AUTOMATIC INDIVIDUAL CELL CHARGING IN MONITORING SYSTEMS

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EXTRACT

This paper will discuss the challenges associated with charging lead-acid battery strings and how a management system that is capable of providing current to individual cells can prevent certain problems from developing, benchmark and track active cell status changes, significantly extend service life, and improve the overall power system reliability.

BACKGROUND

The common current that flows through all of the cells within a battery string results from the *higher than open circuit* string voltage at the attached charging system terminals. Following a recharge, the voltage at the charger remains at the *float setting* and a *float current* continues to flow through the string. When the level of float current from the fixed voltage supply gradually drops to an acceptable level, the battery string is considered by most standards to be fully charged and ready for service. This can create a false sense of security because the level of *string float current* that flows is determined by the *entire string* and can only be a reliable indicator of the state of charge *if every cell is exactly the same* in every respect. In fact, the string is a composite of all of the individual cell variables, such as electrolyte specific gravity, internal resistance (deterioration level) and temperature. *Any one* of these variables associated with *any one* of the cells will affect the common current that flows throughout the entire string. For example, if the internal temperature of one cell increases, the float current for the entire string will increase. With all of the other variables at play in all of the cells, any variable in any cell can cause the overall common string current to change. Maintaining a continuous string float current with elevated voltages is the traditional method of preventing cells from self-discharge during the extended standby periods.

GENERAL

Automated Individual Cell Charging (AICC) is a method of automatically providing an isolated charge current directly into each individual cell or jar within a battery string under computer program control. This individual cell approach can be an alternative to the usual string *float* charge current described above. AICC has the ability to deal with the individual charging needs of each cell and can assist the main charging system to correct charge inequalities that are caused by individual cell differences that exist throughout the string[1]. It can also be used as a backup source of maintenance charge current if the main charger fails or is intentionally adjusted to the fully charged open circuit voltage. AICC can recognize when the voltage of each cell has decayed below the established fully charged open circuit voltage and then provide individual charge currents, but only as the need arises. Since each cell can have a different rate of self-discharge, AICC will exactly match the maintenance current to the individual cell needs.

AICC can also be used to distinguish the relative differences in the active electrochemical behavior of cells within a string and automatically track changes that occur over time[2]. AICC uses the power of the computer and an isolated source of current to recognize and correct charging inequalities and then sustain the new level of string unity over the life of the battery. The ability to test each cell with a precisely measured current from the isolated, fixed voltage power supply can be used to confirm that (1) the internal temperature is not increasing, (2) the charge state has not decreased and (3) that the individual cell circuit is behaving normally. Each cell circuit has an individual current *signature* that can be learned by the system when the battery is in a known, acceptable performance condition. A set of individual cell *signatures* can be saved in a computer file as the *benchmark* signature of the entire battery when it was in a known and acceptable state. A comparison of each successive individual cell current value with the individual cell *signature* is used to automatically track deviations from a benchmarked status as often as every hour. This programmable *trend alarm* permits automatic triggering of a targeted and proactive program to cover the periods between regularly scheduled maintenance and performance testing.

CONNECTIONS TO THE BATTERY

One wire is connected through an in-line fuse to each cell or jar positive post with the last monitor wire connected to the last negative post at the end of each string. As the BMS scans the string, pairs of these wires are selected in sequence to monitor the terminal voltage or serve as a path for charge current that is directed to each cell or jar as needed.

THE INDIVIDUAL CELL CHARGER

The cell charger provides an *electrically isolated* source of current from a regulated DC voltage supply that is adjusted to the appropriate voltage to provide a timed 2 ampere charge current to any target cell within a string under computer program control.

Most battery strings are connected to other electrical equipment such as a charger or UPS. It is important and necessary that all connections to the battery string from external equipment (such as monitoring systems) be electrically isolated with a transformer and with no common physical circuit connections to earth ground. The typical insulation strength is 1500 Volts between the output of the supply and earth ground.

THE STRING CHARGER

The main string charger is needed to recharge the string after a discharge since the AICC has a limited current capacity and would require too much time to restore the lost energy. After recharge, the string charger voltage can be reduced to the open circuit voltage of a fully charged string and allow AICC to provide maintenance charge current to the cells as required. Modern digital power systems can take advantage of the AICC benefits by providing for a programmed reduction the DC voltage to the fully charged open circuit level between recharge cycles.

