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Comparative Analysis of Different Storage Technologies for Energy Critical Application

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***Abstract*—** The scope of this research work is the analysis and study of the rechargeable batteries. During this research, battery testbeds are developed for all under study battery technologies. A few hundreds of charging, discharging experimentation has been performed under a variety of charging profiles and discharging load patterns. These observations have been critically analyzed to capture the behavior of the batteries comprehensively. These behavioral profiles of these batteries have been utilized for developing an accurate battery model. The proposed model is a hybrid model composed of Diffusion model and combined electric circuit-based model, which accounts for nonlinearities of rate capacity effect, recovery effect, capacity fading, storage runtime and open circuit voltage, current-, temperature-, dependency to transient response. This proposed model would be a great help for energy aware circuit designing, because it's an equivalent circuit model that could be co-simulated in circuit simulation environment, like Matlab Simulink. A quantitative figure of merit for the selection of battery system for a specific microgrid application has been devised on the bases of important battery parameters.

***Keywords*—** Battery storage system, Micro-grid, Battery Model, Three stage battery charger, and constant current electronic load.

I. Introduction

The Conventional electrical power grid is undergoing a disruptive change as the development of smart grid is motivated by the energy crisis of the time throughout the globe [1]. The limited amount of fossil fuels availability and more precisely the fear of climate change caused by the greenhouse emissions are the agents of this development [2, 3]. It is prioritized that more Renewable Energy Sources (RES's) must be incorporated into system. Micro-grid is a critical infra-structure to integrate Distributed Energy Sources (DES's) for the deployment of smart gird [4, 5]. This development is around the corner and increasing of amount of research has been undergone in the last decade.

The smart grid is an electric grid integrated with Information and Communication Technologies (ICT) to embody a high-fidelity power-flow control having the ability heal if self, self-healing ability, ensuring a reliable and secure provision of energy [5]. Smart Grid refers to the set of technologies and infrastructure which would put intelligence in the present dump grid to transform it into a digital system which talks, listens, understand and adapt accordingly. Smart grids is demand responsive electricity system that balance out energy consumption and supply, and has the capability to integrate new Renewable Energy Sources (RES), while enabling the integration of energy storage systems and the use of electric vehicles (EV).

A Micro-grid is the local version electric grid implement in a small region and enables the integration of distributed energy resources (DER) having connected with local flexible loads. The micro-grids could be operated both in grid tied and in isolated islanded mode to ensure a required level of high reliability and resilience against disturbances in grid [4]. The micro-grid is a miniature of a smart gird operating into a small premise and having integrated RES's. ESS is an integral part of micro-grid infrastructure which enables it to improve the systems resiliency, stability and reliability. The objectives of the development of a Micro-grid are to provide clean electric energy with increased reliability and sustainability with economic considerations. Energy storage is an integral part of the Micro-grid which enables it to integrate intermittent RES's and to operate in stand-alone mode without compromising on the reliability. Though, the core functionality of a Micro-grid is considered to be the backup for power systems, however, it provides on-site real time control of both supply and demand and manage the available storage capacity and also enables the interaction with the grid to improve resiliency.

Micro-girds are evolving as a vital feature of future power systems that has been developed by different smart-grid initiatives, that can provide substantial environmental benefits by integrating and utilizing energy efficient Distributed Generation (DG) [6, 7]. Micro-grids are considered to provide a promising solution by improving the power system resiliency by integrating local sustainable resources and compensating the intermittent nature of these sources with incorporation of Electrical Energy Storage (EES) with in the systems [4, 8]. Solar PV systems, Wind Power Plants, Micro Hydro Power Plants and Fuel cell are the commonly exploited renewable energy resources and micro-grid incorporates one of them as their main source of energy supply. PV plants and Wind power depends on weather and they also

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have a peak time with it produce maximum [9]. The fuel cells and micro hydro plants have a limited capacity and can't respond quickly to relatively large changes on load side. To make Micro-grids responsive to load changes and to provide the extra power when the source is short of the demand, an EES is employed [8].

