ESTABLISHMENT OF BATTERY STANDARDS FOR CATV STANDBY POWERING

Larry Lindner
Bob Bridge
Alpha Technologies

Charles Marks
Johnson Controls

INTRODUCTION

The reliability of cable television signal distribution systems is increasingly dependent on the reliability of 60 Volt A.C. power back-up. The decreasing quality of utility power, and increasingly frequent interruptions in delivery of power add to the list of challenges to the cable system engineer in his efforts to improve service to subscribers.

Manufacturers of standby power supplies have traditionally left the decisions on selection, installation, and maintenance of the battery sub-system to the cable engineer. Without standards of quality, a clear definition of the requirement, and with potentially unrealistic expectations respecting battery service life, the industry has experienced wide variations in performance and reliability of its standby powering equipment.

It is the object of this paper to lay groundwork for establishment of a process leading to the creation of standards for battery usage in the CATV standby power application. The paper reviews the nature of the CATV standby power battery service requirement, and compares this requirement to available classes of battery service. The special needs relating to temperature, environment, price/performance, and maintenance are discussed, and comparisons made within two main battery types.

The paper concludes with recommendations affecting the use of AGM (absorbed glass mat) batteries and Gelled Electrolyte batteries. Recommendations are also made respecting the establishment of a Battery Standards Committee within the SCTE.

BACKGROUND

CATV Standby Power Battery Service Requirements

Size, Voltage Rating and Discharge Capacity

Typical standby power supplies in CATV use a 36 Volt D.C. inverter as the back-up source. Some designs remain that use a 24 Volt source, although these have largely passed from common usage. Dual parallel battery strings are in use where higher capacities are required to support longer run times. The "standard" 3-battery series-connected 36 Volt hook-up will be the example used throughout this paper. At typical run times of 1.5 to 3 and 4 hours, at 60 VAC loadings of between 7 and 12 Amps, battery sizes in the "group 31" case size offering capacities of greater than 150 minute reserve capacities are commonly used. Batteries commonly produced for the automotive, traction, and marine markets suggest themselves for this application, and are widely available in the capacity range indicated.

Charging Requirements

1) Float Service

The standby power supply battery must be continually maintained at a state of full charge, in anticipation of a discharge cycle at unpredictable intervals. Float service is commonly used by power supply designers. A constant-voltage float is impressed permanently across the battery string. Current flow into the battery string is determined by the total battery series impedance, a function of charge level. At the correct float voltage, a fully charged string of 3 batteries will continuously draw only a small amount of replenishment current to compensate for ongoing self-discharge. At any level of discharge, a demand current proportionate to the required charge will be drawn from the float charger.

2) Temperature Variation

The standby power battery will be used in outdoor enclosures and is therefore subject to most environmental conditions. The most important of these will be temperature variation. The battery will be required to charge effectively, to retain significant discharge capacity, and to provide reasonable service life over a wide range of temperatures. Temperatures will range from extremes well below 0°F to high values in the 120°F to 135°F range. Float charge systems must be temperature compensated to avoid overcharging at high temperatures, and to avoid inadequate charge levels during periods of extreme cold.

3) String Charging

The 36 Volt inverter battery comprises three 12 Volt batteries in series. Use of a single charger to float the three batteries at equal voltages requires that the single float voltage value be divided across three equal-impedance batteries. This requires that the batteries be of identical production, identical age, and in identical condition. Variations between batteries, or early failure of a cell within a battery, will unbalance the charge voltage distribution, usually resulting in overcharge of the remaining batteries. Batteries produced with low-cost materials, and/or in a poor quality-control environment, may have inherent imbalance conditions even when fresh from production. Carefully matched batteries, known as "UPS Grade", have been considered outside the price range of CATV budgets.

Discharge Service

Cable back-up requirements come in unpredictable spurts, depending on local conditions of weather and utility reliability. Outages may occur typically for very short periods on average, but on occasion may be lengthy. National averages have been reported to be in the 20 minute range, but outage classifications within CATV have not been standardized. Outages of seconds, or minutes in duration, are common. During periods of storms, extreme lightning activity, or severe winter weather, outages may last for days.

Battery back-up is normally expected to provide inverter power for up to two hours on average at typical loads. Many CATV franchise agreements today call for four-hour run times, but these are largely unrealistic and in any case are seldom referred to a required amount of load power.

