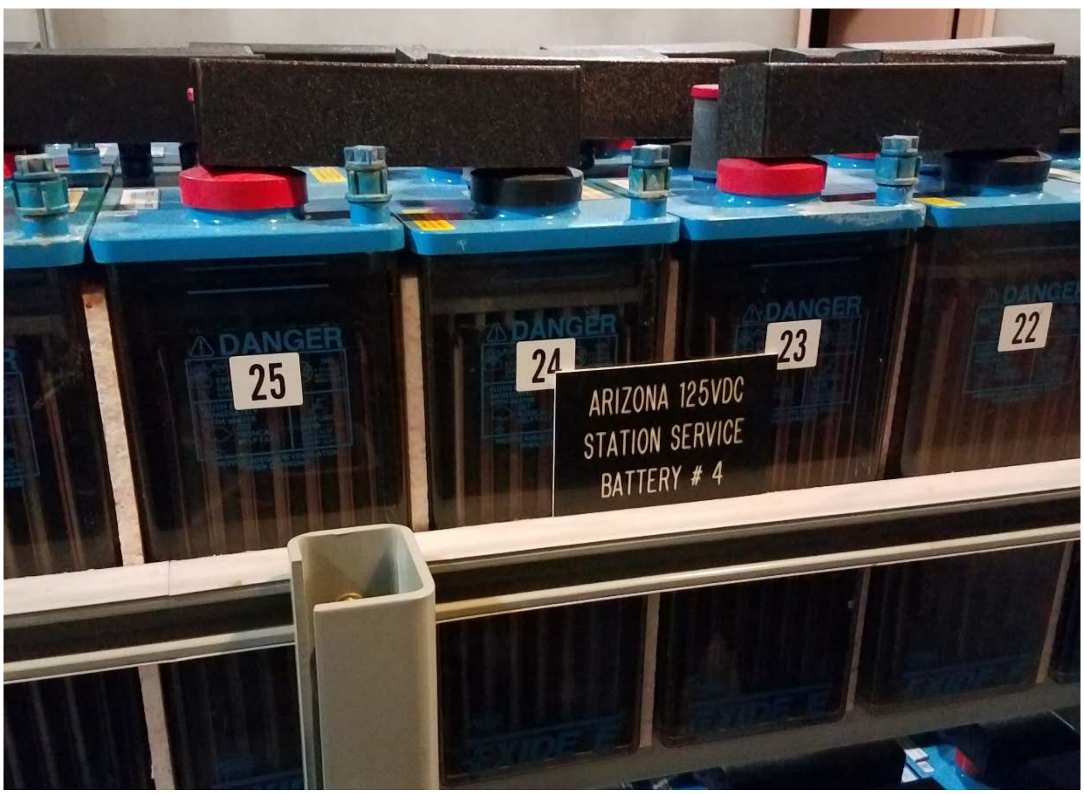
RECLAMATION

Managing Water in the West

Study the use of alternate battery chemistry solutions as a replacement for currently installed lead acid batteries within power generation facilities

Research and Development Office
Science and Technology Program
(Final Report) ST-2017 (ID)-1727



U.S. Department of the Interior
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Research and Development Office

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Study the use of alternate battery chemistry solutions as a replacement for currently installed lead acid batteries within power generation facilities

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Executive Summary

This study is to explore alternative battery chemical storage solutions and other forms of energy storage for power generating facilities. The battery system is critical to the safe operations of a power plant. The DC system is used to provide station service power to protective relays, tripping circuits, pumps, and emergency lighting. The battery systems provide backup power to this system to ensure that critical components operate in an emergency situation. Alternative battery chemistries were examined to evaluate if there is a viable alternative to flooded lead acid batteries for Reclamation's battery storage requirements supporting stations service and Uninterruptable Power Supply (UPS). Reclamation has a need for battery storage capacity in the powerhouses, currently lead acid batteries are used due to the reliability and known standards of maintenance but they are maintenance intensive and require hazardous materials. Nickel cadmium, valve regulated lead acid (VRLA) and lithium ion batteries were evaluated. Other UPS options, fuel cell and flywheel apparatuses, were also examined for their ability to be used for Reclamation's UPS. After evaluating these alternatives, the traditional flooded lead acid batteries currently used best option based on cost, maintenance needs, and service life.

