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Synopsis of the Application of Energy Storage Systems in Microgrids for Clean Energy Production

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Abstract
The concept of an energy storage system is principally based on the operation of devices that store any form of energy at one time and discharge the energy for useful operation at a later time. There are varieties of ways by which the energy could be stored such as potential, kinetic, chemical and electrical or thermal energy. Still, certainly, the stored energy is discharged as electrical energy using different kinds of devices for electric power generation. Undisputedly, renewable energy resources from wind and solar photovoltaic sources are subject to stochastic variation. In most cases, intermittent behaviours of these renewable energy sources make the output power generated from their energy systems fed directly into the electric grid system or consumed at their instance of production using decentralized power generation technology. Instant consumption of such renewable energy systems with stochastic tendency could result in a waste of energy especially in a situation where excess power is generated amidst off-peak period. Small-scale hydroelectric power use in rural communities could also be affected by the seasonality of water flow into the small dam. In this case, there is a need to compensate for a possible energy shortage scenario which may be encountered on the condition of shortage of water availability. The best way to optimize renewable energy sources application for electricity generation in isolated off-grid communities is by hybrid system application. Consequently, the paper presents the state-of-the-art of different kinds of energy storage mechanisms suitable for exploiting hybrid energy systems with at least a renewable-based source.

Keywords: Energy Storage, Microgrid, Hybrid Systems, Renewable Energy

1. Introduction

Energy storage systems are powerful utility tools used in power system engineering to back up energy supply stability and mitigate stochastic characteristics of renewable energy generators. In addition, storage systems are utilized for the reduction of energy crisis scenarios and help in schemes for emission control in line with global atmospheric decarbonization obligations. Energy engineers have a fundamental task to maintain energy balance between utility and the electricity customers to minimize marketing constraints. In some unfolding situations, unanticipated incidences in power systems may conceivably bring about failures of energy such that flexible and compensated equipment be installed to mitigate the sudden loss of power or shortage of energy demand at a definite period. Present growth in the global electric power sector is going through vibrant changes such that the emerging energy storage systems are fast becoming realistic opportunities for restructuring the electricity market, integrating renewable energy resources, aiding localized integrated distributed energy generation, power quality improvement and supporting network operation under more critical environmental scenarios [1]. The stochastic predisposition of distributed renewable energy sources makes them prone to the use of energy storage mechanisms based on the fact that the energy systems are affected by climate and meteorological variability. Variations connected with renewable energy systems is more threatened in a small power capacity, particularly in microgrid (μG) systems used for island power generation.

A μG system utilizing renewable energy sources (RES) certainly needs an ESS to uphold energy balance strategic management to satisfy demand and supply equilibrium. Given the fact that most hybrid power systems are operated on small-scale μG using intermittent RES either as complete or sub-component, hence, the normal operation of μG could be susceptible to arbitrary power exchange between the supplier and the loads with constricted opportunity for power quality control [2]. In this paper, an overview vis-à-vis electric energy storage (EES) systems for µG application involving renewable energy systems for small-scale power integration is presented. Precisely, the framework of the paper covers energy storage systems used for handling solar photovoltaic systems, micro wind and pico-hydro turbines as well as fuel cells of smaller electrical power capacities. At present, there is increasing curiosity in the exploitation of renewable energy sources using hybrid power system configurations. The fluctuating nature of some RES could initiate some operating and planning complexities in the power systems. Thus, EES systems are well considered to be essential devices for mitigating the impacts of variable RES [3-5].

2. General Concept of Energy Storage Systems

The general theory of energy conversion is that one form of energy can be converted into another. Electrical energy can be stored in different forms and later on transformed back to the electrical energy that is to be used. Therefore, the most important varieties of electrical energy storage technologies that have been used for exploiting electricity include conventional batteries, compressed air energy storage (CAES), supercapacitors, pumped hydro, flywheels, fuel cells (FC), and superconducting magnetic energy storage (SMES). Given the benefits presented by these storage systems, they are somewhat not sufficiently used in the present day current electric power sector. The majority of electricity consumers are not fully aware of the benefits of integrating EES into the power sector. Even though they are associated with high capital costs, modern electricity services especially on a commercial scale could demand EES use in many positive impacted scenarios. The present-day electric power sector is going through a structural market revolution to the harmony of EES integration concerning generation and demand satisfaction. However, more research efforts are still ongoing regarding how to decrease cost in connection with the deployment of EES as RE exploitation is increasingly becoming imperative especially in wind power dispatchability [6-10], solar energy [11-17] and fuel cell [6] utilization. Despite the enormous advantages offered by EES, there are also some increasing numbers of challenges affecting the deployment of the systems for energy use.

2.1 Electrical Energy Storage Systems

Electrical energy systems are importantly exploited in the form of electrostatic mechanisms that accept and return their stored energy in the form of electric power. They are potentially versatile energy application systems used in power engineering utilities. They are used as a path for recovering and storing energies. Also, they could however enable the decoupling of electric power generation utility systems from the demand side of the system for quite a reasonable time. In essence, rapid power delivery could be accomplished using electrical energy storage systems. Examples of electrical energy storage systems are superconducting magnetic energy storage (SMES), conventional capacitors and super-capacitors. Considering some vital ranges of benefits electrical energy storage systems could offer, therefore they are becoming more important in the electric power industry. Their rapid potential for the development of energy storage systems in the power industry coupled with anticipated cost reduction could make them more widely adopted.