OPEN CIRCUIT CELL VOLTAGE

The open-circuit cell voltage is a function of temperature and electrolyte concentration as expressed in the Nernst equation for the lead-acid cell[3]:

$$\mathbf{E = 2.047 + RT/F\ ln\ (\propto H_2SO_4 / \propto H_2O)}$$

Since the concentration of the electrolyte is varied, the relative activities of H_2SO_4 and H_2O in the Nernst equation change. A graph of the open-circuit voltage versus electrolyte concentration at 25 degrees C is shown in Figure 1. The plot is fairly linear above 1.20 specific gravity, but shows strong deviations at lower concentrations. The open-circuit voltage is also affected by temperature. Most lead-acid batteries operate above 1.120 specific gravity and have a thermal coefficient of about +0.2 mV/Degrees C.

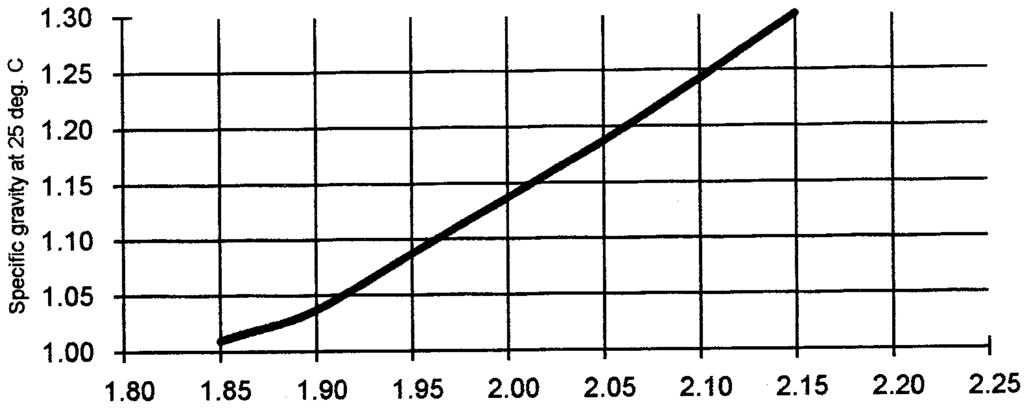

Figure 1 - Open-circuit Voltage at 25 Degrees C

Parameter	*Flooded*	*VRLA*
Specific Gravity	*1.215*	*1.300*
Fully Charged Open Circuit Voltage	*2.06*	*2.16*
Float Voltage	*2.17*	*2.23*
Polarization	*110 millivolts*	*70 millivolts*
Positive Polarization	*40-50 millivolts*	*60-70 millivolts*
Negative Polarization	*60-70 millivolts*	*0-10 millivolts*

Comparison of Typical Flooded & VRLA Cell Parameters[4]
Table 1

CURRENT VERSUS VOLTAGE

Unlike the static nature of voltage, current can characterize the properties of a circuit. The current value is the result of the combined properties within an electrical circuit. The precise amount of current that each cell draws from the fixed voltage supply will be slightly different from the others and can be used to track and confirm factors such as the cell's relative charge state, internal resistance and temperature. This individual *signature* current can thus be used by the BMS to characterize and benchmark the status of each cell or jar during a known good period and then recognize changes as they occur over time.

EQUALIZATION CHARGE

The system also uses the same isolated current that is used for testing to provide an equalizing charge directly to individual cells within the string that have exhibited terminal voltages that are lower than the maximum programmable percent deviation, as compared to the string average. This function maintains the entire string in an equalized condition continuously and eliminates the need to perform regular "equalize charges" on the string[5]. This practice is traditionally accomplished manually or by a timer that periodically elevates the overall string voltage in an attempt to equalize cells that are not fully charged. Raising the overall string voltage is not a very effective way of accomplishing equalization because the terminal voltages of the fully charged cells will rise almost immediately into a severe overcharge range and will account for a disproportionate amount of the applied overall voltage. The targeted undercharged cells are affected very little by the process unless the overcharged cells begin to heat. As the internal resistance rises in the overcharged cells, the internal resistance begins to decrease and causes the cell terminal voltage to decrease. Only now will the target undercharged cells begin to receive the benefit of the equalizing current. Thermal runaway can be triggered by traditional string equalization. This is unlikely to occur with individual cell equalization since the voltage increase is carried out individually and is never elevated on fully charged cells. Some battery applications cannot tolerate traditional equalization charging because sensitive devices that are part of the attached load could be damaged or will malfunction as a result of the elevated string voltage. The voltage rise during individual equalization will not significantly affect the overall string voltage since a 10% individual cell voltage rise is less than 2/10th of 1% of the total voltage for a 60 cell string.

