SYSTEM DESIGN AND MAINTENANCE ISSUES
FOR BATTERIES
IN
RENEWABLE ENERGY HYBRID SYSTEMS

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ABSTRACT

Hybrid electrical energy systems, consisting of a renewable energy source (photovoltaics or wind turbine), a battery string, an inverter/battery charger, and an engine-generator (genset) present special problems to the system designer which, if improperly solved or ignored, can guarantee the early failure or performance degradation of battery strings used in these applications. Any one of several potential problems ranging from variations in system operational energy requirements to the selection of a battery charging strategy can lead to ultimate system failure if a multitude of interrelated issues are not considered and resolved during the design and integration phase. This paper will enumerate the more common battery management problems associated with the design and integration of hybrid systems and present approaches to help recognize and eliminate or minimize the impact of system design problems in hybrid energy systems.

INTRODUCTION

Generally speaking, lead-acid batteries are designed to function either as a power source **or** an energy source with strong emphasis on the **or**. Power batteries are designed to produce high currents for short periods of time; Energy batteries are designed to produce low currents for long periods of time. Power batteries, when used in energy applications such as traction utilization, golf carts and fork lifts, will not meet performance expectations for these high energy requirements. At the same time, energy batteries when used in such an application as SLI (starting lights ignition) automotive batteries will not meet performance expectations for these high power requirements. In other words, if the wrong battery is selected for an application for whatever reason, cost, availability, convenience, etc., performance expectations will not be met. Batteries can be custom designed to meet both high energy and high power requirements but this is often a very expensive option. Usually, the informed system design engineer selects the best compromise between an energy and a power battery to get the best system performance while meeting all system specifications. This problem is becoming even more complicated and risky with the development of hybrid systems.

Until now, the energy/power battery dilemma has not faced the situation where both high power and high energy are typical requirements for battery systems. That is, until the introduction of the renewable/battery-storage/genset hybrid. Much of the time these systems are placed in operations where peak demands are near the capacity limits of the system power conditioning electronics and system genset capacity limit, and the off-peak demands can range to a low 0-5% of peak capacity limits. Consider the power demands of a small village of 5 to 10 homes that have minimal restrictions of the number and type of loads they may use, e.g. refrigerators, hair dryers, lighting, space heating. In on-grid systems, the stiffness of the system allows just such loads with minimal impact on the electrical source. However, small village hybrid electrical generation systems are not stiff and are subject to wide swings in frequency and voltage during minute-to-minute operations. Batteries that are used to stiffen this type of application and are typically exposed to wide swings in demand as power conditioning systems (PCS) use battery energy to regulate the system frequency and voltage. Now, in this situation the battery must act as both a power and an energy source in response to the PCS demands, and there is little room for compromise. However, with proper management, the battery system can meet performance specifications and life expectations if a few rules are carefully followed. The remainder of this paper will focus on these rules which are extremely important in hybrid applications.

PERFORMANCE CONSIDERATIONS

Two types of lead-acid batteries will be considered in this discussion: 1) Flooded-vented lead-acid, and 2) Valve Regulated Lead-Acid (VRLA). Flooded batteries require the regular addition of water making them a high maintenance component. Generally speaking, flooded batteries are lower cost than VRLA. In contrast, VRLA batteries require no watering as they are designed to recombine the hydrogen and oxygen gasses generated during battery charging thereby keeping the water inside the battery. Although the VRLA battery is usually a higher cost initially, life cycle costs are generally lower as less labor is needed to maintain the battery during its active life. The economic benefits and differences between these technologies is beyond the scope of this paper and these topics will not be addressed.

A primary consideration for the maintenance of cycling batteries, as are normally used in hybrid applications, is battery depth of discharge. A rule of thumb for battery life expectancy is that a battery will sustain N number of cycles of useful life depending on the nominal depth of discharge, all other variables such as battery temperature, charge and discharge rate, and state of health (SOH) being constant. In other words, the deeper the discharge depth, the fewer cycles will be experienced before battery end of life.

