Adaptive Charging, a Further Development of Intermittent Float for Charge Maintenance of VRLA Batteries in Telecommunications Standby Systems

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Introduction

In previous papers [1, 2], we have described the benefits of intermittent charging and shown how this technology has the potential to increase the life of VRLA batteries in telecommunications standby systems. The benefits and shortcomings of VRLA batteries are well known and, although they have been very successful in reducing maintenance costs by elimination of watering, they have shorter life than the flooded type. A contributor to this reduced life is exothermic oxygen gas recombination which generates heat inside them. Berndt [3] has calculated that the amount of heat produced in a valve-regulated cell during charging amounts to nearly ten times the heat produced in a vented cell under similar conditions.

In flooded cells: The rate at which heat energy is produced = 31.5mW/100Ah
Removed with gas = 20.7mW/100Ah
Remaining heat = 10.8mW/100Ah.

In VRLA cells: The rate at which heat energy is produced = 101.3mW/100Ah
Removed with gas = 5.9mW/100Ah
Remaining heat = 95.4mW/100Ah.

Since there is minimal venting of gas, this heat is trapped inside and can only be removed by transmission through the container walls. If the batteries are closely packed in an installation, very little heat can be removed. Therefore, they operate at a higher temperature than flooded batteries, resulting in accelerated failure. Another factor is that oxygen recombination depolarizes the negative plate which transfers most of the polarization to the positive plate. There are many factors that influence the distribution of polarization but increased positive plate polarization will increase grid corrosion and water consumption.

Float charging, which has been successfully used for many years and is the industry standard method, is effective for maintaining full charge and providing satisfactory life. However, it is not perfect and has a drawback when used with VRLA batteries. This is that the constant overcharging, higher internal temperature and increased positive plate polarization increases grid corrosion, dehydration, and active material degradation. The objective of the development described later is to reduce these damaging mechanisms so that longer VRLA battery life can be obtained.

Terms such as intermittent float or periodic float describe a strategy involving sequentially float charging for a specific period of time and then placing the batteries on open circuit for a second period of time [4]. The ratio of float to open circuit time has usually been fixed. Although this reduces the amount of overcharge it has weaknesses.

(i) The correct ratio of charge time to open circuit time is critical and depends on temperature and battery condition
(ii) An incorrect ratio can result in overcharging or undercharging.

For example, the reactions that lead to premature battery failure are temperature dependent therefore a fixed float/open circuit time ratio that might be adequate at 25°C will not be satisfactory at higher or lower temperatures because of different rates of corrosion and dry out. Additionally, the rate of self-discharge is temperature dependent and the amount of charge required to maintain 100% state of charge at 40°C will be greater than at 25°C. These magnitudes of temperature fluctuations are common, especially in outdoor cabinets, and it is difficult to continually adjust float voltages and currents to maintain an optimum charge. Therefore the ratio of charge to open circuit time needs to be adjustable to compensate for this. Consequently a fixed ratio will not be satisfactory. In summary:

(i) Float charging causes plate corrosion which determines the end of life for most lead acid batteries

(ii) If battery strings are maintained off-line periodically, positive plate corrosion is reduced and battery life is increased.

(iii) A flexible algorithm that controls the length of time the battery is left off charge will reduce positive grid corrosion and increase battery life.

Adaptive charging is a technology where “signatures” from the battery data are used to determine when the battery needs to be charged and for how long, and to identify other potentially negative events. It utilizes a charging regimen where the voltage of each individual battery is monitored and the charge is continued or terminated when the string voltages are uniform. With dv/dt charge termination the charging of the string stops when the battery is fully charged thereby preventing continuous overcharge and overheating. It adapts to the depth of the preceding discharge and compensates for the effect of temperature. That is, dv/dt=0 indicates that the battery is charged whether it is at 25°C or 40°C. In a multi-string installation, each string is charged independently of the others and every battery in the string is managed. For example, a string may have a low voltage battery indicating a problem. In this case the string will be given additional charge to recover the faulty battery. If this is unsuccessful the string will automatically be taken off line and the network provider will be notified of its status.

Certain signatures, such as open circuit voltage, internal resistance and voltage under load give an indication of whether a battery needs to be charged. For example open circuit voltage is an indication of:

- Electrolyte specific gravity
- State of charge
- Short circuits.

Internal resistance indicates:

- Active material sulfation
- Drying out
- Grid corrosion.