EES serves the purpose of storing electrical energy from the electrical grid at times when it is generated in larger amount then that of the demand and supplies that stored energy at times when there is a shortage of energy on the grid. EES is used to incorporate renewable sources as they are of intermittent nature and thus needs a buffer to compensate this lag. EES improves the reliability and stability of the system with continuous supply of electrical energy. Battery Storage the EES stores energy in off peak hours and supplies back that energy in peak hours. Different EES technologies has been exploited for energy storage and all of them have their own pros and cons. Different Storage Technologies are given here

1) Mechanical Storage System

a) Pumped Hydro Electric Storage (PHES)

b) Compressed Air Energy Storage (CAES)

c) Flywheel System

2) Electrical Storage System

a) Capacitor and Super capacitor

b) Superconducting Magnetic Energy Storage

3) Battery storage Systems (Electrochemical Storage Systems)

4) Thermochemical Battery Storage

5) Chemical Energy Storage

6) Thermal Energy Storage

The listed energy storage systems store energy in one of the forms (potential, kinetic, electrical, chemical or thermal energy) with a certain efficiency and provides it back during discharge. Each of them is utilized in certain systems on the basis of compatibility, advantages and limitations. According the criteria battery storage systems are utilized in micro grid topologies as the most viable option. The scope of this research is limited to analysis of different battery technologies and their viability with a certain micro grid topology.

II. Literature Review

A. *Electrochamical Storage System*

Electrochemical batteries are storage systems which stores electrical energy as chemical energy that could be utilized later by converting back to electrical energy. A Battery is a combination of one or more electrochemical cells, which are connected electrically in series or parallel combination to achieve the desired voltage or current levels, though the stacking is also done for increasing energy storage capacity [10]. An electrochemical cell is composed in a compartment consists of an electrolyte, an anode (positive electrode) and cathode (negative electrode), and a separator (porous insulating material). The composition of these two electrodes are different, and both of them react with each other chemically in the presence electrolyte. The chemical reaction is bidirectional one, which occurs spontaneously during charging and is forced in reverse direction during charging.

These electrochemical cells are classified based on characteristics and state of electrolyte like flooded (wet) or dry (sealed) batteries. The flooded batteries are most widely used due to their low cost, while sealed batteries have been used where maintenance and safety is critical. They are also classificed based on depth of discharge and rate of transmission, and the two categories are of shallow and deep cycle batteries. Deep cycle batteries have thick plates to store charge, with a structure which facilitate high current provision instantaneously and a stable chemistry to with stand the high stress

B. *Maintaining the Integrity of the Specifications*

A number of battery technologies are under evaluation for such large-scale energy storage applications, a summarized review of these batteries will be providing in this section. The secondary batteries discussed here are listed here [11, 12, 13].

a) Lead Acid Battery

i) Flooded Lead Acid Battery

ii) Sealed Batteries

(1) Absorbent Glass Mat (AGM) Battery

(2) GEL (VRLA) Battery

b) Nickel-Cadmium (Ni-Cd) Battery

c) Nickel Metal Hydride (NiMH) Battery

d) Lithium- ion (Li-ion) Battery

e) Lithium Polymer (LiPo) Battery

f) Sodium- ion (Na-ion) Battery

1) *Lead Acid Batteries*

Lead Acid (LA) batteries is the oldest and most established rechargeable batteries, composed of spongy metallic anode, a cathode of lead di oxide and 37% solution of sulfuric acid as electrolyte. Lead Acid (LA) batteries were first developed in 1859, being the first of rechargeable kind of batteries. Since, there invention LA batteries prevails the market due to numerous advantages of, simple manufacturing process, low cost, rapid load response due to quick chemical reaction and good life cycle incase controlled conditions and proper maintenance is provided. The nominal LA cell voltage is 2.05, and the SOC Vs Voltage relations is relatively linear, which makes it desirable electrical energy storage application [13, 14]. The technology LA battery is an old and much mature one owing to its extensive use over the last hundred years [15].

Lead Acid (LA) Batteries are categorized in two distinct verities of flooded or Ventilated Lead Acid (VLA) batteries and Sealed/ Valve Regulate Lead Acid (SLA/ VRLA) Batteries. There are differentiated on the bases of their negative and positive plate structures, the two most commonly used plates flat pasted plates and tubular plates (Iron clad type), while the third type, which is extinct for long Planté plates.

During discharge both positive and negative active material reacts with sulfuric acid (Fig.1) and produce a layer of lead sulfate on the respective electrodes.

