with the high costs associated with placing them underground none currently exist today [3]. Pumped-hydro storage plants are costly and take a long time to plan and build. Other storage technologies do not have the same environmental issues as HPS (although issues may arise if storage systems become more common) [7], but they appear to share the HPS issue of high cost.

B. Compressed Air Energy Storage (CAES)

Compressed Air Energy Storage (CAES) systems use off peak electrical power generated from base load plants or renewable energy sources to compress air into underground cavities (salt cavern, abandon mines, rock structures, ..) or surface vessel. Three air reservoir types are generally considered: naturally occurring aquifers (such as those used for natural gas storage), solution-mined salt caverns, and mechanically formed reservoirs in rock formations. Mainly implementation constraints are related with reservoirs achievement [8,9]. Then during times of high electrical demand this compressed air is combined with a one of a variety of fuels to drive a turbine generator set. The CAES plant uses two third less fuel compared to the conventional units and is able to start up within tens of minutes [10]. It does not require a lengthy startup time that other spinning reserve may require, such as thermal units. CAES plants require a large volume of compressed air to operate for extended periods of time. There are currently two CAES plants in operation today. The first plant was built in Huntof, Germany in 1978. This plant's capacity is 290MW for 4 hours. It has a very impressive performance record of 90% availability and 99% starting reliability. The second was built in McIntosh, Alabama in 1991. This plant's capacity is 110MW for 26 hours. The round trip efficiency for the CAES plants accounting for both thermal and electrical inputs is about 85% [11,12]. The main key to a CAES system is the reservoir has to be air tight and very large. Smaller units using above ground storage tanks are usually limited in their energy storage capacity to only a few hours [13]. The efficiency is approximately 42% to 52% (exhaust gases). Very actual and interesting are the adiabatic CAES which have additional heat storage. In this case the waste heat is stored in this additional heat storage and later used to warm up the compressed air. Therewith the efficiency of the CAES can be increased up to

70% [14].

C. Flywheel Energy Storage (FWES)

Flywheels have had success in the commercial sector for small units in the range of 1kW for 3 hours to 100kW for 30 second [15]. Flywheels are kinetic energy storage systems. Flywheels transform electrical energy into kinetic energy and the other way round, so that the energy is stored as kinetic energy. Basically, a flywheel is composed of a shaft that integrates a flywheel. A rotor of an electrical machine is mounted on that shaft. The flywheel housing contains the electrical machine stator and other elements needed for the appropriate functioning of the machine, for example, the shaft bearings. When electrical energy has to be transformed into kinetic energy, the electrical machine works as a motor that absorbs electrical energy, accelerating the shaft until the working speed is reached. Once that speed has been reached, the electrical machine is disconnected from the net, but the shaft, due to the inertia of the flywheel, goes on rotating for a very long time. In this way, electrical energy has been transformed into kinetic energy, and therefore, energy is stored as the shaft is rotating. To get the shaft rotating indefinitely, mechanical energy losses, such us, bearing friction, aerodynamic losses, and so on must be eliminated. For that purpose, different solutions have been adopted. For example, a vacuum atmosphere or helium atmosphere is created inside the housing. When the stored energy must be extracted from the machine, the kinetic energy is transformed into electrical energy. There are two basic classes of flywheels based on the material used in the rotor. The first class uses a rotor made up of an advanced composite material such as carbon-fiber or graphite. The second class of flywheels uses steel as the main structural material of the rotor. In an integrated flywheel, the energy storage accumulator and the electromagnetic rotor are combined in a single-piece solid steel rotor. By using an integrated design, the energy storage density of a high power steel rotor flywheel energy storage system can approach that of a composite rotor system, but avoids the cost and technical difficulties of a composite rotor. FWES mostly used to provide pulse power. But for power quality application, flywheel systems are widely used in USP, to offer uninterruptible power [16]. FWES has an overall round trip efficiency including the electronics, bearings, and flywheel drag of 80-85%. With the life expectancy of about 20 years [15], the current flywheel designs are modular and can range in size up to 10 plus MW systems, with the larger flywheels being approximately 250kW for 10 to 15 minutes [17]. The self discharge rate of a flywheel is high and depending on design lies between 1% and 10% per hour. Therefore, the use of flywheels for longer period cannot be recommended. Flywheels are characterized by long life time, high energy density, large maximum power output, short access time, high efficiency and small environmental impact [14].