Discharge events can be said to be at random intervals, of widely varying duration. For events which last longer than available capacity, the battery may remain without charge for the duration of the outage until restoration of power by the utility or generator. These events may be at extremes of temperature.

Discharge Current Levels

Standby power supply rated load values are currently in the 10 Amp to 28 Amp A.C. range. This translates to power requirements in the 700 Watt to 1800 Watt range, at 36 Volts D.C., when the inverter is called on to support cable loads and operation of the power supply circuitry. For a 36 VDC string, discharge currents will therefore be in the range of 20 to 50 Amps. By far the majority of standby power supplies will operate in the 12 Amp A.C. output range, (at 60 VAC), calling for a 23 Amp average discharge current level from inverter batteries. "Cranking" ratings, given as "C.C.A.", or "cold cranking amps", describe short-term discharge ratings for batteries used in automotive starting applications. For standby service applications, most 12 Volt batteries in use today are rated for "reserve capacity", in minutes, at 25 Amps discharge. The reserve capacity rating then, is almost directly equivalent to "standby time" attainable at average CATV loads. Batteries used in cable applications should be compared on the basis of reserve capacity, not "amp-hour" ratings or C.C.A. figures.

Vibration Environment

Batteries in most CATV applications are mounted on poles in enclosures at 10 to 20 ft. off the ground, or on concrete pad-mounted enclosures. These are all in direct contact with traffic-generated vibration on cable rights of way, and this vibration is relatively constant. Occasional "whipping" or jolts due to falling ice, high winds, or adjacent use of heavy equipment may be experienced. Mechanically, the environment is not exceptionally stable.

Maintenance Environment

Maintenance of line equipment and subscriber connections tends to dominate the time of the outside plant maintenance staff. Power supply familiarity and battery test procedures are generally low on the priority list of many cable technicians. This can lead to low levels of understanding of the role of the battery in the standby equation. On the plus side, training programs from vendors and a growing sensitivity to power protection is rapidly improving maintenance levels focussed on standby power supplies. Progressive cable operators, using optimum maintenance schedules, may direct field technicians to visit power supplies quarterly or even more often, but correct procedures relative to checking battery health remain somewhat hit-and-miss. Virtually no directives exist which mandate removal of batteries from service until after the power supply ceases to function. It appears that battery *failure* is the only symptom that is universally recognized by the industry as indicative of the end of service life.

Battery Chemistry Review

The lead-acid battery, in common use for over a century, in size, price, and capacity ranges, suited to the CATV application, are considered in this paper for their suitability. A review of lead acid chemistry follows.

The chemical reaction between lead dioxide (PbO_2), lead (Pb), and sulfuric acid (H_2SO_4) provides the lead-acid battery's energy. The electrolyte, which is a 1 to 3 solution of acid in water (under full charge) at 77°F. may be in free liquid (flooded cell), finely distributed into a fibrous absorbent carrier (absorbed glass mat), or suspended in a mineral gelling material (gelled electrolyte). The "active" material of the positive electrode is the lead dioxide, and the active material of the negative electrode is metallic lead (Pb). Both active materials are present in the electrode structure as paste, mounted in a metallic lead frame or "grid" structure. The pastes are porous to facilitate required amounts of surface area needed to support anticipated discharge currents.

On discharge, the active materials are converted to lead sulfate ($PbSO_4$) which is deposited on the grids. The sulfuric acid solution turns to water (H_2O) as the sulfate is consumed and water is produced. During recharge, particles of lead sulfate are converted back to sponge lead at the negative electrode and to lead dioxide at the positive, by the charging source driving current through the battery. The well-known reaction is:

$$\underset{\text{Lead + Lead Dioxide + Sulfuric Acid}}{Pb + PbO_2 + 2H_2SO_4} \; \underset{\longleftarrow}{\overset{\longrightarrow}{\text{discharge/charge}}} \; \underset{\text{Lead Sulfate + Water}}{2PbSO_4 + 2H_2O}$$

Battery Construction Review

Grid Alloys

Lead alloy grids are used to mechanically support the active electrode material. Grids are produced from cast lead, or lead sheet. As pure lead is too soft for grid material, alloying materials such as calcium or antimony are added. Antimony, in 4 to 6% amounts, tends to dissolve from the positive plate and redeposit on the negative plate. This affects operating voltage, increases water consumption, and reduces life as the antimonial battery ages.

Calcium was first used in telephone battery applications as a hardener. Service life was lengthened, and less frequent watering was required. Amounts vary from .03 to 0.10%.