Voltage under load can indicate:

- Increased internal resistance
- Degraded active material.

Monitoring these signatures coupled with data trending gives useful information regarding when the battery needs to be charged. The principles of adaptive charging are:

(i) The batteries are maintained in a standby (off charge) mode by isolating them from the rectifier bus. The system discussed here isolates batteries from the bus while still permitting them to deliver instantaneous backup power. The device inhibits charge in the standby mode and the batteries remain connected to the bus by a switching system involving diodes and MOSFETS that facilitate continuous connection. This utilizes one-way electronic switching which removes all of the EMI and equipment-damaging voltage spikes caused by electro-mechanical contactors and relays. The electronic switch MOSFET is controlled by the software, only for charging the batteries.

When the bus voltage begins to drop from an AC mains failure, the bus voltage will become lower than the battery string voltage. When this happens the diodes will forward-bias and conduct. This happens at the same rate that the bus voltage is dropping, so there are no voltage drop-outs or spikes. The system detects the diode's conducting and turns the MOSFET switch on, reducing switch power loss to about 1 watt at 60 amps of battery current.

(ii) With a system that rests batteries on open circuit and charges based on data rather than a fixed period of time it is critically important to determine when a battery is at 100% SOC. The system utilizes dv/dt to determine the optimal point for charge termination. This method of charging prevents continuous overcharge and overheating. The benefit of this is that life is increased by reducing battery temperature (no oxygen recombination) and its associated grid corrosion and dehydration. Since there is no temperature increase, thermal runaway is virtually eliminated and the need for cooling is reduced. In this standby mode the batteries are still available for instantaneous discharge in case of a power outage.

(iii) The data are compared to a library of trended data and, if stable, the batteries are allowed to remain in the standby mode. If the data show changes greater than embedded set points a charge is initiated.

(iv) Charging is accomplished by placing the batteries on the rectifier bus until they are fully charged. This replaces energy lost through self-discharge and any short term discharges that may have occurred. As soon as the full charge criteria are satisfied the batteries are again isolated from the rectifier. If the batteries have been discharged for more than a preset time during the standby period they are immediately connected to the rectifier for charging to eliminate any possibility of standing in a partial discharge condition.

(v) Following any charge event the battery strings are given a state-of-health test. In this test a short, shallow discharge is applied to the battery and the voltage characteristics are recorded and used to calculate the internal resistance.

This sequence assures that the batteries are charged whenever the data trends indicate that a charge is necessary. This automatically compensates for normal temperature-dependent phenomena such as self-discharge. It can be understood that the batteries only receive charge when necessary and the charge is terminated when the algorithm reaches the termination point. The number of charges to maintain stability is recorded, trended and is used to determine whether the battery is requiring an abnormal number of charges signifying a deteriorating condition such as a short circuit.

A device to accomplish these operations has been developed, comprising two major modules:

- An electronic control module to charge and perform battery function testing
- A software module to sample and organize battery signatures into libraries and to produce trended data charts.

This device has undergone field and independent laboratory testing and has been deployed in a significant number of sites across the USA. The following sections of this paper will describe some of the results obtained to date.

Life Testing

VRLA batteries have been tested in the field and laboratory to verify the life extension benefits of replacing continuous float charging with adaptive charging. An independent test laboratory was engaged to compare the capacities of VRLA batteries over time when they were on continuous float and when managed by the adaptive system. The tests were carried out at 40°C (104°F) to simulate hot weather operating conditions. Four strings of batteries were tested in each case (16 batteries). The battery capacities were measured at the C/8 rate at approximately three month intervals and averaged and charted as shown in Figure 1.