Conventional Capacitors: A conventional capacitor is a two-parallel plate device separated from one another by an insulating material. Their basic function is storing energy electrostatically in an electric field between two parallel electrically conducting plates (electrodes) separated from each other by conventional solid dielectric materials. The storage mechanism of conventional capacitors is dependent on the thickness and surface area of the solid dielectric used. Capacitors can be charged at a faster rate compared to many other energy storage systems like batteries [18]. In many electrical connections, conventional capacitors are commonly used as an integral part of circuit connections for storing energy which is to be discharged whenever the charging source is disconnected. Though not being used for hybrid renewable energy exploitation, in power system engineering it is characteristically used for power factor correction and voltage support stabilization. One negative aspect of conventional capacitors is that they are characterized by limited energy storage potential resulting from low capacity and energy density [19] and for this reason, they have been superseded for large-scale energy storage applications by super-capacitors [20].

Supercapacitors: A supercapacitor can also be called an ultracapacitor. It is an electrical double-layer capacitor [18] (EDLC) as shown in Fig 1. Despite the fact that it is highly developed than the conventional capacitor, their mode of operation traditionally follows the standard of operation of capacitors. While conventional capacitor could not suitably address large problems of handling energy storage of large capacity, recent advancement in the technologies of energy storage brought about remarkable improvement in the capacitance and energy density of capacitors as require for commercial power application, hence, the name supercapacitor. The energy storage potential capabilities of supercapacitors are considerably larger than that of conventional capacitors, by approximately two orders of magnitude (10–100 s kW) [21-22]. Other advantages of supercapacitors include decrease in power fluctuations [23-24] and speedy recharge devoid of the risk of overcharging (−40 to 70 ◦C) [19]. Supercapacitors have long life and virtually no maintenance as well as energy efficiency of about 75–80% [25]. Presently, more research and development efforts are still ongoing among the ESS manufacturing companies in the United States, Japan, UK, Russia and France [18] towards reducing the rapidity of energy discharge in supercapacitors and energy loss due to high self-discharge.

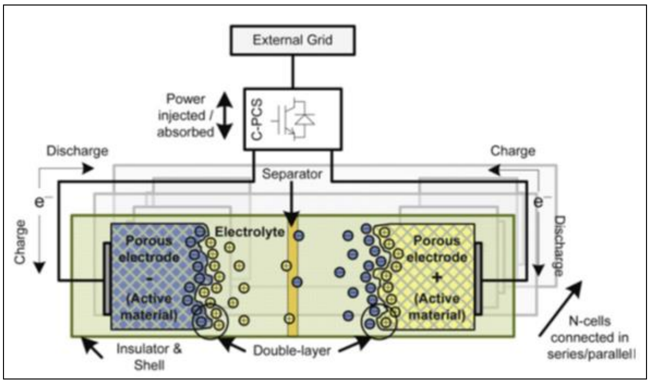

Fig 1: Energy storage system based on a supercapacitor [26]

Superconducting magnetic energy storage: Superconducting magnetic energy storage (SMES) system uses the magnetic field produced inside a superconducting coil by means of the flow of direct current to store electrical energy. Vitally, SMES is the only branded energy storage technology that can store electrical energy directly in the form of electric current [27]. Electrical energy is stored as direct current passing through a coil made from a circular superconducting material so as to make current circulate indefinitely with almost zero loss [18]. The energy storage transition in SMES is accomplished by cryogenically cooling the temperature of the superconducting coil system to a temperature lower than the superconducting critical temperature. A schematic representation of a SMES is shown in Fig 2. The system consists of three units: Cryogenic refrigeration system, a superconducting coil unit and a power conditioning system.

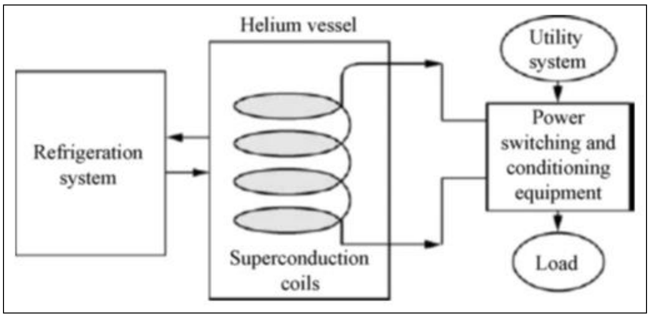

Fig 2: Schematic of an SMES [28]

Conversion energy efficiency in the SMES system is around 95% [29]. Specific areas of applications of SMES in power systems include transient and dynamic compensation for system voltage stability, increasing system damping, and improving the dynamic and static stability of the system [29]. There are limitations demands for high cooling requirements which is expensive to provide and sensitivity to magnetic field environments which require protection [29].

2.2 Mechanical Energy Storage Systems

Conventionally, mechanical energy comprises kinetic or potential energy systems. An ESS is categorized as a mechanical energy storage system if it can be operated using the mechanism of conventional potential or kinetic energy logic. Examples of mechanical energy storage systems are pumped hydro energy storage (PHES), flywheel and compressed air energy storage (CAES). A pumped hydro energy storage (PHES) and compressed air energy storage (CAES) fit into the family of potential energy storage schemes while a flywheel operates on the principles of kinetic energy.