D. Superconductor Magnetic Energy Storage (SMES)

Superconducting magnetic energy storage (SMES) systems store energy in the magnetic field created by the flow of direct current in a superconducting coil that has been cryogenically cooled to a temperature below the superconducting critical temperature. The SMES system includes mainly three parts: a superconducting coil, a power conversion system, and a cryogenically cooled refrigerator. Once the superconducting coil is charged, the current will not decay and the magnetic energy can be stored indefinitely. The stored energy can be released back to the network by discharging the coil. The power conversion system (PCS) uses an inverter/converter to transform AC power to direct current or convert DC back to AC power. The inverter/rectifier accounts for some energy loss in each direction. The SMES loses the least amount of energy in storage process compared to other methods of storing energy. Due to the energy requirements of refrigeration and the high cost of superconducting wire, the SMES system is currently used for short duration energy storage. Therefore, a SMES system is most commonly devoted to improving power quality [16]. A SMES system is inherently very efficient and has sitting requirements that are different from those of other technologies. Because of these characteristics, a SMES system has the potential of finding application in systems with large energy storage requirements. This recently conceived technology meets many of the utility’s requirements for diurnal storage. A usual feature of a SMES unit is the cost scaling with size, which is different from that of other storage devices. For a given design, the cost of a SMES unit is roughly proportional to its surface area and the required quantity of superconductor. The cost per unit of stored energy (mega joules or kilowatt-hours) decreases as storage capacity increases. In addition, the charge and discharge of a SMES unit is through the same device, a multiphase converter, which allows the SMES system to respond within tens of milliseconds to power demands that could include a change from maximum charge rate to maximum discharge power. Both the converter and the energy storage in the coil are highly efficient because there is no conversion of energy from one form to another as in pumped hydro, for example, where the electrical energy is converted to mechanical energy and then back again. The major loss during the storage is the energy required to operate the refrigerator that maintains the superconducting coil in a superconducting state. Because of these characteristics and because it can be easily sited, a SMES has the potential of finding extensive application in electric utility systems [16]. In a SMES system the inverter accounts for about 2-3% energy loss in each direction. SMES loses the least amount of electricity in the energy storage process compared to other methods of storing energy. SMES systems are highly efficient; the round-trip efficiency is greater than 95%. The high cost of superconductors is the primary limitation for commercial use of this energy storage method [18]. In case of large SMES the resulting magnetic field can have an impact on the environment. The disadvantages are small energy density and stability problems for large systems caused by the strong magnetic field [14]. The estimated size for utilities applications was determined to be 5,000 MWh at 1,000 MW [19]. When these large systems would be charged the superconducting coil expands under Lorentz forces and would require a large amount of structure to support the coil to offset these forces. In order to reduce the cost it was determined that placing the coil in an earth trench would be more cost effective [20].

E. Battery Energy Storage System (BESS)

Batteries have been around for over one-hundred years and possess some very unique and desirable qualities. Battery systems are modular, quiet, and non-polluting [21]. They can be located almost anywhere and can be installed relatively quickly. The larger battery systems called Battery Energy Storage Systems (BESS) do not have the environmental challenges of other technologies. These systems can often be installed within a 12 month time frame. The BESS installations can be housed inside a building or some other facility close to the need and of very advantageous when the location is in a city or neighborhood [22]. Because a BESS uses a power converter to change the battery DC power to grid-compatible AC power the units can respond very quickly to load changes on the system. Their response times are about 20 milliseconds (little more than one cycle) and their round trip efficiency is in the range of 60 to 80% [21]. Batteries, however, have some very unique challenges also. Batteries store energy as an electro chemical process. During an electrical charge and discharge cycle the temperature change in the battery must be controlled or it can affect the battery's life expectancy. The type of battery being used will determine how resistant it is to life degradation due to temperature [22]. Another major concern is the batteries life-cycle. Depending on the type of battery and its application the discharge rate maybe its capacity divide by 4, 6 or even 10. This limits the available current in the battery for immediate use. On the other hand, Batteries are generally expensive, have maintenance problems, and have limited life spans. One possible technology for large-scale storage is large-scale flow batteries. For example, sodium-sulfur batteries (NAS) could be implemented affordably on a large scale and have been used for grid storage in many countries. These batteries (NAS) are designed to have a relatively long life (15 years) and come in blocks that can provide 1MW for 6-8 hours. There are many new battery technologies that are being developed to store more energy, last longer, and cost less than the Lead Acid battery. Supercapacitor Energy Storage (SCES)

