



BATTERY OPTIMIZATION SERVICES A GUIDE TO OPTIMIZE YOUR BATTERY MAINTENANCE

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Executive Summary

All telecommunication nodes, from highly critical core sites to remote access sites, rely on standby batteries to keep systems up and running when utility power is disrupted or fails. As batteries are subject to normal and abnormal aging and even occasional manufacturing defects, a battery testing and maintenance program is vital to ensure reliability. Several on-site and remote battery testing techniques are available, each with different costs as well as technical strengths and weaknesses. By combining these different techniques and deploying them throughout the battery life cycle in a dynamic fashion - taking site criticality, age, battery size and previous test results into consideration - it is possible to design an optimized maintenance regime that will deliver improved battery reliability that is fully cost effective.

Introduction

It is essential that batteries are maintained to ensure reliability. Traditional maintenance techniques can be labor-intensive and expensive, limiting the application of preventive maintenance (PM) to only the most critical sites. However, with a clear understanding of the key failure modes of standby batteries and how to measure and estimate battery condition using tailored combinations of testing methods, it is possible to define an optimal battery maintenance strategy for the entire network without exceeding budgetary constraints.

Background

Today's consumers have a much lower tolerance to lost communication; the reliability of the entire network depends upon the integrity of the power provision and, in the event of a utility outage, this requires the availability of reliable standby batteries. More critical sites require large batteries (>1000 Ah) to provide autonomy times of an hour or more. In some locations a backup duration of several hours may be required. The capital investment (CAPEX) in batteries for these sites can be large, but batteries still must be replaced before they fail to ensure the network is not at risk. With that in mind, it is important that operational expenses (OPEX) for maintenance are used to protect the capital investment and optimize the service life of the batteries. Similarly, the costs of battery inspection and maintenance have to be balanced against the larger costs in lost revenue and reputation if the network is unreliable. Batteries have a finite service life affected by various factors, so, although many can deliver usable power for the majority of their design life, many others suffer early-life failures (dry-out, sulfation, thermal runaway) and have much shorter service lives.

At end-of-life, battery capacity declines and capacity retention of 80% is the industry accepted limit for end of life.

Battery Replacement Strategies

Common replacement strategies, especially in access networks, are reactive rather than proactive i.e. either waiting for a fault or waiting for a certain 'age' before replacing. These strategies pose significant risks to the supported load.

Optimum battery reliability can be achieved only with a good level of maintenance and inspection so you KNOW the battery condition and can plan replacement of defective cells before the load is placed at risk. This can be achieved with a proactive, condition-based maintenance strategy that combines the strengths of various techniques in an intelligently scheduled dynamic program adapted to the current condition of the battery.

Preventive, Predictive and Corrective Battery Maintenance

In order to really know the condition and optimize the service life of any standby battery, an approach combining preventive with predictive and corrective procedures should be adopted.

Preventive - These procedures increase battery reliability by taking action to prevent accelerated deterioration

Predictive - These procedures measure changes in battery condition and allow trend analysis to predict the health and expected service life of the battery

Corrective - These procedures provide remedies to faults or problems that have been detected.

Condition-Based Maintenance

For VRLA batteries, annual discharge testing initially became the preferred method for measuring battery capacity and assessing condition. This remains the most accurate but also the most costly way of verifying battery condition - and is valid only at the time of the test. It cannot predict remaining service life in a battery.

In recent years, improvements in VRLA battery design and the high cost of discharge testing have resulted in many users looking for ways to reduce their maintenance regime and costs. The technique most frequently used instead of full discharge is a partial discharge using site load. This method has a major weakness in that many faults still can go undetected until the accepted service life limits of a battery have been exceeded.

With today's technologies there are better options to the current practice of performing the same battery test year after year to verify the condition of the batteries. A condition-based maintenance program uses tests that are best suited for the current age and condition of the battery. This would typically involve regular lower-cost techniques that provide an acceptable indication of battery State of Health (SoH) early in its life cycle. When those tests show deterioration above certain levels, appropriate capacity tests would be introduced along with regular SoH tests at the same or higher frequency. Over a battery life cycle there are substantial savings to be made.

Battery Testing

Battery testing falls into two categories: performance testing or State of Health (SoH) testing.