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Introduction

This study is to explore alternative battery chemical storage solutions and other forms of energy storage for power generating facilities. The battery system is critical to the safe operations of a power plant. The DC system is used to provide station service power to protective relays, tripping circuits, pumps, and emergency lighting. The battery systems provide backup power to this system to ensure that critical components operate in an emergency situation. Uninterruptable Power Supplies (UPS) are also used as part of this system to supply an AC electrical system with emergency power to a load when the main power source fails. These are common in datacenters, computer systems, emergency lighting, and many other applications where power at all times is critical. The UPS may or may not utilize the same bank of batteries as the DC system depending on the setup of the plant. The station service DC system is an “always on” application that connect the battery banks to the station service DC distribution system, providing 8 hours of power during normal operations or at least enough power for the orderly shutdown of the plant in an emergency during maintenance operations. The uninterruptable power supply activates instantaneously and is “on” for a few minutes at most. This is so that another power source, the standby power source can activate.

Lead acid batteries were the very first rechargeable battery in existence. These were created by French physicist Gaston Planté in 1859 and have been a dependable rechargeable battery since. If a different chemistry was determined to be advantageous Hoover Dam Power Plant was planned for the operational testing location. Flooded lead acid batteries have been used for Hoover Dam’s station service power since the 1940’s. Since then, there have been several advances in battery and power technologies. Many of these options are reviewed and vetted based on their lifetime, safety, maintenance needs and costs. All maintenance guidelines for batteries and fuel cells are from the Bureau of Reclamations FIST manual section 3-6. If there is no maintenance guideline for the battery chemistry outlined in FIST 3-6, the industry recommended guidelines are used.

Station Service Power Supply Options

Flooded Lead Acid Batteries

These are currently used. Due to their long life and low costs, these are the status quo. The flooded lead acid battery is used in Hoover Dam currently for its station service power and UPS system. The lifetime of these batteries are 15 to 20 years if maintained properly. The initial cost of these batteries are relatively low. The maintenance interval prescribed in FIST 3-6 and FIST 4-1B is monthly with additional tasks quarterly, annually, and on a 5 year cycle. With proper ventilation and maintenance, these batteries are relatively safe. Flooded lead acids have over 150 years of development and tolerant to overcharging. These batteries are capable of delivering high currents and can be left on float charge for long periods of times. The purpose of a float charge is to ensure that the battery is fully charged and ready to provide its rated power. The float charge is the act of setting the battery charger voltage just above the battery voltage.

Valve Regulated Lead Acid (VRLA) Batteries (Gel Cells)

VRLA batteries are commonly called gel cell batteries or maintenance free batteries. These are typically used for datacenters where the user can just install it and forget about them for years for convenience purposes. Since the FIST 3-6 manual states that maintenance must be done monthly, even on VRLAs, this limits the maintenance advantage of using these. There is not a need to specific gravity reading on the electrolyte solution or fill these batteries but the operational voltage and temperature readings must still be done. The average life span for VRLA batteries is 3-5 years. The ambient temperature will affect the service life of the batteries. The ideal operating temperatures for all batteries is 25°C (77°F) but for VRLAs this is more important due to the thermal characters that the cells do not effectively dissipate heat and are therefore more prone to thermal runaway. As a rule of thumb, for every increase of 8 °C (15°F) in temperature, the lifetime of the battery will decrease by half. Due to the temperature in the battery room in Hoover, these can be expected to last around 5 years. In FIST 3-6 VLRA batteries are not recommended for station service applications due to these properties. The cost of a 2V 600 amp hour VRLA battery at $600 is comparable to a 2.5V 535 amp hour flooded lead acid battery currently in use. Having one fourth the service life means that cost of ownership is 4 times as much as the current technology in use.