***Pumped Hydro Energy Storage (PHES)*: ** Is a storage system whereby water is pumped from a lower reservoir to another one at a higher altitude using hydraulic gravitational potential energy offered by the difference in height between the two reservoirs. In most cases, the pumping mechanism is usually executed during the period of off-peak having low electricity demand by the customers. At a high-peak scenario with a higher demand for electric power, water is released from the upper reservoir via a hydroelectric turbine to generate power and collected in the lower reservoir [30]. Fig 3 shows a schematic of PHES accommodating other important hydroelectric power plant components. Hydroelectricity is one of the renewable energies with nearly negligible environmental pollution. Therefore, PHES is in the category of energy storage system for renewable power exploitation. Currently, PHES is the most prominent large-scale ESS for large power applications [31] and the global potential has been estimated at 129GW installed at various locations of over 200 sites [20].

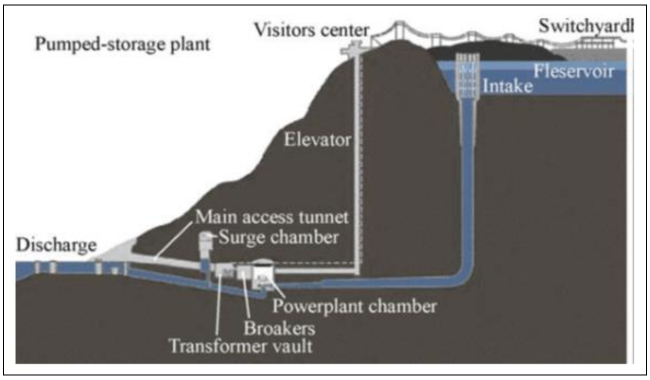

Fig 3: A schematic of pumped hydro energy storage [32]

Storage capacity and power potential of PHES is determine by the size in volume of the reservoirs and height difference between the two reservoirs. Available space to build two large dams [31] is another important factor which must be put into consideration. PHES can be used for leveling power variation associated with renewable energy. The use of PHES can be divided into 24 h time-scale applications, and applications involving more prolonged energy storage in time, including a number of days [33]. PHES has elongated lifespan of about 30-50 years and efficiency of 65-75% [26] and capital costs of 500-1500 €/kW and 10-20 €/kW h [34].

***Compressed air energy storage*: ** Compressed air energy storage (CAES) is another major ESS which can be used in hundreds of megawatts of electric power beside PHES. CAES (Fig 4) is established on the technology basis of conventional gas power plant and consist of five essential parts: motor/generator, air compressor, turbine train, cavity/container and control equipment. The motor/generator unit make use of clutches to offer exchange of commitment to the compressor system. The air compressor system is responsible for accomplishing the air compression process with the aid of cooler systems while the turbine train maintains low- and high-pressure demand of the system. Compressed air storage requirement within the system is accomplished by the cavity/container which could be system using existing underground facilities such as salt domes, rock caverns or abandoned mines [5] with potential to store gas in the range of 4-8MPa [18, 31, 35]. Control equipment executes complementary functions such control of fuel consumption, exchange of process heat, monitoring of cooling requirements. In the work conducted by Cavallo [36] the use of CAES for handling wind energy exploitation has been validated for wind leveling and management of output energy. There are only two CAES power plants in the world one with 290MW in Huntorf (Germany) [37] and 110MW in Alabama (USA) [38] and they have both being confirmed for high reliability and economic feasibility, thereby sparking substantial concern for constructing more for wind integration [5]. CAES has a very limited environmental impact on the surface of the earth due to its characteristic underground storage system [18, 39].

Compare to PHES, CAES how lower capital cost of $400–800/kW [5] and depending on the system storage capacity. Exploitation of CAES could be confronted by a number of factors such as difficulties in the exploration for geological feasibility study for the determination of suitable and potential site for adequate storage system construction, overall economic viability and carbon emissions from the system due to natural gas consumption.

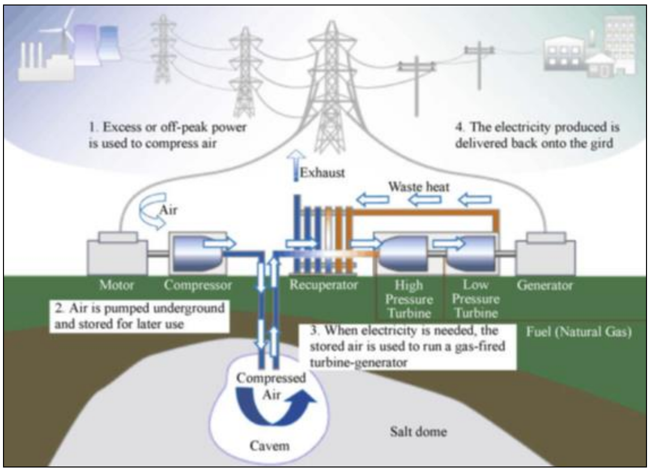

Fig 4: System depiction of Compressed Air Energy Storage [40]

***Flywheels*:** A flywheel system is a mass that stores/retrieves energy according to its change in acceleratory rotational velocity, and is a promising technology because of its long life of 15–20 years, long cycle life of 10,000-100,000, and high efficiency of 90–95% [18, 41-42]. Flywheels have been used to store energy for thousands of years [27, 43]. Fig 5 presents a schematic of a flywheel energy storage system. The system has the benefit of long-life span over batteries and that makes it capable of providing several hundreds of thousands of full charge-discharge cycles [43]. The operation of a flywheel with respect to system energy capacity is dependent on the speed of the rotor as well as physical size. In addition, the power output rating of the system is determined by motor-generator system capacity. Usually, flywheel energy storage system is suitable for high power and short duration application due to their fast response, high power, and rapid recharge characteristics. The cost for flywheel is in the range of $1000–5000/kW h and presently application of flywheel in electric power industry is not widespread. Flywheels have been used in pulse power, power conditioning, uninterrupted power supply and its application for variable renewable energy exploitation has started to gain increasing recognition.