Float voltage measurements on a cell or monobloc (bloc) level are measured to ensure correct charging. Any cells showing significant float voltage deviation from the string average could indicate defects but will not provide any indication of the battery capacity or remaining service life.

Measuring float current, ambient and battery temperature can help to warn against the onset of thermal runaway. Monitoring temperature also can help assess the impact of high temperatures on the aging of batteries. Float current will increase as batteries age and approach end of life, but it is not a sensitive indicator of SoH and will not indicate capacity.

Performance Testing

A Full Discharge Test is used to determine the performance of a battery compared to manufacturers' published performance data, usually in terms of capacity measured in Ah. This requires external load banks, is labor-intensive, and the battery being tested will need to be disconnected from the load. In the event of a mains outage - either during the test or immediately afterward - the load is under increased risk, which can be minimized by disconnecting no more than 50% of the battery on one day.

Discharge testing to >90% depth-of-discharge (DoD) provides a reliable measurement of battery performance, but only at the time of the test.

An alternative to full discharge testing is to perform a partial discharge using the system load. This technique involves reducing the load placed on the rectifiers, allowing the entire battery to support the load.

The performance of the battery is typically assessed by the "Run Time", as depth of discharge often is too shallow to allow comparison with published performance data.

In the event of a mains outage, there is a risk to the load as all batteries are discharged simultaneously and therefore available backup will be reduced.

In the event of a battery failure, the rectifiers remain online but at a reduced voltage.

Partial discharge can estimate capacity by extrapolation if the cutoff voltage is in the published data tables, but it does not give the high accuracy provided by full discharge.

State of Health (SoH) Testing

Incorrect float voltage, and temperatures outside of normal operating limits, can soon have a detrimental effect on the State of Health of a battery. Various common fault modes such as Sulfation or Dry Out can also quickly degrade a battery SoH.

Capacity testing will detect batteries where the state of health has declined to the point of near end of life, but will not indicate how much life is remaining. What we need is a way to measure the SoH with a parameter that changes predictably over the life of a battery.

Ohmic testing is a generic term for electrical measurements of SoH. This can be further broken down into impedance or conductance derived from an AC signal technique, or internal resistance derived from a DC technique. A battery, however, has a complex, non-linear electrochemical element and various factors will affect the reading, including frequency, amplitude of the test signal and the resolution of the test meter. This means that readings acquired using one technique may not correlate to readings acquired using another. Consistency in both equipment and test procedure is essential throughout the life of a battery.

When data is acquired correctly and consistently, internal resistance has been shown to have a strong correlation with capacity and, although it is not a direct measure of capacity, it can be used as a SoH measurement to predict battery performance in a discharge.

Battery Life Cycle

The battery life cycle chart (Figure 1) shows the change in capacity and internal resistance over the service life of the battery, with different stages of State-of-Health (SoH) color coded for Safe, Warning, Alert, and EoL.