The overall discharge reaction is:

$$\mathbf{Pb}O_2 + \mathbf{Pb} + 2H_2SO_4 \rightarrow \mathbf{2Pb}\,SO_4 + 2H_2\mathbf{O}$$

Anode:

$$\mathbf{Pb} + SO_4^{2-} \rightarrow \mathbf{2Pb}\,SO_4 + 2e^-$$

Cathode:

$$\mathbf{Pb}O_2 + SO_4^{2-} + 4H^+ + 2e^- + \rightarrow \mathbf{2Pb}\,SO_4 + 2H_2\mathbf{O}$$

When connected to charger, the reaction reverses its direction and thus the layers of lead sulfate on the electrodes starts to convert back into lead and lead dioxide. The overall reversible cell reaction looks like this;

$$\mathbf{Pb}O_2 + \mathbf{Pb} + 2H_2SO_4 \rightleftharpoons \mathbf{2Pb}\,SO_4 + 2H_2\mathbf{O}$$

2) Nickel-Cadmium (Ni-Cd) Battery

The Nickel-Cadmium (Ni-Cd/ NiCad) battery is invented in 1899 by Waldemar Jungner, offering many advantages over the only available lead acid rechargeable batteries [16]. In the mid of twentieth century NiCad batteries came as the first and only choice for portable electronic devices and power storage critical low power applications until 1990's when Nickel Metal Hydride (NiMH) and Lithium ion (Li-ion) cells took over [17].

NiCad battery is a type of secondary batteries having a positive electrode (cathode) composed Nickel hydroxide (Ni(OH)2), a negative plate composed of Cadmium hydroxide (Cd(OH)2), Potassium hydroxide (KOH) as electrolyte and a separator of nylon or polypropylene (Fig.4). NiCad batteries have nominal voltage of 1.2V, which is maintained quite steady until full discharge in contrast to other batteries. This enables NiCad cells to deliver full high power until total discharge [16, 17]. The low internal resistance of NiCad batteries also enables them to deliver such high discharge power.

The basic chemical reaction and active materials of all types of NiCad are same, weather sealed or safety vented valve type. During charging, the active material of negative electrode, Cadmium hydroxide (Cd(OH)2) transform into metallic Cadmium (Cd) and release hydroxyl ions (OH-), while the active material of positive electrode transforms from nickel hydroxide (Ni(OH)2) into nickel oxy-hydroxide (NiOOH) by receiving the hydroxyl ions (OH-) [17, 18]. During discharge the reaction moves in reverse direction, the chemical reaction that occur in NiCad cells are;

The reaction on the negative electrode:

$$Cd(OH)_2 + 2e^- \longrightarrow Cd + 2OH^-$$

The reaction on the positive electrode

$$Ni(OH)_2 + 2OH^- \longrightarrow NiOOH + H_2O + e^-$$

The discharge and charge reversible reaction NiCad cells:

$$Cd + NiOOH + H_2O \rightleftharpoons Cd(OH)_2 + Ni(OH)_2$$

3) Nickel Metal Hydride (NiMH) Battery

There was a continuous effort to improve battery performance, energy density and power density, in the later-half of 20th century Nickel Metal Hydride (NiMH) is developed to cope some of the problems of NiCad [19, 20]. The research work on NiMH batteries had started at the Battelle-Geneva Research Center in 1967. In early years, the process was halted due the instabilities of metal-hydride and led to the development of the nickel-hydrogen (NiH) instead. With discovery of new hydrides in the 1980's, the stability is eventually achieved and NiMH battery has been developed with a double specific energy than that of NiCad.

The operating characteristic of NiMH mostly resembles to those of NiCad because it's technically an extension NiCad, with replacing Cadmium with hydrogen-absorbing metal alloy for the negative electrode. This substitution brings about improved energy density, provides the ability to increase storage capacity, it doesn't have the effect issues, and would easily construct in sealed packages (Fig.5) because the released O2 and H2 gases would be effectively consumed [18]. NiMH is considered environment friendly because it doesn't have that toxic cadmium. However, it lacks the capability high discharge power rates of the nickel-cadmium battery and it's less tolerant to overcharge and fast charging thus, charging would have to be managed. NiMH also have a very high self-discharge rate and relatively short cycle life compared to NiCad.

The electrical characteristic of NiMH is more and less same as those of NiCad, it has the same nominal voltage of 1.2V, during discharge the voltage curve as flat as that of NiCad but the internal resistance is relatively low [19]. However, NiMH is more sensitive to discharge condition as compared to its predecessor, because a low discharging and overcharging results in loss of cycle life. It also shows negative effects for trickling charge and thus a very small trickle charge is preferred.

The chemical reaction during charging that occurs on the cathode of NiMH is same as one occurs in NiCad:

$$Ni(OH)_2 + 2OH^- \longrightarrow NiOOH + H_2O + e^-$$

The reaction on anode of NiMH during charging is:

$$M + H_2O + 2e^- \longrightarrow MH + 2OH^-$$

During discharging both of these reactions revert their direction backwards. The overall reversible chemical reaction that occurs in NiMH battery is:

$$MH + Ni(OH)_2 \rightleftharpoons M + NiOOH$$

This overall chemical reaction shows the transfer of single H atom between metal alloy (M) and Ni(OH)2, depending that a charging or discharging operation of the cell.