Flywheels have been used by Urenco Power Technologies for smoothing wind turbine output and stabilizing of a small-scale island wind supply [18]. A study conducted by Nakken *et al*. [44] reported that a 5-kW h, 200 kW, flywheel is used to stabilize 10 household grids in Utsira, Norway, in a wind hydrogen system. As well, research by Beacon power had revealed that the storage system can be used for mitigation of cloud cover effects for solar photovoltaic by preventing voltage disturbances, and as an energy buffer for mitigating wind power ramping [45]. A very important aspect of viable flywheel construction is reasonable system overall efficiency which could thus reduce losses. All these had eventually increased the tendency of using the flywheel storage system for several applications. Also, include increasing efforts for renewable energy exploitation couple with other future application covering essential areas of grid support application, transmission backup and electric vehicle systems. Strategies have been suggested to integrate the characteristics of flywheels, i.e., fast ramping and low energy, with another device, such as PHES, hydrogen, or diesel to remove the weaknesses of both devices for better variable renewable energy system integration [44-46].

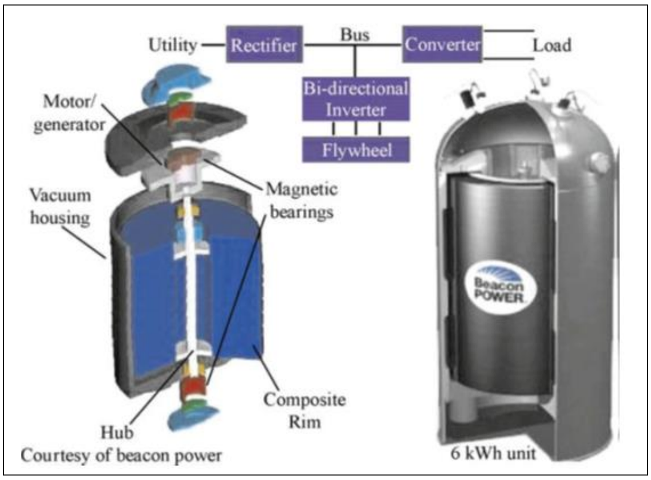

Fig 5: A typical Flywheel system [43]

2.3 Chemical energy storage systems

Batteries are devices with characteristic reversible chemical energy storage mechanisms. Mainly, a battery energy storage system comprises batteries, a control and power conditioning system (C-PCS) and the rest of the plant [47] for energy dispatch. In battery storage technology, the chemical energy stored in the system is converted to electrical energy and vice versa. Various significant designs of batteries in the modern world have emerged in recent times for different applications in electric power concepts comprising industrial and residential homes. However, new designs are targeted towards increasing some specific important features such as energy density, efficiency, depth of discharge, life span, self-discharge and system operating temperature. It is important to note that not all kinds of batteries are suitable for electric power applications [48]. Batteries designed for electric power exploitation are being thought of going for large scale regarding the unit production and high output power in the future. While some batteries are characterized by technological maturity (lead acid), some others are still at a premature stage. Technical and economic feasibility of battery storage technologies are ongoing area of research efforts in industries and academic institutions. Centrally, cost reductions as well as increase in electrical energy storage capacities of batteries have occupied a very important agenda of researchers to achieve some envisioned future advantages of batteries towards electric power grids applications. Among the various battery technologies used today to harvest electric power, a few batteries that are promising and sustainable for electricity applications are discussed in this framework.

***Lithium ion*:** Lithium ion (Li-ion) batteries could either be phosphate or cobalt based and to achieve the flow of current in the system, lithium ion migrates between anode and cathode. The anode of a lithium-ion battery is made of graphitic carbon while the cathode is a lithiated metal oxide. The battery system electrolyte is a solute of lithium salts dissolved in a solution of organic carbonates. Typically, the battery has high energy density among others in the family of battery energy storage system (BESS). There is a feature of high-power density of the battery coupled with high efficiency thereby making the storage system suitable for power quality management. At present the battery system has been used predominantly in portable electronic systems such are laptops, mobile phones and space communication technologies. Research on the uses of the battery for renewable energy storage applications is revealed to be very reasonable in the future [49] due to higher efficiency of approximately 100% [50]. Generally, lithium battery of any kind has a major drawback of sophisticated battery management [51] and high cost [52].

***Lead acid*:** Lead acid (LA) battery is also known as lead-acid accumulator. Regarding technological maturity, LA has been recognized as the most widespread battery for electric power applications. LA battery cells are made up of spongy lead anode and lead acid cathode, immersed in a dilute sulphuric acid electrolyte, with lead as the current collector [20]. There are two types (flooded and valve-regulated) of LA. While both uphold the same electrochemical technology, the major difference between the two is physical size and capital cost as well as a maintenance procedure. Deep-cycle lead-acid batteries are ideal for small-cycle renewable energy integration applications; these batteries can be discharged repeatedly by as much as 80% of their capacity [53] and hence are suited for grid-connected systems where users sell power back to the grid through net metering [49]. There is general low cost of purchasing LA compare to other kind of batteries. This outstanding advantage has been responsible for the widespread use of the battery especially in automobile industries. It is also suitable for uninterrupted power supply (UPS) application and resolution of power quality problems.