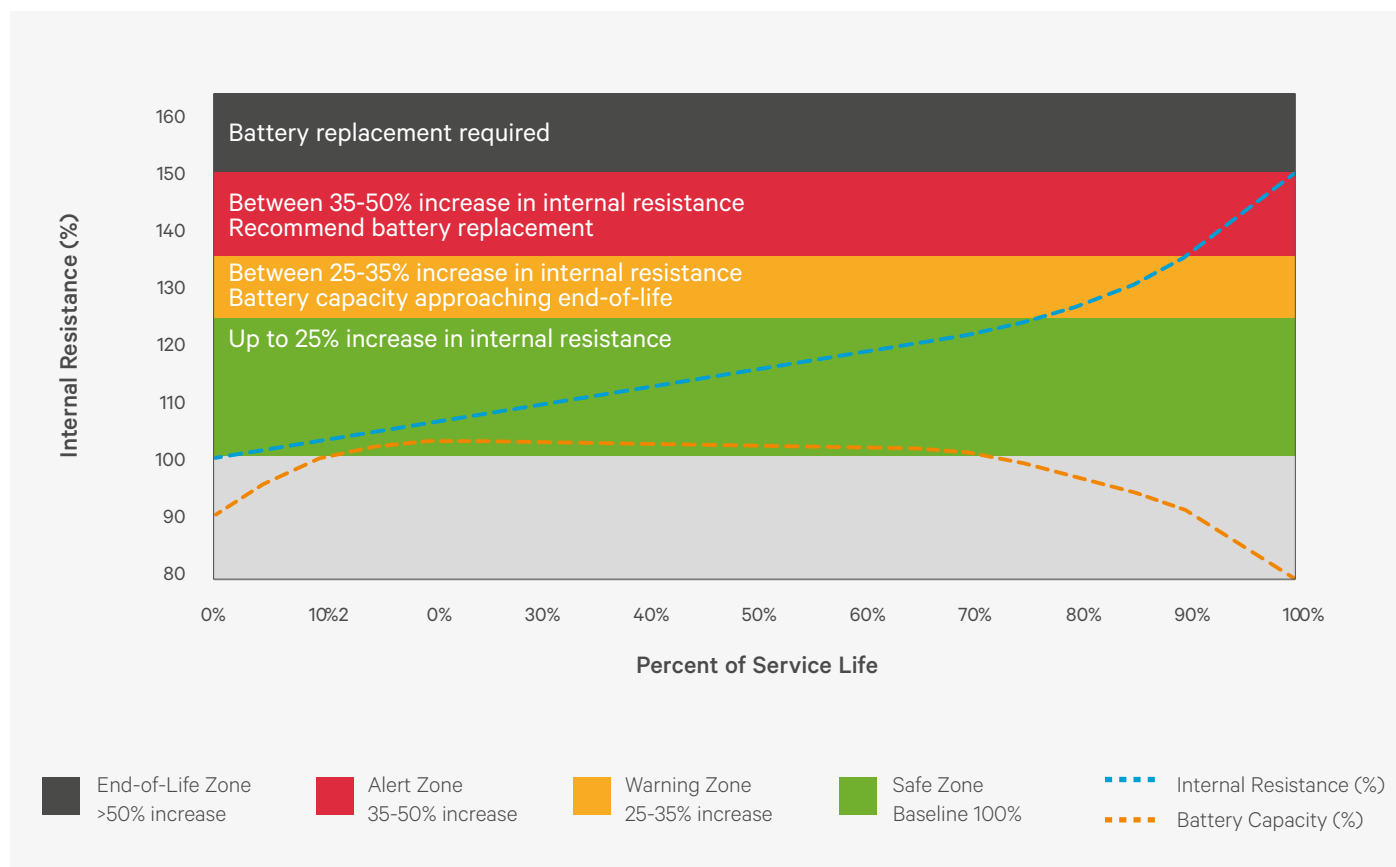


Figure 1. Battery Life Cycle Chart

Capacity

Some batteries reach 100% rated capacity only after they have been in service for a short while and have experienced a few discharge / charge cycles in service. They will then deliver 100% rated capacity for most of their service life. As the cells age and deteriorate, the capacity will decline toward the 80% end-of-life limit. This decline becomes more rapid as they reach end-of-life such that remaining life after this becomes unpredictable.

Internal Resistance

Once the initial settling-in period has stabilized, the normal aging experienced by all healthy cells will cause a gradual increase in Internal Resistance (IR). This tends to approximate linear growth until it exceeds 25% over initial values. During this time the cells are typically still able to deliver 100% capacity. Between a +25% and +50% IR increase, the rate of change accelerates and the cell capacity will be in decline, until at over +50% the cell is likely to be below end-of-life capacity limits.

Abnormal aging caused by dry out or other early life defect mechanisms typically will show as a faster rate of change in IR, which can be detected before a cell fails. These issues may not show in a discharge test until the battery has reached or exceeded fault level conditions.

Correlation Between Capacity and Internal Resistance

Displaying DoD and IR on the same chart in ascending IR order demonstrates a very clear relationship between IR and capacity. The majority of cells in the green zone for IR are >95% DoD. The majority of cells in the amber zone are <95% DoD. All cells in the red zone are between 70 and 80% DoD. The two cells in the black zone are <70% DoD. (Figure 2). This correlation between IR and capacity enables Ohmic testing to be used as an indicator of battery condition.

Individual cell faults or anomalies can be identified from the IR measurements. However, care should be taken when evaluating only a single set of IR data; it is possible to see a wide range of IR values, especially on new cells, while capacity is still within acceptable limits. A baseline value should be determined for the battery when new, and then IR data should be trended over time to evaluate the changes in battery condition.