Charge and discharge rate is also a life affecting factor which must be considered, all other variables remaining constant. High rates, for example rates for battery capacity (Ampere hour capacity of a battery is normally referred to as C for the one hour rate) divided by 4 (C/4) to greater than C (power delivery for less than one hour within the capabilities of the battery), to deep discharge depths for energy applications requires a battery specifically designed for the application. The key in this situation is "energy" which indicates that a battery is specifically designed for low rates such as C/20 or less. Low rates, less than C/100, to deep discharge levels is highly stressful for a battery, even one designed specifically for deep cycle operations. Charge rates also impact battery performance. A battery which is discharged at a low rate, for example at the 100 hour rate (a 100 amp-hour battery discharged at a one amp rate, C/100) and is fully charged at an 8 hour rate (C/8) will not restore the battery state of charge (SOC) to the same SOC that the battery contained unless a long float period is allowed at near top of charge to convert materials deep in the interior paste of the battery plates back to a charged condition. Ideally, a battery should be charged at the same rate it is discharged to restore 100% of the charge removed plus 5-25% additional charge as specified by the battery manufacturer to account for charge inefficiencies for the battery.

Another factor which plays an important role in battery SOH is how long a battery sits idle at some intermediate state of charge, not being actively charged or discharged. In a flooded cell, stratification of the electrolyte occurs as the electrolyte is converted to water and sulfur dioxide is deposited on the plates during discharge and water, being lighter than sulfuric acid, tends to rise to the top of the battery and concentrated sulfuric acid tends to collect at the bottom of the battery. The deeper a battery is discharged and held at a low SOC, the more pronounced the effect. The water at the top attacks the pure lead materials in the top of the battery while the acid at the bottom attacks the plates and paste. When a battery is charged, gassing occurs at near top-of-charge when hydrogen molecules collect on the negative plates and oxygen molecules collect on the positive plates. When the bubbles of gas grow to a size that increases their buoyancy to the point that causes them to release from the plates, the bubbles rise to the top of the electrolyte and escape out the battery vent. This bubbling action "stirs" and re-circulates the electrolyte thereby eliminating stratification if the gassing activity is allowed to proceed for an extended period. During the manufacturer's recommended equalization procedure, gassing is usually adequate to de-stratify the battery. Equalization should be performed periodically, according to the manufacturer's recommended procedure, to minimize the effects of stratification and to maintain battery SOH. Although some amount of stratification takes place in AGM VRLA batteries, the effect is minimal as the migration of the electrolyte (water and sulfuric acid) within the glass mat separators is very limited. In GEL VRLA batteries the effect is almost negligible.

Temperature management, both environmental temperature and battery temperature increase due to charging operations, is a very important factor in the maintenance of battery SOH and life expectancy. High temperatures result in the reduction of battery life; low temperatures result in the reduction of available capacity. Battery performance parameters provided by the manufacturer are usually referenced at the ideal battery operating temperature of 25 °C (75 °F). This can be interpreted to mean that if the battery is operated at any other average temperature, then a de-rating factor must be applied to battery capacity and life expectancy specifications. In other words, if one chooses to operate at a temperature other than the ideal, then one must be willing to accept the penalty of reduced battery performance and/or life expectancy. If the penalty is more than one can tolerate for their installation, then it is important to introduce mitigation components such as HVAC or heating elements to keep the temperature at an acceptable level to allow the battery to perform up to life and capacity expectations.

BATTERY SELECTION CRITERIA

Modern conventional wisdom has dictated that the primary driver for battery selection in hybrid applications is cost - cost - cost, not only battery cost but the cost of other battery support sub-systems also. This decision alone has lead many a hybrid battery to its doom. I submit that the primary drivers for battery selection should be the application and the environment. Many questions on these two requirements need to be answered before proper battery selection can be made. These are the more important questions which drive battery selection:

1. Is the battery going to be in a remote inaccessible location?
2. Is the battery going to be exposed to varying temperature extremes or constant high temperatures?
3. Are there going to be qualified maintenance personnel available to care for the battery?
4. Is there adequate energy resources available to periodically charge and equalize the battery?
5. How long must the battery last, required life?
6. How long do you want the battery to last, desired life?