4) Lithium- ion (Li-ion) Battery

The research on Lithium for battery application begun in 1912 under G.N. Lewis and it was Armand in 1970, who developed the first non-rechargeable lithium battery prototype that were made available for commercial use. Lithium being the lightest of elements has the greatest potential to be provide highest energy density batteries, this propels the research work and it was 1991 when Sony commercialized Lithium-ion (li-ion) rechargeable batteries with a (LiCoO2) as the active positive material [21, 22].

The synthesis of electrode materials for negative electrode was complex achievement as compared to that of positive electrode [34]. Research works has shown that graphite and some other carbonaceous materials can be blended with lithium ions, though this process of intercalation of solvent molecules of carbonaceous materials is complicated due to solvent reduction and Disruption of the carbon structure. Later, a stable battery chemistry was achieved, with a lithium ion cell having graphite anode (e.g. mesocarbon, microbeads, MCMB), and a cathode composed of lithium metal oxide (LiMO2, e.g. LiCoO2) while the lithium salt (e.g. LiPF6) is used as an electrolyte. The electrolyte of lithium salt is a mixture of organic solvent (e.g. ethylene carbonate–dimethyl carbonate, EC–DMC) which implanted on the propylene made separator [23, 24].

The basic structure of li-ion secondary cell is same, it's composed of two electrodes (anode and cathode), electrolyte and a separator, though the technology realization is quite complex (Fig.6). While, the basic internal operational methodology is the transfer lithium ion from one electrode to another depending charging or discharging operation. During discharging state, lithium ion flows from anode, through the electrolyte to the cathode, while in charging operation lithium ion moves backward [16]. The cathode of the li-ion batteries is of significant importance, and effects the battery characteristics greatly. The cathode of li-ion battery is composed of lithium metal oxides, the ones used commonly are lithium cobalt oxide (LiCoO2), Lithium iron phosphate (LiFePO4), lithium manganese oxide (LiMn2O4), Lithium manganese nickel oxide (Li2Mn3NiO8), lithium nickel cobalt aluminum oxide (LiNi0.8Co0.15Al0.05O2), and lithium nickel manganese cobalt oxide (LiNi0.33Mn0.33Co0.33O2) [22, 23]. These low conductivity and diffusion constant of these materials is improved by blending it with a conductive corban material. The commercially available li-ion batteries are named on their respective lithium-ion donating material as being the determinant of cell characteristics, such as nominal voltage etc [35, 36, 37, 38]. The commonly used anode material is graphite though some manufacturers uses lithium titanate (Li4Ti5O12). The mixture of lithium salts and organic solvents are used as electrolyte. The commonly used salt is lithium hexafluorophospate (LiPF6), lithium perchloride (LiClO4) and hexafluorosenate (LiAsF6). The most common separator is made of propylene and polyethylene. The lithium-ion batteries are available in different shapes (cylindrical and flat stacks), sizes and capacities.

The discharge reactions of lithium-ion cell with lithium cobalt oxide (LiCoO2) based cathode and graphite anode (C6) are;

The half reaction t positive electrode (cathode) during discharge:

$$\boldsymbol{CoO_2 + Li^+ + e^- \rightleftharpoons LiCoO_2}$$

The half reaction of the positive electrode (anode) during discharge:

$$\boldsymbol{LiC_6 \rightleftharpoons C_6 + Li^+ + e^-}$$

The overall li-ion cell reaction during discharge and charge operation is:

$$\boldsymbol{CoO_2 + LiC_6 \rightleftharpoons C_6 + LiCoO_2}$$

The over-discharge of the cell leads to the production of lithium oxide (Li2O), while overcharge produces cobalt oxide (CoO2) through irreversible reactions which causes loss capacity and release large amount of heat.

5) Lithium Polymer (Li-Po) Battery

Lithium Polymer (Li-Po) batteries are and advancement of lithium-ion (li-ion) batteries and thus have almost the same operational characteristics predecessors. The nominal voltage is 3.7V, same li-ion cell, while the specific energy is increased further. In Li-Po batteries a polymer electrolyte is used instead of liquid electrolyte [25, 26]. This polymer has ion transport properties comparable to those of commonly used liquid ionic solutions. The Li-Po batteries have many advantages due its polymer electrolytes compared to the conventional li-ion batteries, as they have no risk of internal shorting, no chance of electrolyte leakage and the reactant products are non-combustible[25]. The second variation is the use of metallic lithium for electrode which makes the design further lighter and increases energy density of the cell.