The super- or ultra-capacitor is not a new technology. It has been around since the 1960's . The super- or ultra-capacitor is an electrochemical double layer capacitor (ECDL). The ultracapacitor is an electrochemical device. There are no chemical reactions involved in the ultracapacitor's energy storage mechanism. The EDLC is a charge storage device, which utilizes a double layer formed on a large surface area of a micro porous material such as activated carbon. EDLC stores the energy in the double layer formed near the carbon electrode surface. There are two layers: one layer of electrolyte molecules and a second layer for diffusion. In the first layer, the electrons cannot move at all. In the second, layer the electrons can move around a little. This mechanism is highly reversible, and allows the ultracapacitor to be charged and discharged hundreds of thousands of times. Some vendors advertise in the million plus cycle range. The ultracapacitor is also temperature resistant with an operating range between -40°C to +65°C and is also shock and vibration resistant [21]. The EDLC has many good features. Virtually unlimited cycle life is the best among them. The EDLC can be fully charged in seconds, and it can be cycled millions of time. The EDLC has a simple charging method; there is no need to build any protective circuits. Overcharging or over discharging does not have a negative effect on the lifespan, as it does on that of chemical batteries. After a full charge, it stops accepting charge [23]. EDLCs do not harm the environment because they do not contain pollutants like some batteries. The EDLC doesn't contain heavy metals or toxic materials like Ni, Cd, Pb. Therefore, an EDLC is more environment friendly than batteries. ELDC offers a round trip efficiency of 84-95%. This combined with the ability of modular, quiet, non-polluting, quick charge and discharge capability, long life (10 to 12 years) and very high cycle life makes the ultracapacitor a very desirable energy storage device. There have been advances in the design of the ultracapacitors using nano-tube technology to improve the surface area of the capacitor. This "nano-tube ultracapacitor" would improve the ultracapacitor's energy density to be compatible with that of a chemical battery. However, the electric double layer capacitor is not an ideal component. There are some limitations. The cells have low voltage, and if there is a need for a higher voltage, a series connection is needed. If there are more than three capacitors in series, voltage balancing is required. EDLCs have a high self-discharge rate. After one month, the charge of the capacitor decreases from full to 50 %.. Also, the ultracapacitor has a relatively low energy density compared to a battery. Its capability is usually on the order of a magnitude less energy density than an equivalent battery. The power density however is a much better in the ultracapacitor. The power density for an ultracapacitor is a magnitude better than that of a battery. Ultracapacitors are currently available in many sizes. Their current voltage ratings are up to as high as 2.7V with a maximum string voltage of 1,500V. In order to be a viable alternative in a large scale energy storage system they will need to be able to handle multiple kV [24].

F. Hydrogen Along with Fuel Cell (FC)

Hydrogen is also being developed as an electrical power storage medium. Hydrogen is created using electrolysis of water and then stored for later use with hydrogen based generating equipment. Hydrogen is not a primary energy source, but a portable energy storage method, because it must first be manufactured by other energy sources in order to be used. However, as a storage medium, it may be a significant factor in using renewable energies. A fuel cell is an energy conversion device that is closely related to a battery. Both are electrochemical devices for the conversion of chemical to electrical energy. In a battery the chemical energy is stored internally, whereas in a fuel cell the chemical energy (fuel and oxidant) is supplied externally and can be continuously replenished [25]. During the operation of a fuel cell, hydrogen is ionized into protons and electrons at the anode, the hydrogen ions are transported through the electrolyte to the cathode by an external circuit (load). At the cathode, oxygen combines with the hydrogen ions and electrons to produce water. The system can be reversible through the use of an electrolyzer, allowing electric power consumption for the production of hydrogen and its storage [26,27]. Fuel cells can store large amount of the power, but with low efficiency (25%) [14]. The efficiency of hydrogen storage is typically 50 to 60%, which is lower than pumped storage systems or batteries. Therefore, the efficiency of whole storage system comprising hydrogen production and storage along with fuel cell system is about 12-15 % which is very low.