***Sodium Sulphur*:** Sodium Sulphur (NaS) battery is made up of liquid Sulphur at the positive electrode and liquid sodium at the negative electrode. The system uses liquid sodium as active material and is separated by a beta alumina electrolyte. The conventional operation of the battery is such that permits only the positive sodium ions to pass through it and combine with the Sulphur to produce sodium polysulfides. In the charging state, sodium polysulfides is break down to liberate positive sodium ions. The Na+ ions produced then recombine and deposit as sodium elements via the electrolyte. The discharging cycle process pushes for the flow of electron as the positive Na+ flows through the electrolyte. The proper functioning of sodium Sulphur battery is such that require a condition of high temperature in the range of 300-350ºC. The battery has characteristic high efficiency and energy density with prolonged life cycle. The battery system is fabricated from low-cost materials. It is widely used for grid energy storage support.

***Flow batteries*:** There are different kinds of flow batteries. Typically, flow batteries use their external electro-active electrolytes to store energy and convert the energy directly into electricity when needed. Flow batteries are classified into redox structures (all vanadium, vanadium-polyhalite, vanadium–polyphide, iron-chromium, hydrogen–bromine) and hybrid structures (zinc-bromine and zinc–cerium) [20]. Very common advantages of flow batteries are that they are characteristically suitable for large power applications with uncomplicated upgraded trend but negatively affected with high cost combine with technological immaturity related to large-scale use. Also, Zn-Br flow batteries were reported to show evidence of complications dealing with corrosive and toxic materials [54]. Notwithstanding, some of the batteries especially Vanadium redox batteries (VRB) have been used for some suitable electric power applications such as renewable energy stabilization, uninterrupted power supply, power quality, load leveling and hybrid energy systems involving wind and solar energy devices.

***Nickel Cadmium*:** Nickel-cadmium (Ni-Cd) is one of the robust and technologically matured kinds of batteries which could be ranked next to lead-acid accumulators. A typical Ni-Cd battery uses a potassium hydroxide electrolyte, nickel oxy-hydride as the cathode and metallic cadmium as the anode. In their early stage of development, the batteries were very popular and useful for energy storage. However, they have been overshadowed by the discovery of another battery, Nickel metal-hydride) Ni-MH with superior characteristics to take precedence over the deficiencies so far recorded in the uses of Ni-Cd such as charging memory effect, toxicity of cadmium element, low rate capacity and discharge rapidity. Ni-MH also has the advantage of improved high-rate capability (due to the endothermic nature of the discharge reaction), and high tolerance to over-discharge [55]. Both Ni-Cd and Ni-MH share some similar features compare to acid accumulators such as a better life cycle, low maintenance requirements but quite expensive. From technical perspective Ni-Cd can suitably replace lead acid battery due to its ability to deliver power for a longer period of time. Ni-Cd could be environmentally unsuitable if the toxic cadmium it contains is allowed to be discharged in any uncontrollable circumstances into the surrounding environment. Ni-Cd batteries present lots of advantages in PV applications and factors such as their cycling ability, robustness, long life and reliability make them ideal in service under unfavorable conditions [56].

***Hydrogen Energy Storage (Fuel cell)*:** A fuel cell (FC) energy storage mechanism uses the technology of electrochemical transformation with the aid of the exchange of chemical reactions between the fuel (anode) and oxidant (cathode) via the electrolyte for power generation. Fuel cell is one of the main facilitating technologies for the development of future hydrogen economy [57], this is because hydrogen is the appropriate fuel used in the system for electricity generation. The operating action of fuel cells is reversible and designed such that the reactant and electrolyte combine actions to produce electricity in addition to products, which can be electrochemically upturned by the application of electricity to convert the product back into the original reactant. There are different kinds of FCs [Table 1] and they have been used for different applications in the last two decades.

Table 1: Characteristics of different types of fuel cells [58-60]

Fuel cell type	Operating temperature (°C)	Electrolyte	Charge carrier	Catalyst anode	Fuel for the cell	Electrical efficiency (%)	Qualified Power (kW)
Alkaline (AFC)	70-100	KOH (aqueous solution)	H^+	Ni	H_2	60-70	10-100
Proton exchange membrane (PEM)	50-100	Perfluor-sulphonated polymer (solid)	H^+	Pt	H_2	30-50	0.1-500
Direct methanol (DMFC)	90-120	Perfluor-sulphonated polymer (solid)	H^+	Pt	Methanol	20-30	100-1000
Direct ethanol (DEFC)	90-120	Perfluor-sulphonated polymer (solid)	H^+	Pt	Ethanol	20-30	100-1000
Phosphoric acid (PAFC)	150-220	Phosphoric acid (immobilized liquid)	H^+	Pt	H_2	40-55	5-10,000
Molten carbonate (MCFC)	650-700	Alkaline carbonate (immobilized liquid)	CO^{2-}	Ni	Reformate or CO/H_2	50-60	100-300
Solid oxide (SOFC)	800-1000	Yttria-stabilized zircon (solid)	O^{2-}	Ni	Reformate CO/H_2 or direct CH_4	50-60	0.5-100

Advantages offer by fuel cells include application for small and large power, high energy density and easy use in mobile electric power services such as aerospace and submarine technologies. Major disadvantages of fuel cells for electric power use are low power efficiency and high cost. FCs has numerous potential areas of application for technological development such as replacement for gasoline in automobile system which is illustrated in Fig 6. Hydrogen fuel cell vehicles (HFCVs) have been used as a zero tailpipe-emission substitute to the battery electric vehicle (EV) because of its emission free nature [61]. Other important areas of application of FCs include replacing internal combustions engines, providing power in stationary systems and portable power consumptions [57] as well as automobile technologies for auxiliary power supply.