When Ohmic techniques are managed and applied correctly, they are an invaluable tool in assessing battery SoH.



Figure 2. Discharge Data and Internal Resistance in Ascending Order

Optimized Battery Maintenance

A dynamic, battery maintenance program will provide optimum information on overall battery health and improved battery reliability for each testing dollar spent. Such a program should combine preventive, predictive and corrective maintenance and dynamically perform both SoH and performance testing throughout the battery life cycle, taking site criticality, age, battery size and previous test results into consideration. In order to design the optimal testing program for a specific battery bank, an objective comparison of the available test techniques is required. To perform an objective comparison, users first must define parameters for what is expected or required from the battery maintenance.

Key Requirements for a Battery Maintenance Program

In our analysis we have identified six key requirements. The individual characteristics of several maintenance techniques are assessed against these needs. The ideal battery maintenance program would score 10/10 on each requirement and can be conveniently presented by a six-axis spider chart.

- 1. Capacity Estimation:** The most fundamental battery requirement is to provide the capacity needed to support the load for the designed backup time. On-site full discharge testing remains the best way to measure capacity. Partial discharge is not as accurate, and IR tests do not give a measure of capacity. Rather, they can indicate the probability a cell will or will not meet rated capacity.
- 2. Faulty Cell Detection:** Even in a new battery, a single cell or monobloc failure can lead to loss of critical power. Detecting these faults enables optimum protection for the load. Although discharge tests give absolute proof of cell condition, IR tests can detect the early signs of failure BEFORE critical capacity loss occurs.
- 3. Remaining Life Estimation:** The service life of a VRLA battery is often far less than the design life. It is affected by a number of variables, including temperature, charging, early-life defects and other problems. With appropriate SoH testing and trending, the remaining service life can be estimated. Replacements can be planned before a battery failure causes a reduction or even complete loss of available backup time.
- 4. Mechanical Issue Correction:** Links, straps and connecting hardware require regular checking and correction, as do physical issues such as leaking acid, swollen cells or monoblocs, high temperature and other factors. This always requires a site visit to correct problems but, with remote testing of link resistances, many link faults can be detected to allow a targeted remedial response.
- 5. Cost Effectiveness:** The results from each technique must provide a good return on the OPEX invested. The CAPEX on batteries is a significant investment, often higher than the DC plant it supports. An ideal service program should be able to maximize battery service life so CAPEX turnover and total cost of ownership (TCO) can be reduced.
- 6. Test Risk Avoidance:** With any battery test technique, it is important that the load is not put at any unnecessary risk. Techniques and procedures used should be designed to minimize this risk and maximize available backup power during the test procedure.

Different maintenance and diagnostic techniques will score between 0 and 10 for the various features required, where 10 is a perfect score.

**Example 1:
On-Site Discharge – Full Capacity
Testing with an External Load**

Battery discharge testing is acknowledged in the industry as the most effective method of determining the actual capacity and ability of a battery to provide a reliable source of power. Discharge/load testing also verifies the integrity of the battery string conduction path without placing the plant in jeopardy of failure during testing. Notwithstanding all the advantages, however, it is also the most time consuming and costly method of testing, and it cannot predict the remaining service life in a battery. These characteristics generate the highest possible score on “Capacity Estimation” and “Faulty Cell Detection,” and low scores on “Cost Effectiveness” and “Remaining Life Estimation.” As this is an on-site test, it’s easy to do a visual inspection and check mechanical issues that also generate the highest score. See figure 3.