III. ESS Applications

Energy storage systems possess several vital applications in power systems including:

A. Renewable resources intermittency removal

It is expected that growing trend in renewable resources installations will remain and that wind power will play a very important role in the near future. Due to sudden and large changes in renewable sources, the power output from them can have large fluctuations. The energy storage system has both real and reactive power control ability. Therefore, the intermittency problem of renewable resources can be overcome effectively and generated power can be consumed every time is required [16].

B. Price Arbitrage (Peak Shaving)

By means of Storage systems extra generation capacity can be stored in off peak hours and effectively used at demand peak hours. Being able to store the excess available energy that has not been consumed not only helps peak shaving, it also increases the overall efficiency of the power system [6].

C. Ancillary Services Procurement

Another benefit associated with energy storage systems is in the provision of ancillary services. These include spinning reserves, regulation, VAR support, congestion management, black start capability and so on [28].

1) Spinning Reserves

Storage systems can provide a reliable source of power in order to covering system emergencies and reserve requirements. Stored energy can be released quickly any time is required without ramp rate problems of conventional generating units [6].

2) Regulation

"Regulation" refers to the need for power grid operators to precisely match, moment to moment, the supply and demand for electricity. If supply and demand go too far out of synch, the power system can become unstable, consumer electrical equipment and appliances can be damaged, and ultimately the grid can fail. Because demand is constantly changing, the output of some power plants on a power system is constantly varied, up and down, to match demand. Regulation service from conventional generators has worked reliably for decades, but in principle a storage device provides the service more efficiently [14].

3) VAR Support

Another service that is essential to maintaining the stability of the grid is reactive power supply. Although generating plants produce real and reactive power, additional reactive power must be injected at various points throughout a power grid. This is currently accomplished by specialized devices, but storage systems are another potential option [14].

4) Congestion Management

Through enhancing transmission capacity of power lines and relief of overloaded transmission lines form an efficient congestion management scheme. Energy storage can be used to cover the relatively few and short periods when the line capacity is exceeded [29].

5) Black Start Capability

Since after massive system failures (blackout) there is a need to independent power sources in order to starting generating units, ESS can provides a good mean for power plant restart instead conventional diesel starters [1].

6) Transmission Upgrades Deferral

Storage systems can be used to defer an upgrade to a transmission line. In this case, system loads are approaching the capacity of an existing transmission line, and ongoing load growth requires that action be taken to prevent an overload. If the upgrade can be deferred for a full year, the financial benefit derived is equal to the annual carrying charges for the cost of the upgrade [28].

IV. ESS and the Smart Grid

Power grid modernization proposals are often made under the rubric of the "smart grid," a term that encompasses technologies that range from advanced meters in homes to advanced software in transmission control centers. There is no standard definition of the smart grid. The smart grid can be viewed as a suite of technologies that give the grid the characteristics of a computer network, in which information and control flows between and is shared by individual customers and utility control centers. The technologies would allow customers and the utility to better manage electricity demand, and include self-monitoring and automatic protection schemes to improve the reliability of the system. Although grid technology has not been static over the years, the smart grid concept would implement capabilities well beyond any existing electric power system.

The smart grid involves integrated operation of the power system from the home to the power plant and could encompass management of centralized and distributed EPS. In principle a smart grid system would optimize the full range of available resources including the various kinds of distributed storage and net metering distributed generation to meet multiple needs, including peak shaving, backup power in the case of outages, electricity regulation, and ensuring that distributed battery systems are charged during non-peak hours. The close relationship between the development of storage and the smart grid is clear. The ability to accommodate a diverse range of generation types, including centralized and distributed generation as well as diverse storage options, is central to the concept of a smart grid. Through these generation and storage types, a smart grid can better meet consumer load demand, as well as accommodate intermittent renewable-energy technologies.

Distributed resources can be used to help alleviate peak load, provide needed system support during emergencies, and lower the cost of power provided by the utility. Like electricity storage, the smart grid is for the most part a developmental rather than operational technology. Other than installation of smart meters in some localities (which permit interactive communication and in some cases appliance control between homes and utility control centers) deployment of the "full" smart grid, which would include optimization of storage and other resources, has not progressed beyond pilot projects [29].