The commonly used polymer gel electrolyte is Poly ethylene oxide, Poly acrylonitrile, Poly methyl methacrylate, Poly vinyl chloride, Poly vinylidene fluoride, and Poly vinylidene fluoride-hexa-fluoro propylene. A Li-Po battery is designed by sandwiching the polymer electrolyte between the metallic lithium anode and a composite cathode. The electrochemistry is quite the same as that of Li-ion cells.

The discharge reactions of lithium-ion cell with lithium cobalt oxide (LiCoO2) based cathode and graphite anode (Li) are;

The half reaction on the positive electrode (cathode) during discharge:

$$\boldsymbol{CoO_2 + Li^+ + e^- \rightleftharpoons LiCoO_2}$$

The half reaction of the positive electrode (anode) during discharge:

$$\boldsymbol{Li \rightleftharpoons Li^+ + e^-}$$

The overall li-ion cell reaction during discharge and charge operation is:

$$\boldsymbol{CoO_2 + Li \rightleftharpoons LiCoO_2}$$

Here we don't have that heavy graphite anode, which made it possible for the manufacturer to build slick and thin batteries, in whatever design they like and secondly the packaging becomes quite simple and easy such as the pouch type batteries.

2.7 Sodium- ion (Na-ion) Battery

Due to numerous advantages over its comparative technologies' lithium-ion batteries got wide recognition and a large share of battery market. With this boom li-ion prices hiked and availability of lithium is felt unsustainable to the rising demand, which draws great interest from researcher to find a cheaper alternative such as Sodium (Na) ion based batteries. For many years Sodium-ion (Na-ion) batteries (NIBs) has been under researched, mainly focused on sodium intercalating materials. However, after 1970's and 1980's the attention of the researcher shifted towards lithium intercalation materials, until fairly recently, when a more stable and economical replacement of Li-ion is felt crucial, attention shifted back towards NIBs [27]. The researchers have been intensively working for a decade, on the development of stable and potentially competitive Sodium-ion (Na-ion) based batteries to replace Lithium-ion batteries, at least for application where energy density is not that critical [28].

Sodium is one of the abundantly available elements, and battery grade sodium salts are also cheap, the main challenges is development high-performance and stable electrode materials [29]. The development of stable and competitive sodium batteries is infant stage and requires intensive research and development.

III. Research Methodology

In this study lead acid batteries, NiCad, NiMH, and Lithium-ion cells were charged and discharged and the patterns has been observed. An efficient, recognized and smart charger capable of data logging abilities and smart programmable loads to discharge these batteries at different schemes and to keep log of these discharge patterns for later analysis and comparison were must for this research.

A. Experimental Setup

The chargers needed for these experiments, has to be capable of measuring the amount of charge stored in a battery or cell and also have to log the charging current and voltage data during the charging for later analysis. For charging purpose, an "IMAX B6AC" professional balance charger was used, which is capable of charging Li-ion, Li-Po, Li-Fe, NiCad and NiMH single/multiple cells. While for lead acid batteries, a three-stage buck based charger with data logging capabilities is designed.

For observing the discharge patterns of the cells and batteries under study, the loads have to be capable of logging discharging current, voltages and amount of charge that is retrieved during discharging experiments, for later analysis and comparison. We have a "BK PRECISION 8510" programmable DC electronic load, that was used for battery discharge profiling of all the cells and batteries including NiCad, NiMH, Li-ion and Lead Acid batteries. This load has a discharge limitation of 120 watts, so, its unable to discharge lead acid batteries at a current greater than 10 Amperes, that's why we have to design a boost based constant current load for a current greater than 10 Amperes having data logging abilities.

B. Analytical Creterion

To evaluate these batteries for their energy efficiency, their charge and discharge operations eed to be observed. Having accounted for the temperature effects, capacity rate effect (Peukert's law) and recovery effect, batteries are discharged at low currents (C/10) for a specific time (to discharge a 10% of SOC), and then left the battery idle or at a very low discharge current (C/100) for a period of 30 minutes to enable recovery effect and avoid high temperature. This procedure is good for observing short term and long-term transients and in 30 minutes period of low current discharge give us an idea of the recovery effect. For capacity rate effect observation, batteries have been discharged at different C-rate from full charge level to full discharge.