Nickel Cadmium Batteries (NiCd)

Due to a longer lifetime, the nickel cadmium do seem like a viable alternative to lead acid batteries. The fumes are not corrosive so they can be around electrical equipment. Each battery is typically three times the initial cost of the lead acids. The tradeoff is that the maximum life span of these batteries have an extra 5 years (25 years). They are resistant to non-optimal conditions such as overcharge, deep discharge, reverse charge, and can even be stored at any charge. NiCd batteries are more forgiving to thermal deviations from the standard of 25°C (77°F) ambient air temperature. They do lose about 20% of the service life for every 18°F above 77°F but they are rated to operate at -58 to 140 °F without failure. Nominal voltage of these batteries sold in the industry are typically 1.2V compared to the currently used lead acid nominal voltage of 2.5V.

Putting them in series can make this feasible if the space is available, but there is the subsequent doubling the amount of connections to be maintained. The size for a NiCd battery cell ~6.5”X 6.4” X 17.4” vs ~6.6”X 11” X18.7” for flooded lead acid used at Hoover Dam Power Plant. The physical size difference is nominal but not conducive to a direct replacement without modifying the battery rack to meet the requirements of the new batteries. According to FIST 3-6, these batteries have a maintenance schedule of once a month, not saving on the recurring maintenance time for the plant.

Lithium Ion Batteries (Li-ion)

Lithium Ion batteries are currently widely in use in the consumer electronics industry and gaining in use in the electric vehicle industry. Their high energy density makes them attractive in applications where smaller, lighter batteries can lead to longer operating times between charging. The use of li-ion was the original focus of this proposal but it is somewhat limited due to the cost, safety, and federal regulations. It is considered a class 9 hazardous material therefor shipping must be done on the ground. Cost is a large deterrent. For example, each cell of the flooded lead acid battery is around $580 for a 2.5V 535 amp hour battery, where its lithium ion counterpart costs $8,000 for a 12V 600 amp hour battery. The equivalent flooded lead acid battery would need 5 cells to equal the output of this specification costing $2,900 over a 20 year lifecycle. The li-ion battery has a 10 year lifecycle costing $16,000 over 20 years. Lithium ion batteries require purpose built charging and battery monitoring equipment to ensure the safe operations of the batteries. This is to protect the system from overcurrent, short circuiting and to properly charge the batteries. The safe Li-ion batteries incorporate lithium iron phosphate (LiFePO4) and during discharge produces heat and oxygen. The safe Li-ion battery has a less reactive battery chemistry but at a lower power density. These are mostly used in larger applications like UPS systems and electric cars. A short circuited string of batteries/cells may result in explosion and/or very high temperature lithium fire with an internal oxidizer. These fires can cause a great deal of damage to the dam. LiFePO4 is the best bet for the battery chemistry (used in the industry). International Air Transport Association (IATA) states that a lithium battery involved in a fire can re-ignite and emit flames multiple times, as heat is transferred to other cells in the battery. The Fire Protection Research Foundation performed tests on lithium car fires and noted that the battery would be capable of reigniting even after "Everything looked normal". In one case the battery reignited 22 hours after the fire was thought to be extinguished. Element Material testing showed that using water to put out a lithium fire will only intensify the fire. Water even has the potential to reignite the lithium fire due to hydrogen releasing because the reduction of lithium in the water. Only class D fire extinguishers that contain a copper powder are approved for combating a lithium fire. Nathan Myers, Manager, Hydropower Diagnostics and SCADA Group from the Bureau of Reclamation Technical Service Center, stated that the he would advise we do not use them for critical functions due to how cutting edge lithium ion batteries are. He advises that the risks due to the high energy density in a Dam could be catastrophic.