V. Power Market Regulation and ESS

Restructured and traditional power markets pose different challenges to EPS projects. The constantly changing market prices in restructured markets also provide additional opportunities to use EPS for price arbitrage. Countering these advantages, restructured markets operate using complex rules that have probably not been designed to accommodate the specific characteristics of electricity storage, such as the ability of a single facility to serve transmission and generation functions or the short discharge duration of some storage technologies. In 2008 and 2009, RTOs began to change their rules, procedures, and operating software systems to account for electricity storage. ISO New England, the New York ISO, and the Midwest ISO (MISO) have all adopted temporary or permanent rules changes to facilitate the use EPS for regulation services. However, these changes do not address other storage services or the potential contribution of large-scale storage projects.

On the other hand, utility commissioners may be reluctant to spend ratepayer money on what they view as technological experiments. Another consideration is the economic incentives utilities face in traditional markets. In these markets the allowed rate of return is in part a function of the size of the utility's "rate base" that is, the amount of capital invested in plant and equipment. Other things being equal, the larger a utility company's capital investments the more money it will be allowed to earn in rates. This incentive can make public utility commissions skeptical of utility plans to invest in expensive new technologies [6].

VI. ESS Categories and Comparisons

First and second parts of this section offer storage systems categories base on storage level and typical run time. Third part offers some useful tables in order to compare various ESS technologies.

A. Classification Based on storage Level

EPS technologies can be broadly categorized into two groups, including: centralized bulk power storage and distributed storage.

1) Centralized Bulk Power Storage

Centralized bulk power storage facilities are relatively large and complex installations designed to store large amounts of electricity. Capacities range from tens to hundreds of megawatts, and the units can supply power to the grid for hours at a time. The primary form of centralized bulk power storage and in fact the only form of EPS of any type in commercial and widespread use is hydroelectric pumped storage (HPES). The other form of centralized bulk power storage is compressed air energy storage (CAES) [6].

2) Distributed Power Storage

Distributed multipurpose power storage includes facilities dispersed through the power system and used to meet specific, local needs for power. The facilities can be located at generating plants, on the power transmission or distribution systems, or at an end-user site. The facilities are typically small but this may change as technologies mature. All of these technologies are still in the developmental stage including all storage technologies except hydroelectric pumped storage (HPES) and compressed air energy storage (CAES) [6].

B. Classification Based on Typical Run Time

The following part will provide a brief overview of energy storage technologies, categorized by their typical run times into hours, minutes and seconds.

1) Hours

There is already a large installed energy storage systems based on pumped hydro systems. On a similar scale of hundreds or even thousands of megawatt-hours, compressed air energy storage (CAES) systems have been proposed, and smaller CAES systems have been operating for many years. While hydro and CAES systems provide economical energy storage, there are three factors that limit them: (1) they are geologically limited; (2) their scale does not lend itself to use at the lower load levels of weak grids; (3) they cannot react instantly, but behave similarly to generators. In recent years, there have been a number of advances in unconventional battery systems, mainly in the field of high-temperature technologies and flow batteries. Flow batteries represent a dramatic departure from traditional battery technology, in that the power rating is determined by the size of bipolar electrode stacks and the energy is contained in electrolytes that are pumped through the stacks. In this manner, the power and energy are separated from one another.

2) Minutes

While smaller installations with conventional batteries may be engineered for hours of operation, the most promising aspect of this group of technologies related to energy storage applications is their ability to supply significant power levels for several minutes. In this operating mode, they can provide significantly more energy than short-duration devices such as flywheels and super capacitors. Furthermore, they are able to work with other generation on the network, rather than in competition against it as the bulk storage technologies are attempting to do.

3) Seconds

The three main storage options for seconds of run time are flywheels, super capacitors, and systems based on superconducting magnetic energy storage (SMES). The SMES systems are still at the demonstration stage and are grappling with issues such as high cost and strong magnetic fields. Flywheels and super capacitors (also known as ultracapacitors), however, are now starting to enter the mainstream. Flywheels and super capacitors share a number of characteristics that set them apart from batteries.