3. Energy Storage Systems in Hybrid Renewable Energy-Based Electric Power

The idea of exploiting renewable energy sources for power generation is predominantly triggered by the prevailing quest for tackling climate change orchestrating from contaminating conventional electricity generation systems. This has forced up some renewable energy systems such as wind turbines [63] and PV systems [64]. As earlier pointed out, wind turbines and photovoltaic electric systems are highly characterized by stochastic behaviors and consequently generate electricity with intermittent outputs, especially at µgrid level. A µgrid system is a very flexible form of power system which is capable to explore different kinds of renewable and conventional energy sources but yet maintain some weak characteristics regarding system reliability, quality and stability. Fig 7 presents a block diagram of the hybrid power conversion system of PV. Renewable energy systems from solar PVs and wind turbines without energy storage systems is much more associated with power quality and output reliability challenges. In this perspective, utilization of suitable energy storage mechanisms with reliable energy density is the best solution to guarantee the voltage and frequency stability of the power network.

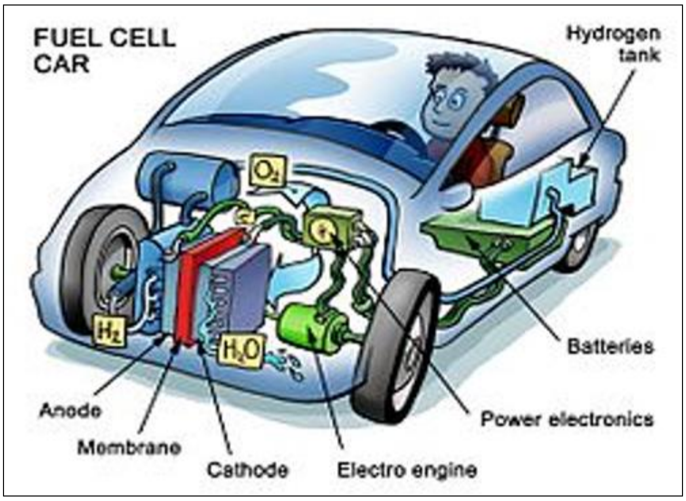

Fig 6: Configuration of components in a fuel cell car [62]

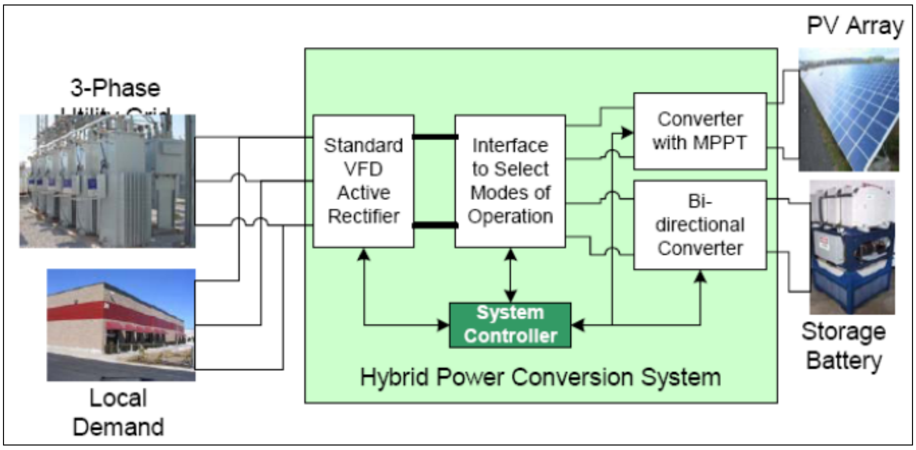

Fig 7: Block diagram of the Hybrid Power Conversion system of PV [65]

At the moment, many hybrid power schemes are deployed with a high fraction of renewable energy infrastructure operating on small-scale. While it is possible to install μpower system without any storage system, it is important to note that such is only reliable in exceptional conditions where electric power availability is only required at a certain period of time. At the same time, in such a situation grid connection is either always available or it might be that resource supply availability is guaranteed. The present situation and projected future electric power demand scenarios revealed that electricity may not only be stored on both small and large-scale but potential consumers could also store electric power in decentralized storage mechanisms at the comfort of their homes for use at any period of their choice. This accomplishment will be determined by the emergence of energy storage intelligent appliances using a combination of hardware and software applications. Renewable energy systems depend mostly on battery energy storage systems to help fulfill decentralized power requirements in most rural communities where they are installed. Not all energy storage systems are suitable for variable renewable energy exploitation. Batteries energy storage systems are the most suitable for wind and solar energy exploitation especially when both energy systems are connected in a hybrid mode as shown in Fig 8.