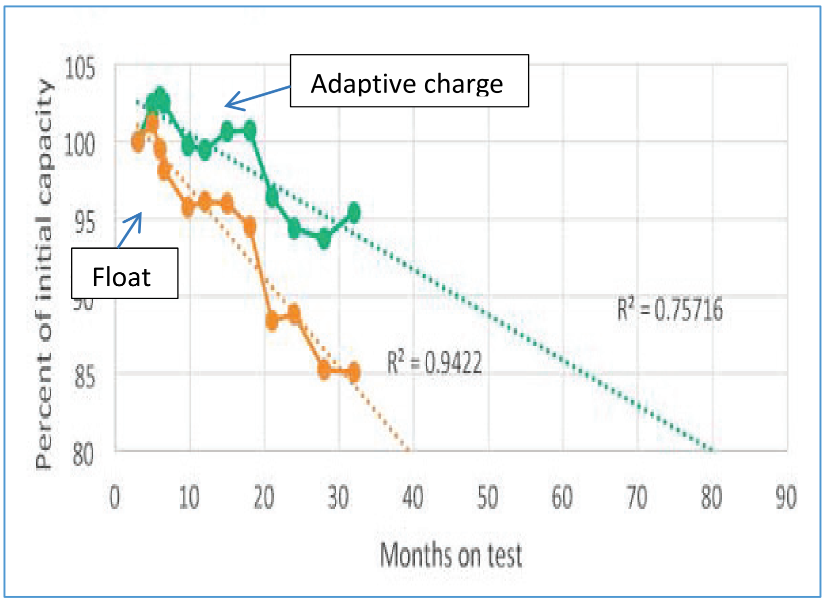

Figure 1: Life predictions of batteries on continuous float and operated by the adaptive charge management system. Test temperature = 40°C.

A clear trend developed showing that the batteries under management by the adaptive charge protocol showed higher capacity retention than those on continuous float. If the trend-line equations are solved, the expected lives to a failure point of 80% of their initial capacity are:

- Batteries on float = 39 months at 40°C
- Batteries under adaptive charge = 79.5 months at 40°C.

Tear-down analyses of batteries from life testing showed that the principal mechanism of failure was positive grid corrosion. Examination of the positive grids showed that the degree of grid corrosion in the batteries under adaptive charging was approximately one half of that of batteries on float.

Field Testing

Field applications of the adaptive charge management system have been underway in locations throughout the USA for approximately three years. The examples cited below are intended to show typical examples where either life and battery performance were increased, or where deteriorated batteries were detected.

Case Study A: Identifying defective rectifiers and extending battery life for remote sites in Arizona

Monitoring batteries at Company A showed some unusual data. Many of their sites experienced brief power outages, sometimes multiple times per day. Examples of these are shown in Figure 2.

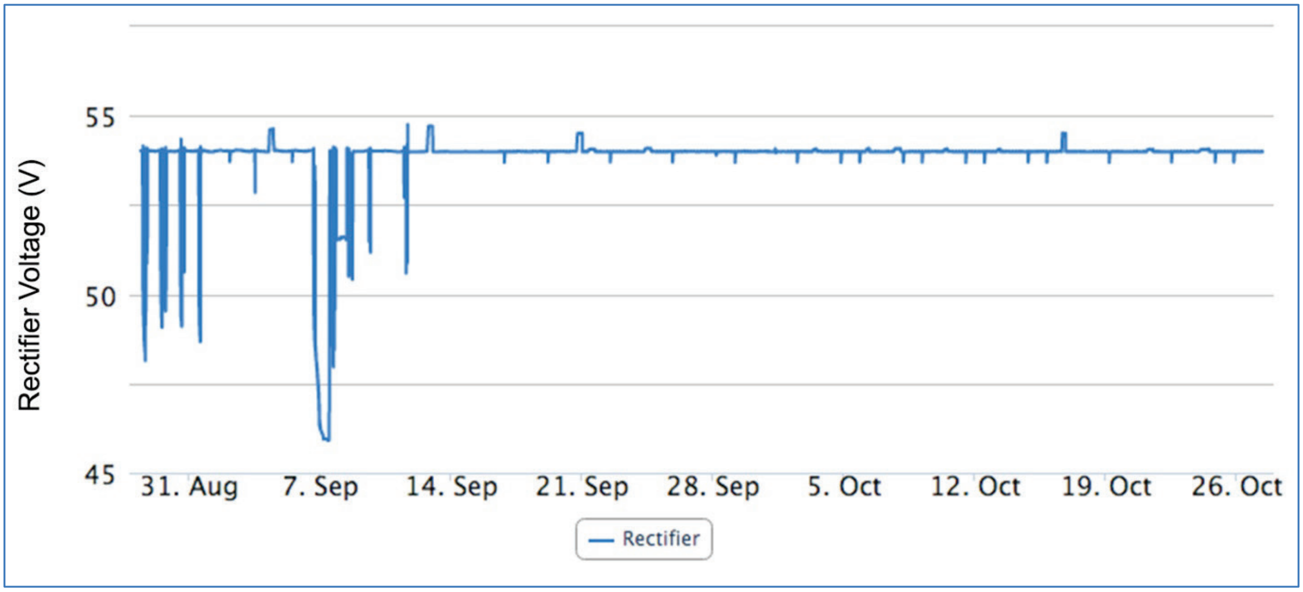

Figure 2. Example of power outages for Company A. The plot shows the rectifier output voltages vs date.