Fuel Cells

Fuel cells are best used for UPS systems that require long back up times at a low power consumption. This is not ideal for this project at Hoover since this method of back up is not recommend to back up vital life-saving operations such as fire protection/suppression systems. Industry used fuel cells also take up to 20 minutes to ramp up to full load capacities which is not ideal for Hoover's purposes. Due to this another form of power is needed to carry load so the load is not dropped during this ramp up time. For Hoover, the ramp up time would likely be significantly longer than the amount of time the fuel cells are actually being used.

Flywheel

A flywheel apparatus is a battery-less alternative for UPS power storage applications. It works by converting rotational energy into mechanical energy, which is then stored to bridge the power gap should normal utility power fail. These systems are designed to work for several seconds (From GE's models for the load needed, it will last 65 seconds maximum). The flywheel is normally set to produce DC power at 600 V so a direct DC connection to station service would not be feasible. This type of connection would need to be run through a DC to DC converter to reduce the voltage to usable level. A flywheel system is a fairly maintenance free replacement for an UPS that is backed up by a dedicated standby generator. This is not the case for power plants where the station service is not always backed up with a generator that can supply critical loads. Since the standard for USBR is 8 hours, this option is not viable. This would be a technology to evaluate for data centers as a flywheel UPS provides a lot of the same benefits as battery storage in an UPS system without the maintenance requirements associated with batteries. They can be installed parallel to a battery system in cases where high reliability is required so that battery power is available if the generator fails to start. In this setup the flywheel would be used for counteracting the small power fluctuations and power conditioning activities that would normally be relegated to the storage batteries. The flywheel would contribute to extending the service life of the batteries by limiting the number of discharge events the battery bank would experience.

Conclusion

In terms of battery longevity, the flooded lead acid battery is outlasted only by the nickel cadmium batteries. However, the typical cost of nickel cadmium batteries are three times as expensive and will need twice as many due to the typical nickel cadmium battery is a 1.2 V cell and the current flooded lead acid batteries used are 2.5V cell. The flywheel's service life is as long as the flooded lead acid batteries, however, it will not deliver power long enough for Reclamation's needs. Fuel cells are used typically for very low power consuming systems. This is not viable for Hoover Dam's UPS. Valve regulate lead acid batteries, also known as maintenance free battery, lasts three to five years. The cost of purchasing a valve regulated lead acid cell is comparable to the cost of a flooded lead acid call but have one quarter the service life. There are maintenance benefits to these batteries but due to the FIST and IEEE guidelines, maintenance still must be done at the same schedule as flooded lead acid batteries. The amount of time saved in the monthly maintenance does not make up for the loss of service life. Adjusting the FIST manual to relieve some of these requirements will not save enough man hours to make up for having to change out the batteries more often while still maintaining critical station service power. Therefore, using valve regulated lead acid batteries in a station service DC setting is not recommended. Lithium ion batteries have a higher initial cost and shorter service life than flooded lead acid batteries. They are used in some UPS systems due to their low recurring maintenance requirements. However, due to safety concerns for the Dam, these systems shouldn't be used indoors. Lithium batteries have the potential to cause high temperature fiery explosions. This option is cost prohibitive for the batteries alone and requires a rated battery management system as well. The lithium ion batteries have half the service life of the flooded lead acid batteries. Due to these facts, the flooded lead acid batteries are currently the best options due to their lifespan, cost, and dependability. Our research shows that 150 years later, there is still no cost-effective alternative battery technology that is better than lead acids for DC station service power.

Table 1. Comparison of battery service life, maintenance requirements, and cost

Type	Lifetime	Maintenance	Cost
Flooded Lead Acid	15-20 years	Monthly (FIST)	LOW
VRLA	3-5 Years	Monthly (IEEE/FIST)	LOW
NiCd	20-25 Years	Monthly (FIST)	MODERATE
Li-ion	Up to 10 years	Quarterly (Manufacturer)	MODERATE
Flywheel	20 years	Annually (Manufacturer)	HIGH
Fuel Cells	Up to 10 years	Monthly (Manufacturer)	MODERATE

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