The efficiency of each and every cycle was calculated and a pattern of decrease in efficiency during the later cycle life and capacity degradation is observed. On the basis of this data, the useful life of a battery is verified. While keeping in account the initial cost, cycle life and the energy efficiency, the cost per KWH was calculated. The other important aspects, such as specific energy, energy density, and specific power have been measured and compared against authentic literature,

The formula for energy efficiency is;

$$Energy\ Efficiency\ \eta = \frac{E_{out}(KWH)}{E_{in}(KWH)}$$

IV. Analytical Comperision

The energy efficiencies can be measured with a tolerance of 5% because it's dependent on a variety of the variables namely temperature, charging or discharging profiles, and DOD. The scope of this research has been limited to the Lead Acid, NiCad, NiMH, and Li-ion batteries . A summary of the important observations of the batteries under observation are presented in the table.

TABLE I. Important Parameters of Different Batteries

Battery System	Specific Energy (Wh/kg)	Energy Density (Wh/L)	Energy Efficiency (%)	Specific Power (W/kg)	Cycle Life
Lead Acid (Flooded)	30	80	70-80	200	500 @ 50% DoD
Lead Acid (Sealed)	50	100	75-85	250	1200 @ 50% DoD
NiCad	70	200	70-80	300	1500 @ 60% DoD
NiMH	100	200	70-80	300	1500 @ 60% DoD
Li-ion	200	300	85-95	500-1000	3000 @ 80% DoD

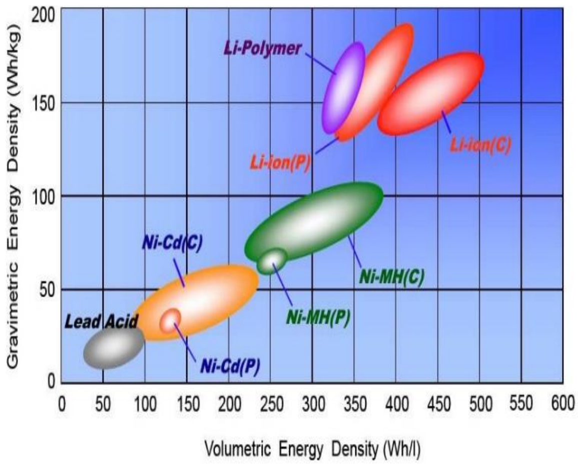

Figure 1. Volumetric Energy Density Vs Gravimetric Energy Density.

The cost of per KWH stored energy is most crucial for selection of a battery, which is directly attached to the estimated durability of the system. The useful life of the battery is normally defined on the basis of two aspects, battery capacity reduction and decrease in efficiency. The most reasonable limit for end of useful life is a reduction of 70% battery capacity, or when the efficiency decreases below 50%. These two limitations don't have a coherence, when batteries are discharged deeply the capacity reduction is faster, while in case of high temperature and unmanageable charging the efficiency limit is reached earlier, but whatever limit is reached the has to be disposed then.

The cost calculation of per KWH stored energy is a complex and tricky concept, which has tackled in several ways by researcher. My observation and studies show that investment in a battery system has to be made weighing the durability (Cycle Life), storage capacity, and efficiency of the that specific technology. The cost of electrical and electronic infrastructure that needs to be installed for that specific battery technology is kept out of this calculation, because it's a one-time cost but batteries should be replaced after end of life. The formula based on this research for cost calculation of per KWH of stored energy, which would beneficial for making a smart and economical selection of a battery is given here;

$$\boldsymbol{Storage\ Cost} = \frac{\boldsymbol{Cost\ (KWH) * Cap * EC + Capital + MC}}{\boldsymbol{\eta * Cap * EsC}}$$

Where:

Storage Cost = Cost per Unit (KWH) energy storage

Cost (KWH) = Cost of Unit (KWH) energy

Cap = Storage Capacity of Battery

sC = Estimated Life Cycle (at an average DoD)

Capital = Initial Capital Investment

CoM = Cost of Maintenance

CONCUSLION

This research work results into development of an quantized creteria of camparision and selection of a specific battery system for a specific application. This analysis has been done for LA, NiCad, NiMH, and Li-ion batteries, and provides an accurate depiction of these technologies. A simple empirical formulas for the calculation of the energy efficiency of the batteries and per KWH cost of the stored energy in a specific storage system has been that could be used for battery selection. The research provides an understanding of how could we asses performance of a battery and estimate useful cycle life of a battery.

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