Grid Pastes

Lead oxide pastes applied to grids by hand or machine contain measured amounts of a mixture of lead oxide, sulfuric acid, and water. Fibrous additives may be present for increased strength and binding ability. Expanders may be used to increase porosity, and subsequent current-supporting surface area.

Pastes with low density (high porosity) are used in high-rate shallow discharge service. Pastes where a deep discharge is required at relatively low rates need to be higher in density (less porous). Deep discharge stresses the paste material as it grows during discharge on the grid structure. These stresses will work to loosen the paste material from the grid. High density paste will hold onto the grid through the stress of deep discharge. Each deep discharge cycle of the battery will obviously work to weaken the paste-grid bond, and batteries in deep-discharge service will be cycle-life limited.

The paste curing process during production helps to determine its service characteristic. Flash drying after initial pasting, and subsequent lengthy cures at specific temperatures and humidity levels will determine paste-grid bonding and paste densities.

Battery Assembly

Positive and negative plates are electrically insulated from each other by separators. Separators include PVC, phenolic/celluloid, microporous rubber, or polyolefin. Some sealed batteries use glass fiber mats. Separator materials are porous or permeable to allow ionic conductivity. Current flow through separators will be a function of pore size in the separator: internal impedance then, is partly a function of separator material. Separator types can have a dramatic effect on service life.

"Formation" of the battery is the initial charging of the assembled unit. Electrolyte is added to the battery and charging current applied. During this process, the sulfuric acid in the paste material transfers to the electrolyte, resulting in a final specific gravity higher than that of the electrolyte added. The battery is now ready for service.

Battery Service Categories

In producing batteries for different types of service, the production parameters such as grid size, alloys used, paste mix, paste density, paste cure, separator material, and the internal physical dimensions of the case may all be varied and optimized. The service requirement will be dictated by parameters of capacity, cycle life, "float service" life, cost, and discharge depth. The majority of 12 Volt lead-acid storage battery service requirements have been divided into three classes of service: "SLI" or "starting-lighting-ignition", "Deep Cycle", or "Traction" batteries, and "Stationary" batteries.

SLI Batteries

An ability to deliver maximum amounts of current in minimum amounts of time characterizes this category. The automotive starting application is the most familiar use for this type of battery. The battery design and construction is therefore optimized for low impedance by maximizing plate exposure to electrolyte. This calls for thin plates (to maximize number of plates) and low density (porous) active material. Discharge depth is typically shallow, as perhaps only 1% of the batteries total capacity is taken off during a typical 'short burst' discharge in a starting application. If deep discharges are taken off of an SLI type battery, very few cycles will be available, as the paste-grid bond is severely stressed by the electrode growth during the discharge. The thin plate structure and porous paste will be seriously weakened by deep cycling. SLI batteries are also characterized by low-cost materials and economic construction.

Deep Cycle Batteries

The deep cycle application implies discharge cycles to as much as 80% of the capacity of the battery. The use of thick grids with high paste density is required to support the stresses of discharge to these depths. Premium separator material is usually required, with possible additional use of fiberglass mats, to assist in support of the paste material on the grids. Reduced surface area of plate to electrolyte contact will increase internal impedance and reduce values of discharge currents. Typical applications are in running small electric trolling motors, and in supporting inverters or other DC equipment in motor homes and boats. ("RV" and "Marine").

Stationary Batteries

Batteries which are required to support lengthy discharges (up to 8 hours) and long life in service, particularly in the 48VDC battery plants used by telephone company central office equipment, have come to be known as "stationary batteries." These units are normally racked in place, and are typically high-quality flooded designs using premium materials and high-quality construction methods. These batteries are assembled with much more care than automotive or deep-cycle products. Stationary units typically are rated for 20 year life on float service.

Sealed Batteries

All three of the main service categories may be produced in sealed designs. Sealed batteries are designed to eliminate the need to add water, increasing the convenience and safety to the user.

Flooded batteries, typical of the SLI category, may be sealed if extra electrolyte is used to provide the additional reserve of water. Lead calcium grids should also be used in a sealed flooded model to minimize gas production. These units are normally supplied as "maintenance free" batteries in the SLI market.