These devices are capable of delivering theirentire useful energy content over a discharge time of up to about 20 s. This means, however, that a 15s system must be doubled in size for a 30s run time, or quadrupled for 1min.

4) Distributed Power Storage

Distributed multipurpose power storage includes facilities dispersed through the power system and used to meet specific, local needs for power. The facilities can be located at generating plants, on the power transmission or distribution systems, or at an end-user site. The facilities are typically small but this may change as technologies mature. All of these technologies are still in the developmental stage including all storage technologies except hydroelectric pumped storage (HPES) and compressed air energy storage (CAES) [6].

C. Comparisons

The most important parameters in order to rating storage technologies are storage capacity, power level, response time, unit investment and O&M costs, round trip efficiency, physical dimensions, life time, availability, and Environmental Impacts. For the technologies introduced in section II, all relevant technical characteristics of them are summarized in Table I [14]. As mentioned earlier, energy storage systems installed within an electricity system can be provided by a range of technologies and can add value in a variety of ways. Abovementioned technologies along with relevant applications are summarized in Table II [2].

TABLE I
TECHNICAL CHARACTERISTICS OF ENERGY STORAGE SYSTEMS [14]

Technology	Flywheel	Capacitor	SMES	NAS Battery	Pump Hydro	CAES	Hydrogen
Storage Capacity (MWh)	2.5	Small	0.003	Several 100	500-8000	500-2500	Several 1000
Power Capacity (MW)	25	Large	10	Several 100	100-1000	Several 100	Several 100
Energy Density (kWh/m3)	1000	5	2.8	400	-	-	-
Cycle Life Time	10^6	10^6	Several 1000	2500	-	-	-
Life Time (Years)	20	10	20	15	50	40	-
Access Time	ms	ms	ms	ms	1-3 min	10 min	-
Self Discharge	1-10 %/h	10 %/Day	Cooling Power	No	No	-	-
Efficiency (%)	90-95	90	< 95	90	75	54-70	25
Power/Energy	25MW->5min 5MW->30min	Rated Power for sec up to Several min	High Power for Several sec	Rated Power for Hours, Very High Power for Minutes	Rated Power for Long Time	Rated Power for Long Time	Rated Power for Long Time
Environmental Impact	Small	Medium	Small	Medium	High	Medium	Medium

TABLE II

POSSIBLE APPLICATIONS OF VARIOUS ESS TECHNOLOGIES [2]

Full Power Duration Storage	Applications and Possible Replacement Of Conventional Electricity System Controls	H+E+FC	CAES	PHES	Redox Flow BES	Other BES	FWES	SMES	ELDC
4 Months	Annual Smoothing Of loads, PV, Wind, Small Hydro	√							
3 Weeks	Smoothing Weather Effects: Load, PV, Wind, Small Hydro	√							
3 Days	Weekly Smoothing of Loads and Most Weather Variations	√	√	√	√				
8 Hours	Daily Load Cycle, PV, Wind, Transmission Repair	√	√	√	√	√			
2 Hours	Peak Load Lopping, Standing Reserve, Wind Power Smoothing	√	√	√	√	√			
20 Minutes	Spinning Reserve, Wind Power Smoothing, Clouds on PV	√	√	√	√	√	√		
3 Minutes	Spinning Reserve, Wind Power Smoothing of Guts	√		√	√	√	√		
20 Seconds	Line or Local faults, Voltage and Frequency Control, Governor Controlled Generation				√	√	√	√	√

VII. CONCLUSION

It can be seen from presented issues that there are numerous options to energy storage systems. Depending on the technology and application needs they can assist in load leveling and shifting, spinning reserves, frequency control, VAR support and voltage regulation, relief of overloaded transmission lines, release of system capacity and more effective and efficient use of capital resources. By locating energy storage facilities appropriately throughout the transmission grid they can help stabilize the system by translating the power from the remote generation units closer to the load. They can provide many of the power quality and system regulation duties. Any excess power will be captured by the energy storage devices for later use. Utilization of renewable energy such as solar, wind and tidal will become a reality due to the enabling technology of energy storage devices. No matter when or where it is needed in the system it could be made available for use. This evolutionary change of adding large, medium and small scale energy storage devices to the power system in key locations will be a major step in the solution to the use of renewable energy along with the current issues of reliability, stability, and power quality.

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