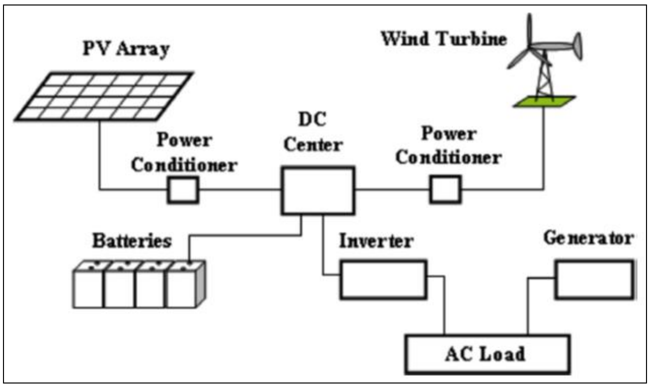

Fig 8: General scheme for a standalone hybrid power supply system [66]

4. Summary of Energy Storage System Characteristics

There are several characteristic features of energy storage devices. The most prominent characteristics are energy efficiency (%), power capacity (MW), capital cost of purchase (usually in $/kW), energy density (Wh/kg), response time (measured in fast, very fast, slow and very slow), lifetime (year), life cycles, self-discharge (per day), maturity (matured, immature, commercial or developed), charge time (seconds, minutes or hours), environmental impacts and thermal requirements. Realistically, different energy storage systems have different system storage characteristics even with energy storage systems belonging to the same family. For example, a Pb-acid battery has a range of power capacity between 0-40MW with an energy density of 30-50Wh/kg compared to a NaS-battery with 0.05-8MW and a higher energy density of 150-240Wh/kg. In addition, by a measure of self-discharge, the Pb-acid battery maintains a low value in the ranges of 0.1-0.3% which is as high as 20% in NaS per day.

5. Roles of Energy Storage System in Renewable Electricity

Undoubtedly, energy storage systems of various kinds have found suitable areas of application in the modern power sector integrating variable renewable energy systems (VRES). This can be achieved either as a small-scale autonomous or large-scale grid renewable energy integration. Based on current research, there are efforts towards harnessing better future potential directions for grid integration of renewable energy with the help of energy ESS. Aggressive research supported by the electric utility industry and government agencies is encouraged to develop technologies with a large capacity to increase penetration of renewable energy in the power sector. The current increasing rate of RE penetration into the power sector particularly in developed countries has introduced many technical and non-technical issues, including load management, reliability of output power generated, power quality, system protection, grid interconnections and control strategies, as well as economic operations. Thus, using a charging and discharging scheme, ESS could help resolve peak demand problems, and provide solutions to night-time utility power consumption and load control using a combination of renewable systems and energy ESS operating mechanisms.

5.1 Power quality, energy management and bridging power

An effective power quality allows consumers to enjoy an electricity supply without disruption in the supply frequency and voltage spikes and sags. In conventional power system, SMES, capacitors and flywheel energy storage systems are essentially important in power quality management systems. However, more than one energy storage system could be combined with a hybrid renewable energy system to ensure power quality management, mini-grid stabilization and maintain the rapid response required for reliability assessment. In energy management, customers get the best of their demand without wastage of energy supply to their residence and utility also derive optimum supply conditions especially by allowing peak shaving via shifting of peak demand from one period to another and eventually reducing consumers' charges. Fig 9 shows three main areas of application of energy storage systems comprising power quality, bridging power and energy management.

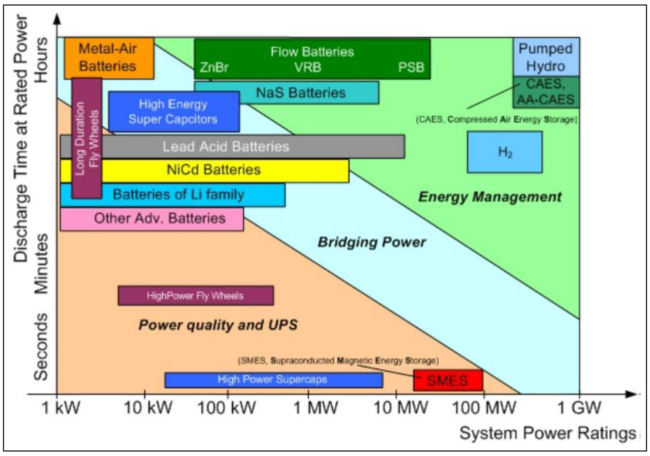

Fig 9: Energy Storage applications [67]

5.2 Storage of excess energy, mitigation of intermittency and generation deferral

In the last a decade, the cost of renewable power generation has been rolling down and this achievement holds a better future for energy market in the context of global energy demand and supply situations. With the penetration of energy storage systems, renewable energy exploitation is exceptionally promising and future improvement in renewable energy technologies could drive down investment costs and thus increase consumers' affordability. Actually, in most cases, periods of consumers peak electricity demand do not coincide with excess power generation from systems using renewable sources. This stems from the fact that sun and wind are not produced at will. In reality, the intermittent nature of these energy sources gives the needs for suppressing renewable energy variability. In this case, there is a need to provide an alternative to avoid the waste of energy produced which could cause some negative economic effects. As a result, energy storage systems are needed for storing excess of the energy produced which could be used at a period of peak electricity demand. This helps the utility to meet random fluctuations in electricity demand at various times. In addition, the concept of generation deferral has been the most appropriate way to enhance energy storage in distributed generation and conventional grid power networks. This is because additional generation of electric power is not required if excess energy from a power network could be stored for use at a time other than their instance of production. In this situation, an electric power network incorporating energy storage systems could suspend further generation of electricity.