This was an unexpected result since it had been assumed that the rectifiers were working normally. Based on the data collected, the management software showed healthy batteries. As the batteries were charged the rectifier voltage dropped to below the specified value. The system was able to detect a voltage drop in the rectifier which signaled a fault. When the rectifiers were examined they found indications of faulty control modules. As they began replacing the control modules at these sites it was clear that the outages had been caused by these faulty modules. Had they not been replaced the batteries would have been damaged. Once replaced, the outages ceased.

Case Study B: Signature analysis and predictive analytics

Figure 3 shows an example of increasing internal resistance of a deteriorating battery in a telecommunications network. This was from an aging battery in a string. In this case other batteries in the same string were showing a constant resistance indicating that they were operating properly. This allowed timely changing of the battery to prevent deterioration of other batteries in the string.

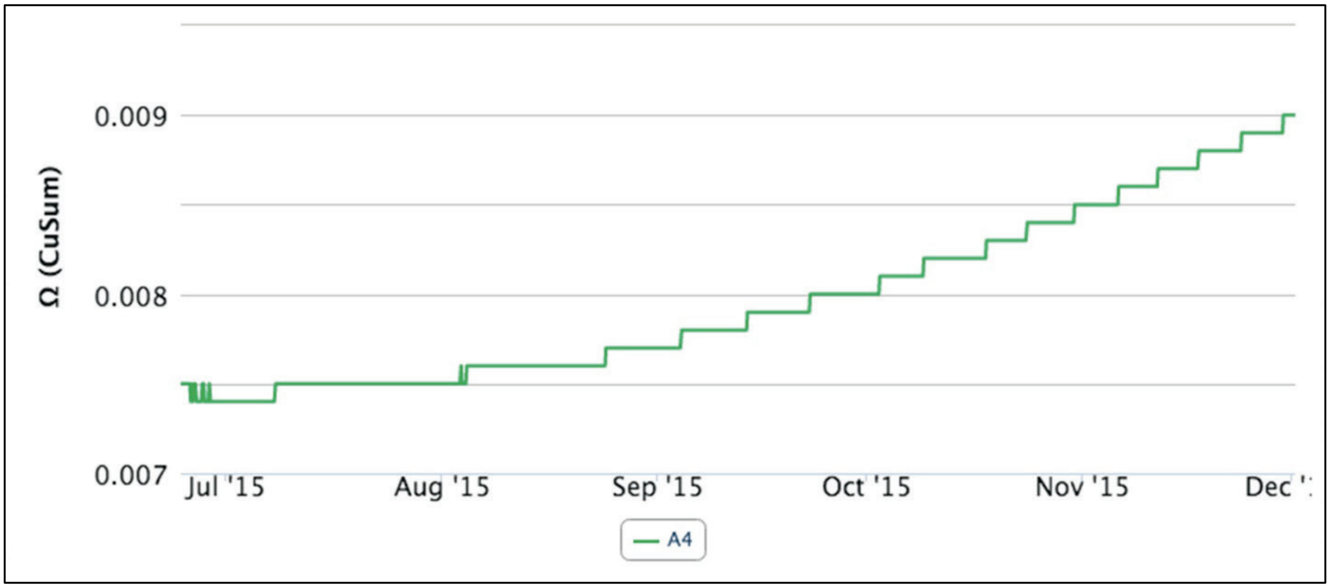

Figure 3. Change in DC resistance with time for a VRLA battery in a 48V string. The plot shows resistance in mΩ vs date.

Case Study C: Open circuit voltage

In Figure 4 the OCVs of a string of 12 volt VRLA monoblock batteries is shown. Battery A3 had a declining OCV and was replaced by the network provider. A subsequent autopsy of this battery revealed that it had a manufacturing defect that was causing a short circuit. It should be noted that if the batteries were on float this would not have been detected.