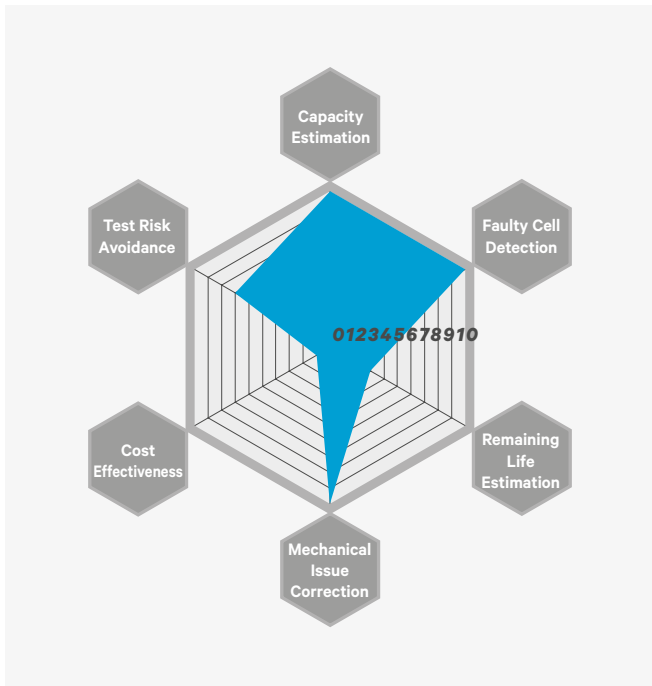


Figure 3. Scores for On-Site Discharge with an External Load

This off-line test method discharges the battery into an external load and provides an accurate measure of capacity at the time of the test.

**Example 2:
On-Site Internal Resistance Testing**

This technique has gained wide acceptance in the industry by both battery manufacturers and users as a reliable method to determine the SoH of a battery. Internal resistance testing is quicker and more cost-effective than discharge testing, and the battery capacity remains 100% available to the critical load throughout the test. It is also a useful technique to detect faulty cells and monoblocs. Furthermore, in regular maintenance it is used to predict battery failures before they lead to a loss of power to the critical load. This leads to the highest score on “Test Risk Avoidance” and “Mechanical Issue Correction” and high scores for “Cost Effectiveness,” “Faulty Cell Detection” and “Remaining Life Estimation.” See figure 4.

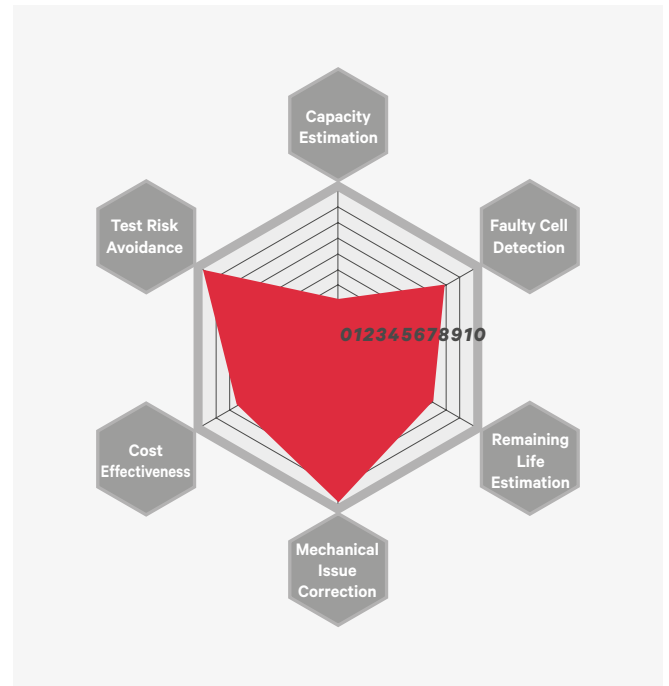


Figure 4. Scores for On-Site IR Testing

SoH internal resistance testing should be considered a valuable supplement to discharge testing. Many users consider it to be reliable enough to replace discharge testing; however, if absolute proof of battery capacity is required, only a capacity discharge test will provide this.

Selecting the Best Program to Suit Particular Battery Maintenance Requirements

By defining parameters and values for features of various battery maintenance techniques, it becomes clear that no single technique can deliver optimum battery health information and score high on all desirable features. To gain maximum benefit from battery maintenance, a holistic, dynamic life-cycle approach is required.

Proposed Solution for Access Level of a Network (less critical nodes)

Remote Testing: Partial Capacity Testing with the On-Site Load

For a typical access node in a telecom network, the usual solution is zero maintenance. Batteries are replaced either on a predetermined schedule based on age, or on a break/fix system that only reacts after a node has suffered downtime. As mentioned above, these strategies are risky, and the potential losses could be high enough to justify a low-cost maintenance program. A basic remote monitoring service, with minimal additional hardware to perform annual remote partial discharge tests, could generate enough savings in CAPEX turnover and reduced downtime to provide satisfactory return on investment and enhanced reliability for the nodes (Figure 5).