5.3 Grid system applications

Energy storage systems integrated into a grid power system have quite a lot of roles to be played as illustrated in Fig 10. The functions include but are not limited to renewable energy integration, commodity arbitrage, transmission support, distribution deferral, power quality, distributed generation (DG) support and off-grid system application. The area of applications here covers the entire span of power system operations from generation and supply of uninterrupted and high-quality electricity via transmission scheme to the level of electricity distribution to consumers.

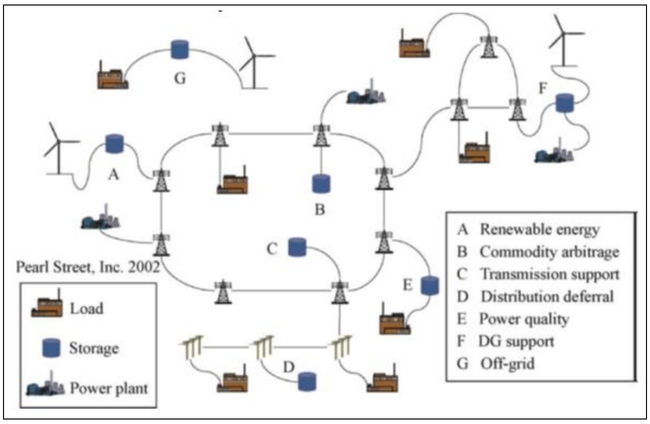

Fig 10: Energy storage applications in grid [68]

5.4 Decrease in environmental pollution and strategic resolution of global energy crisis

On a global scale, there are vast opportunities to satisfy a reasonable fraction of energy demand which could drastically reduce the current degree of dependency on fossil fuels. Radical reductions in fossil fuels consumption could eventually reduce critical environmental issues like greenhouse gas emissions. In recent times global climate change has engrossed a very serious center of attention and responses is invoking action initiatives like clean development mechanisms in line with the Kyoto Protocols and Renewable Portfolio Standard (RPS). Unfolding economic and technical issues related to renewable energy development is potentially undeniable towards offering a better future. Additions of energy storage systems to renewable energy systems for electric power generation revealed a very significant benefit of storage systems to decrease environmental pollution because generation capacity could be lowered and decrease fossil fuels-based electricity generation. Therefore, deployment of energy storage systems is going to be another vital control principle for future energy systems in the pursuit for minimizing environmental pollution associated with energy generation and consumption. As well, shortage of energy known as "energy crisis" is a common trend in the world today especially in developing countries including some countries with emerging economies. As a support tactic for energy crisis resolution, ESS have been used in power system engineering to accomplish several operational practices helping to increase availability of electricity to the consumers.

6. Concluding Remarks

Lee and Gushee [69] acknowledged that substantial electricity storage is a significant technology needed by renewable power if it is to become a foremost source of baseload dispatchable power. Table 2 summarizes the advantages and disadvantages of different kinds of energy storage systems including their areas of applications. It is also critical to note that there are ranges ESS available for handling the variability in renewable energy systems using energy storage systems. Up till now, large-scale use of energy storage systems is quite expensive but notwithstanding research and development could curb such a critical challenge. To deal with the variability in hybrid renewable energy systems, batteries are most suitable for the analysis herein. Apart from the use of batteries, other energy storage systems like capacitors and flywheel systems could also be used to address power quality problems and grid-connected stability constraints. Since the world is moving towards increasing the potential of renewable energy contribution to the global energy supply then a corresponding progression on the use of energy storage systems is also expected. In this case, sustainable economic scenarios, compensation for sporadic electricity interruptions, increase storage efficiencies, improvement in the design of various energy storage technologies for commercial applications and substantial improvement in renewable energy consumption could be promising issues in the years to come for the utility industry.

Table 2: Advantages and disadvantages of major ESS [70-71]

Technology	Advantages	Disadvantages	Technological maturity	Application	Cost	Remarks
Mechanical energy storage Pumped storage hydro (PSH)	High capacity, Low efficiency	Special site requirement	High	Energy management	Low cost	Suitable for Load leveling
Compressed air energy storage (CAES)	High capacity	Special site requirement need gas fuel	High	Energy management	Low cost	Suitable for Load leveling
Flywheel	High power	Low energy density	High	Power quality management		Suitable for short duration in sec or min (voltage dip)
Electrical energy storage Capacitors/Supercapacitors	Long cycle life/high efficiency	Low energy density	Medium	Power quality management		Suitable for short duration in sec or min (voltage dip)
Superconducting magnetic energy storage (SMES)	High power	Low energy density and high production cost	Medium	Power quality management	High production cost	Suitable for short duration in sec or min (voltage dip)
Lead-acid		Limited cycle life when deeply discharged	High		Low capital cost	Renewables and power plants
Chemical energy storage Flow batteries: VRB, ZnBr, PSB	High capacity, independent power and energy ratings	Low energy density	Medium	Power quality and energy management		Renewables and power plants
NiCd	High power/high efficiency	High energy density, High Cost	High	Power quality and energy management		Renewables and power plants
Li-ion	High power/high efficiency	High cost and needs special charging circuit	Medium	Power quality management		Power quality management
Metal-air		Electrically not re-chargeable				
NaS			Medium	Power quality and energy management		Renewables and power plants

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