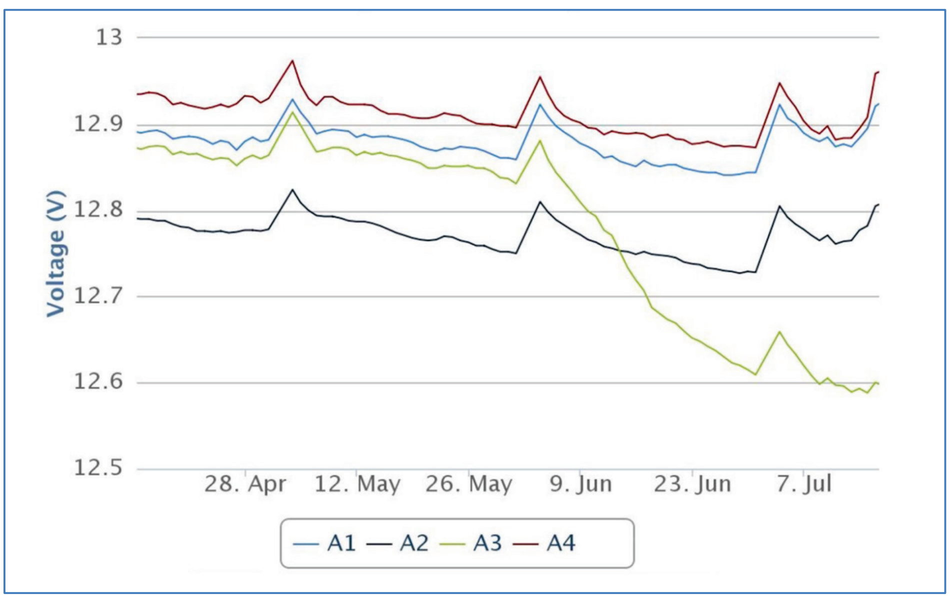

Figure 4. Example of OCVs of a string of batteries. Battery A3 is defective due to a manufacturing defect.

Case Study D: Battery capacities from field installations

Field trials have been conducted for almost 3 years and at several sites a direct comparison is being made between adaptive charging and continuous float. This is insufficient time to reach firm conclusions that battery life can be doubled as indicated by the laboratory testing but there are indications that life is being increased from capacity tests on the strings with and without adaptive charging. At an installation in Arizona two strings of new batteries of the same type, one floated and one with the adaptive charge protocol have been monitored for 21 months. These are in the same OSP and, therefore, are subjected to the same environmental conditions and use pattern. The batteries with the adaptive charge are showing higher capacity than a control string on float. The data are shown in Figure 5. This is similar data to that seen in the laboratory testing over the same time period.

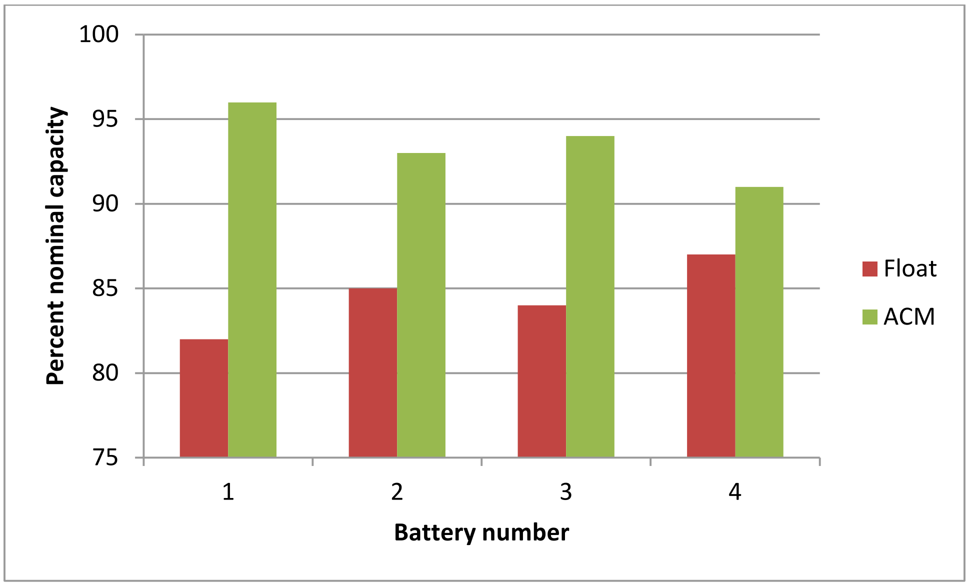

Figure 5. Comparison of capacities of batteries on float to batteries on adaptive charge after 21 months.