Lets look at each of these questions and see if the right answers can lead to a viable and acceptable battery selection. Question #1 leads one to a decision on whether a valve regulated (VRLA) or flooded design is indicated. A flooded battery will require periodic and regular watering, an impossible task in a remote unmanned location. If a battery cannot be inspected and watered on a regular schedule, then do not attempt to integrate a flooded design in a remote system.

Lets look at question #2. Temperature extremes are important considerations. High temperatures guarantee that a battery will not meet ideal life expectancies; low temperatures guarantee that the battery will not meet the name plate capacity for nominal operating temperatures, usually 77°F. High temperatures can be easily controlled with HVAC installation, but costs usually prohibit this option, and batteries are frequently exposed to very high average temperatures resulting in premature end-of-life. Flooded batteries are more robust at high temperatures while VRLA batteries have better performance than flooded batteries at low temperatures. Consideration of operating temperatures can help lead one to the most robust battery selection but the best solution by far is to control the temperature of the battery environment and use the battery most suitable to the application and not the environment.

Question 3 helps make the VRLA vs. flooded selection but the qualifications and reliability of trained maintenance personnel must be carefully considered if you want reliable management of the battery system. Battery systems are very unforgiving and if the plates are exposed above the electrolyte level during battery operation, the battery is compromised from that time onward. If there are no qualified inspection and maintenance personnel available on a regular basis, then VRLA batteries and their accompanying support electronics are the only choice.

The answer to question #4 is critical to the maintenance of battery state-of-health (SOH). If the answer to this question is not carefully determined, the battery is doomed before it is ever turned on. Batteries must be fully charged periodically and the resources must be available to guarantee that the battery can be fully charged. In addition, equalization of the battery will be needed on a periodic basis and resources must be available to equalize the battery according to manufacturer's specifications.

Tradeoffs may be necessary. However, before tradeoffs can be made, questions 5 & 6 must be answered. Question #6 is easy to answer from a life cycle cost perspective; question #6 is obviously answered with"as long as possible". Question #5 is the real driver for tradeoffs and its answer drives the answers to questions 1-4. If temperature controls battery life expectancy, then temperature must be controlled. If you have limited charge capability for the battery, you are compromising life expectancy; you must provide additional charge resources to insure acceptable battery life expectancy. If you have unreliable watering and inspection resources, you are compromising life expectancy. The tradeoffs are usually made in such a way that the battery life expectancy is compromised. The proposed fixes: add a little extra water, we won't worry about a few days (weeks) (months) operation at elevated temperatures; it won't hurt to undercharge the battery for a few months during the year; why temperature compensate - no real payoff there, a cheap charge controller will do the job, hey! it's just a battery, ad nauseam. All excuses and justifications which will ultimately lead to the premature death of the battery.

OPERATIONAL CONSIDERATIONS

Battery life is dramatically impacted by the way the batteries are used in the hybrid operational environment. In a typical electrical system where power and energy measurements can be made on the nominal background load and the typical peak load, parameters can be specified which define system power and energy limits. These measurements set the operational limits for the electrical system. In a typical hybrid system where the user is a domicile or small village, one can only set limits on battery discharge rates and generation rates to meet the anticipated varying load demands.

To overcome stresses which are placed on the battery because of demand variations and discharge rates, it is extremely important that the battery be managed under carefully applied operational constraints. For example, opportunity charging should receive high priority to minimize the length of time the battery spends at low and intermediate SOC. The battery system should be prepared to use excess energy generated by the renewable resource to recharge as the opportunity presents itself. In addition, equalization charging must be scheduled as frequently as necessary to minimize stratification effects and maintain battery SOH. In order to perform these functions, some level of intelligence must be built into the system control which keeps track of temperatures, loads, rates, and times so that proper charging can be performed as needed to keep the battery above some minimum SOC and to perform equalization charging as necessary.