AGM batteries, or "absorbed glass mat" products are also known as "starved electrolyte", "acid limited", or "recombinant" batteries. In this sealed lead-acid product, a mat of fine glass fiber material functions as a plate separator with up to 95% void volume in the mats. The mat acts as a "sponge" to hold electrolyte between the plates. About 95% of the void volume is filled with acid, leaving residual volume for gas transfer during recombination. H_2 and O_2 gases, freed from the electrolyte during discharge will normally vent to the atmosphere in flooded batteries. In the AGM product, these gases will recombine with the negative plate and the electrolyte during recharge, with virtually no gas production released to the atmosphere. An internal overpressure is maintained in AGM products to aid in recombination by retaining the gases long enough to recombine.

Gel Batteries

Gelled electrolyte batteries function as starved electrolyte batteries, but do not use a glass mat. The high-density gel material takes on a porosity through development of "fissures" in the gel during initial formation and charging of the battery. Gas transfer during recombination then is facilitated by way of the fissures. Gel materials in common use are fumed silica, sodium silicate, boron phosphate and polymer microspheres. Gel products have exceptional shelf life. Self-discharge rates in storage may average 3% per month at room temperatures.

Battery Charging

Charging methods for lead-acid batteries may be divided into:

1. constant current
2. taper
3. pulse
4. trickle
5. constant potential

Constant current chargers force a fixed value of current through batteries on recharge irrespective of the state of charge of the battery. This can lead to overcharge. Trickle chargers are simply low-rate constant current chargers. Pulse chargers use current pulses which are periodically disconnected to measure open circuit voltage. Constant potential chargers (float chargers) deliver current in proportion to the charge needs of the battery. Float chargers need to be temperature compensated. Taper chargers are low-cost constant potential chargers.

As batteries are only about 80% efficient, more energy is delivered to the battery during recharge than is taken off during discharge. During the last 5 to 10% of recharge, a normal "overcharge" condition exists. Gassing occurs during this portion of recharge. In a flooded battery these gases are released to the atmosphere; in AGM or Gel products, gases are recombined.

Lead-Acid Battery Failure Modes

Loss of Capacity

Normal end-of-life will be corrosion of the positive grid. Corrosion of the positive grid is the slow conversion of the lead alloy material to lead dioxide, resulting in a loss of support for the active material. As the grid material corrodes, its resistance increases. This increasing internal impedance is equivalent to decreasing capacity. As the grid corrodes, the lead dioxide material takes up more room than the lead alloy did: this is "positive plate growth". Without design for this expansion, internal shorts result. In designs where low impedances and high-rate discharges require thin, closely spaced plates, this type of failure mode is more likely than in low-rate, thicker-plate designs.

Thicker grids will obviously take longer to corrode away. Long-life batteries therefore are characterized by thick grids. Stationary batteries may have grids up to 0.30". For similar capacity ratings, (say in the 160 minute reserve capacity category) an SLI flooded grid will be .030" to .040" in thickness, whereas Gel and AGM products may be up to .115". The AGM product, with the mat acting as electrolyte support, needs less room between plates for separator and electrolyte, allowing greater thickness to be used, resulting in closer plate spacing.

Paste Failure

During charge and discharge cycles, lead sulfate builds up on the lead dioxide plate material. Lead dioxide is a brittle, ceramic-like material, and is more dense than lead sulfate. This repeated expansion and contraction of the composite plate stresses the active material, causing it to break loose from the grids. Deep cycling obviously causes great stress. Deep cycle batteries may incorporate several layers of material or envelopes over the plate to retain the active material in place. Again, high density materials will tend to remain in place in the grid under the stresses of deep cycling.

Shorts due to Dendrite Production

Cell shorting can occur in several ways. Most commonly it occurs when the design has not allowed for positive grid growth. Cell shorting can also occur, due to "dendrite" formation, when batteries are very deeply discharged. Dendrites are conductive lead paths that penetrate the separator. Dendrites occur as the battery is discharged and the electrolyte specific gravity (S.G.) is lowered. Lead sulfate from the plates becomes more soluble in the low S.G. electrolyte. Upon recharge, this lead sulfate turns into metallic lead forming dendrites. AGM batteries seem to be more susceptible to this deep discharge problem as they are designed to be an "acid starved" system and to use up most of the sulfuric acid. The gelled product maintains a higher specific gravity which tends to inhibit lead sulfate solubility and resultant dendrite formation.

Accelerated Grid Corrosion

Positive grid corrosion occurs under all conditions in a lead-acid battery. The rate of corrosion is dependent on grid alloy charging voltage, temperature, and electrolyte specific gravity. Improper float voltage, high temperature, and elevated electrolyte S.G. will all increase the rate of positive grid corrosion. In general, AGM batteries operate at a slightly higher S.G. than gelled batteries to compensate for the limited electrolyte volume. If this type of battery is not designed with the slightly higher grid corrosion rate in mind, it will fail prematurely, particulary at higher temperatures. High float voltages that increase grid corrosion point out the need for proper temperature compensation.