In another trial in Colorado, the adaptive charging protocol is being used on a battery string approximately 4.5 years old next to a new string being floated. The strings are subjected to the same climatic and usage patterns. After 21 months (total battery life = 6.25 and 1.75 years) both strings are showing 96% nominal capacity as measured with a C/4 discharge. Although the data are confounded because of different total battery ages it supports a conclusion that the adaptive charge has been beneficial, since it would be expected that the capacity of the 6.25-year-old battery string would be lower.

Conclusions

Continuous charging as a method of maintaining standby batteries at 100% state of charge has been in use for many years but has some negative consequences. It accelerates battery failure due to increased temperature, grid corrosion, plate degradation and dry-out resulting in high replacement costs. Battery life can be increased by removing these harmful failure mechanisms and by charging only when necessary and only for as long as necessary (the universal practice in most non-standby applications). Adaptive charging, a new concept in battery management and monitoring, removes standby batteries from continuous charging while still allowing them to be available for discharge when needed. Other benefits are:

- **Battery Isolation** – Batteries are isolated from the DC power system in an off-float manner that preserves battery life while maintaining their availability to deliver immediate backup power when needed.

- **Improved Useful Battery Life and Reduced Energy Consumption** – Adaptive charging maintains batteries off constant float charge and charges them only when necessary and only for as long as necessary, increasing their useful life and reducing energy consumption by over 85%.
- **Reduced Gassing, Grid Corrosion, and Positive Plate Softening** – By maintaining the batteries off constant float charge the rates of gassing; grid corrosion and plate softening are reduced, resulting in healthier, longer-lasting batteries.
- **Daily Battery Maintenance** – The adaptive charge regimen automates the operations and maintenance of battery strings in the field. It performs a testing and charging routine that returns the strings to full charge and tests their state of health and identifies any battery in the installation that does not meet the required standard. It takes the string with the defective battery out of service to protect the remaining batteries from either undercharge or overcharge. This intervention allows defective batteries to be identified and replaced by new ones before they can cause further damage.
- **Remote Monitoring** – Through remote monitoring the state of health of the batteries is determined and reported without requiring a maintenance visit. The voltage trending algorithm detects deterioration so that technicians can be alerted and can prepare for a site visit ready for the maintenance routines required.
- **Daily Monitoring** - Daily polling and trending analysis of every battery and string, including battery voltage and resistance, notification of power outages, and status of the system.
- **Web-based Dashboard and Alerting** - Detailed, real-time views, available via an easy-to-use web-based system with a dashboard feel and simplified stoplight metaphor (e.g. green, yellow, red) to identify developing trouble spots. Email alerts provide real-time information. Users can choose which adaptive charge device to receive information from and can configure the types of alerts and information they want to receive including daily summaries, alarms, and recovery notifications.
- **Proactive Trend Analysis** - The adaptive charge monitoring tools can show trends in battery health and provide early warnings of potential battery failure so replacement visits can be planned well in advance.
- **Scalable Monitoring Program** - Managers can monitor a single battery, a complete installation, a network of systems within a network, or entire corporate networks that contain thousands of sites.

The adaptive charge also delivers other measurable benefits in four strategically important areas:

- **Safety and Community Relations** - The system protects batteries from electrical abuse, damage and potentially dangerous thermal runaway by maintaining them in a standby state. These are areas of substantial concern for communities, so mitigating them can enhance the user’s reputation in the communities it serves.
- **Service Reliability and Availability** - Using the adaptive charge system’s remote monitoring software, plant engineers can get instant indications of the state of health of backup systems at all their locations which allows for better maintenance planning, fewer site visits, more reliable backup systems, and more confidence.
- **Environmental Stewardship** - Lower battery temperatures and remote monitoring capabilities result in longer life, fewer replacements, less recycling, lower fire risk, fewer maintenance visits, less community disruption, and lower energy consumption. When spread over many locations, these benefits have a positive effect on carbon footprint and reputation.
- **Reduced Cost** - The adaptive charge system is designed to have a reductive effect on many costs, particularly backup system capital and maintenance operating expenses.

References

[1] Boden, D., Paper presented at Battery Power Conference, 2011.

[2] Boden, D., Paper presented at Battery Power Conference, 2013.

[3] Berndt, D. Valve regulated batteries- gas and heat management. INTELEC, 1998.

[4] T. M. Phuong Nguyen, et. al., *Trends in Communications Technology*, ed. by Cristos J. Bouras, In Tech, 2010.