A string of 60, 720 amp-hour flooded cells (under float charge) indicating the "as found" voltage deviations in a station battery is shown below in Figure 2.

- Cell Unbalance (% Deviation)
- Before Automated Single Cell Charging

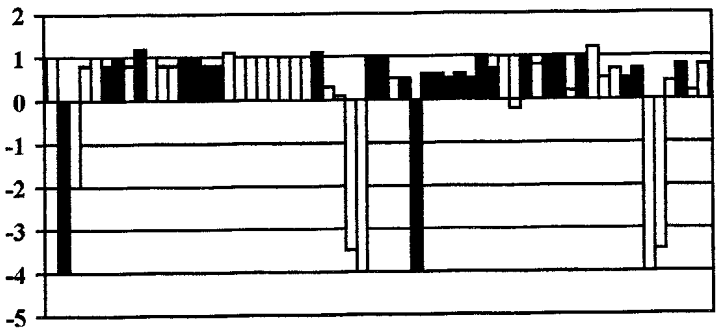

Figure 2 - Cells 1 through 60

The same string is shown in Figure 3 below after 8 days with AICC. Note that the seven undercharged cells have been corrected and that the battery is *unified* with a +/- 1-% balance deviation.

- Cell Unbalance (% Deviation)
- 8 Days With Automated Single Cell Charging

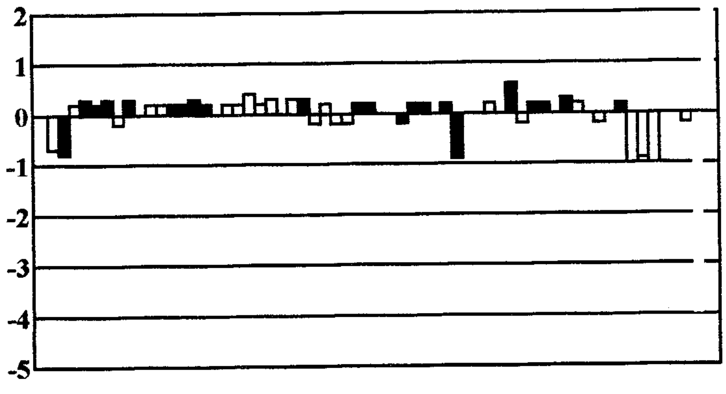

Figure 3 - Cells 1 through 60

CELL LIFE

The rate of positive grid growth in a lead acid cell has been shown[6] to be a function of the magnitude of the voltage (polarization in Table 1) that exists between the electrolyte and each plate. During traditional float charge, the cells are continuously in overcharge. The string voltage remains elevated sufficiently above the fully charged open circuit string voltage to cause charge current to flow and to accommodate the range of differences that are present in the string, thus preventing the cells from self discharging during standby periods. Self-discharge cannot be permitted, not only because of the obvious loss of capacity, but also because the plate surfaces will sulfate if the specific gravity of the electrolyte is permitted to remain below the design point for a significant period of time. Continuing to charge the string beyond where the electrolyte specific gravity is at the fully charged concentration can be defined as being *in overcharge*. Battery aging studies have shown that batteries operating under continuous float charge lose approximately half of their field lives[7].

AICC can be used to supply maintenance recharge current to the cells on an individual basis. Rather than overcharging the string continuously with the traditional float current, AICC makes it possible to minimize the amount of time that the cells are being charged. The system automatically adjusts the number of cell charges to match the individual rates of self-discharge. This is accomplished by continuously monitoring all of the cell terminal voltages during *no charge* periods and then charging the individual cells, but only when each cell voltage decays below the fully charged set point. Temperature compensation can also be programmed as part of the charge algorithm.

By reducing the amount of time that the cells are subjected to overcharge, it is possible to significantly reduce the rate of grid growth deterioration and extend the life of the cells. For example, if the charge period averages 36 seconds per hour compared with the full time period of 3600 seconds per hour, the cell life can be potentially *doubled* if the other life determining variables remain constant.

CONCLUSIONS

A monitoring system with the ability to target and deliver a measured current to individual battery cells can maintain charge unity, provide frequent confirmation of active status, automatically trend the data and potentially double the useful life of the battery.

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