Sulfation

Normal production of lead sulfate during discharge is converted to the usual reaction products during recharge. If batteries are left to stand on self-discharge and experience lengthy periods of stand-time at partial charge levels, a hardening of the lead sulfate sets in, which is much more difficult to break down on recharge. This hard sulfate acts to close the "pores" of the active material. Obviously batteries should be charged as soon as possible after discharge. Sulfation is accelerated at elevated temperatures. Sulfation can be reversed somewhat by sustained overcharge, to break down the sulfate material. This will produce excess gassing and is not recommended for sealed batteries. Excess gases in sealed batteries will be vented by pressure-relief valves, resulting in reduced battery life.

Sulfation is also enhanced by low electrolyte level in flooded batteries (at the exposed tops of the plates), by higher specific gravities, and by higher operating temperatures. Continuous undercharging due to inadequate float voltages or inadequate temperature compensation will increase sulfation rate.

Operation at Elevated Temperatures

The chemical processes at work in all lead acid batteries will proceed more rapidly as a function of increasing temperature. The rule of thumb is "..for every 15°F. of continuous operating temperature over 77°F., battery life expectancy will be halved.." This implies that a battery with an estimated 60 month life at room temperature will have a 30 month life if operated continuously at 92°F. At 107°F., the anticipated life is reduced to 15 months. Battery life can be maximized through operation at reduced temperatures, and with correct temperature compensation of charging current.

CONCLUSIONS

It is evident to CATV engineers that a sealed-construction battery is first choice for the standby power supply application on grounds of ease of handling, safety, UL approvals, and local electrical codes. Flooded batteries are to be avoided due to hazards in shipping, transporting to power supply locations, warehousing, disposal, and lack of approval by UL or local jurisdictions for use on poles or in ground-mounted installations on public rights-of-way.

The choices are reduced to Gelled electrolyte products or AGM products, which have been made available in the capacity and price ranges compatible with customary cable industry budgets. This reduces the choice to sealed, non-flooded products aimed at deep-cycle ("traction") applications and stationary applications.

AGM or Gel products with thick plates, designed for potentially lengthy discharges without cycle damage will be suitable candidates for use in the CATV application. The greater susceptibility of the AGM product to accelerated corrosion, dendrite growth, plate growth, and capacity reduction, with all of these increased at higher temperatures, will result in shorter service life for this choice.

AGM units will be economic choices in cooler, or relatively constant room temperature environments. The Gel product should offer lengthier service life, all things being equal, as it appears less susceptible to the processes leading to failure. "Dry-out" of the Gel product due to sustained overcharge at elevated temperatures has been reported as a common failure mode of this battery type in power supplies without temperature compensation circuitry.

Imbalances in internal impedances due to production process variations can be expected to have equal effects on both types. The lower production cost of the typical AGM product relative to the Gel product suggests more proneness on the part of the AGM to variations between individual batteries in a given production run. Gel products now made for long life stationary battery applications can be expected to have tight quality control content and higher quality materials used in construction than AGM's manufactured for trolling motor markets and subsequently marketed as CATV standby power supply batteries.

Prices of AGM products made for mass markets have been a significant attractant for tight CATV budgets. Typical purchases have been driven by "price per unit", with little regard for service life. Simple arithmetic points out that a battery product with a typical two-year service life supplied to the market at (say) $75.00, will have an annual amortization of $37.50. Another product with a potentially longer service life of (say) three years, at pricing of $85.00, amortizes at $28.33 per year. When price/performance comparisons of service life are made in this way, the "more expensive" product may be up to 25% less costly in the long run.

RECOMMENDATIONS

A committee to serve the needs of the CATV community, specialized in battery expertise, should be established to provide guidelines on battery evaluation, battery maintenance, and battery selection for use in CATV standby power applications. The committee could be established under the auspices of the SCTE, and should be made up of engineers from the battery industry, cable engineers, and power supply designers. With the help of such a committee, and the guidelines it could supply, users of standby power supplies will be able to plan battery purchase and usage guidelines for the most efficient use of their powering budgets. Maintenance planning and battery replacement criteria will also benefit immensely from the establishment of clear standards.

References

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