To be fully effective, the system control intelligence must also be sensitive to the battery type and model as each battery model has it own voltage, temperature and control parameters requirements. For example, charging voltage set points can range from 13.2 v to 16.4 v for a 12 v battery module (2.20 v to 2.73 v per cell). Equalization voltage set points must be set to ±0.01 volts per cell according to the manufacturers specifications. In addition, these voltages must be adjusted at the same precision to compensate for the internal battery temperatures, again in accordance with manufacturer's specifications. The hybrid system integrator is key to satisfying the management requirements for the battery by his selection of the system control strategy.

In a hybrid environment, the genset is an important key in managing battery SOC as it can supply power to both the load and the battery during the charging activity. But the dilemma is that the genset is the last component one wants activated in order to conserve fuel and minimize run time for maintenance reasons. This means that when the genset is activated, it must be operated at its most efficient settings in order to maintain genset SOH. Again, intelligent controls are needed to meet this criteria.

CONCLUSIONS

Batteries in hybrid systems can meet performance expectations for life and capacity IF they are properly integrated and managed in the hybrid environment. And that is a strong IF. Every battery that I have seen in failure in a hybrid system was driven to failure by poor or inadequate system design. Many of the causes have been discussed in this paper. When a battery fails in such a system, it is very easy to blame the battery because "it's just a battery". I submit that a battery is a precision instrument and when treated as a precision instrument and as recommended by the battery manufacturer, it will deliver all that is promised by the battery manufacturer in the battery specification. If one chooses to treat the battery otherwise and the battery fails prematurely, it is not the fault of the battery or the battery manufacturer. One only has to look as far as the system designer and integrator to find the cause of the failure.

System Design and Maintenance Issues for Batteries in Renewable Energy Hybrid Systems

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Hybrid Systems
Presentation Overview

- ☐ **Introduction**
- ☐ **Performance Considerations**
- ☐ **Battery Selection Criteria**
- ☐ **Operational Considerations**
- ☐ **Conclusions**

Hybrid Systems
Introduction

❒ Hybrid Components

- Renewable Source
- Storage Component
- Engine-generator

❒ Hybrid Applications

- Off Grid Home Power Source
- Small Villages
- Mobile Emergency Source

Hybrid Systems
Introduction

- ❐ **Battery Types**
  - ◆ **Energy**
  - ◆ **Power**
- ❐ **Battery Designs**
  - ◆ **Flooded Lead-acid**
  - ◆ **VRLA**

Hybrid Systems
Performance Considerations

- ❐ **Depth of Discharge**
  - ◆ **Rate vs Depth**
  - ◆ **Cycle Life Impact**
- ❐ **Effects of Charge/Discharge Rates**
- ❐ **Stratification**
  - ◆ **Causes**
  - ◆ **Long Term Effects**
- ❐ **Temperature Effects**

Hybrid Systems
Battery Selection Criteria

- ❐ **Flawed Conventional Wisdom**
- ❐ **Drivers for Battery Selection**
  - ◆ Location
  - ◆ Operational Environment
  - ◆ Maintenance Issues
  - ◆ Resources for Battery SOH Management
  - ◆ Required Life/Desired Life
- ❐ **Tradeoffs**

Hybrid Systems
Operational Considerations

- ❐ Establishing Rate/Depth Limits
- ❐ Opportunity Charging Issues
- ❐ Equalization Issues
- ❐ System Controller
  - ◆ Variations in Battery Requirements
  - ◆ Need for Intelligent Controller
- ❐ Genset Considerations

Hybrid Systems
Conclusions

- ❐ **Performance Expectations**
  - ◆ **Integration Impact**
  - ◆ **Management Impact**
- ❐ ***"It's Just a Battery"!!!***
- ❐ **Precision Instrument???**
- ❐ **Root Cause of Many Failures**