During these tests, the output voltage of the rectifiers is lowered in order to make the batteries discharge to feed the load. Should the battery fail completely, the rectifiers will remain online to keep the site up and running so there is limited risk during the test.

Proposed Solution for Medium to High Criticality Nodes

Remote monitoring and remote testing may not be possible on all sites. More critical loads or higher-value batteries that need clarity on battery condition require more accurate discharge testing.



Figure 5. Scores for Partial Capacity Testing with Site Load

The proposed solution would be a combination of annual IR tests with the addition of condition-based full-discharge tests and condition-based additional IR tests as the battery approaches end of life (Figure 6).

Condition-based testing uses SoH information from the annual IR tests to set trigger points for additional tests. Discharge tests are most beneficial when they are performed during the declining capacity part of the battery life cycle. As illustrated in the battery life-cycle chart (Figure 1), this decline in capacity typically corresponds to an increase in IR of about 25 to 50% above baseline. To accurately assess the decline in capacity from 100% to 80%, the proposed optimized solution would perform a discharge test at 20 to 25% increase in IR, then at 30 to 35% increase in IR, and finally at 40 to 45% increase in IR.

The battery life-cycle chart also shows that the rate of change of internal resistance accelerates closer to end of life, so the optimized maintenance solution would perform additional IR tests to capture the accelerated aging. The recommended trigger point for increasing the frequency of IR tests would be when the average IR value for the battery is 25% above the baseline. Going from one IR test a year to two IR tests a year should be sufficient, but the flexibility of the optimization concept allows for more tests if criticality demands.

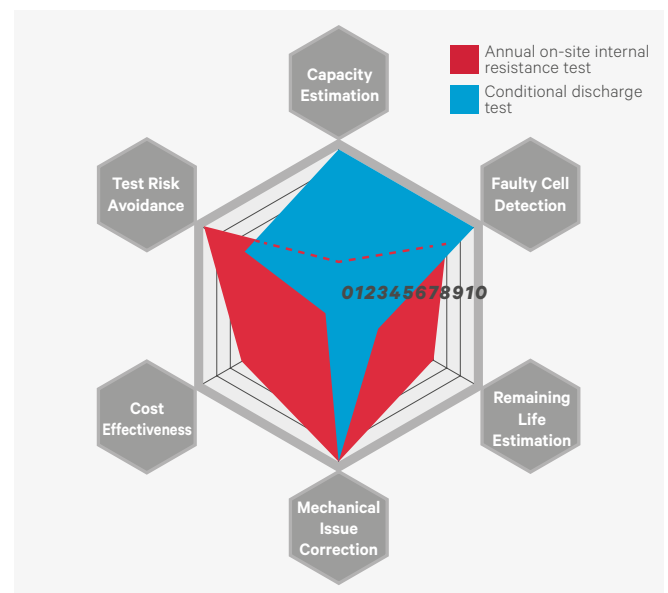


Figure 6. Annual On-Site IR Test with Condition Based Discharge Test

Proposed Solution for High Criticality Nodes

Remote Testing with Dedicated Hardware: Partial Discharge and Internal Resistance Combined with Annual Site Visits

For the most critical sites where downtime is not an option, the solution that offers the highest confidence in battery condition and reliability is a combination of remote tests with on-site tests including all essential visual, mechanical and environmental checks. (Figure 7)

This solution would use annual remote partial discharge tests and four remote IR tests per year as the basis for regular condition assessment, as well as one annual site IR visit. This combination provides ongoing state-of-health assessment along with regular estimates of capacity. However, if absolute confirmation of capacity is required then an on-site full capacity test can be added close to end life. These combinations will give the full benefits of 24/7 monitoring coupled with the essential visual, physical and mechanical checks that are required for maximum battery reliability.

State-of-the-art monitoring hardware can deliver 24/7 information on battery condition. Apart from discharge data and IR data, information on alarms, temperature, utility reliability, system load and many other parameters can be used to assess complete system performance and health. A remote monitoring solution cannot, however, provide physical and visual inspections, check and adjust torque settings or clean leaking cells. Prevention by cleaning and re-torquing of connectors is an important part of battery maintenance, and routine site visits still should form part of a comprehensive battery maintenance program.

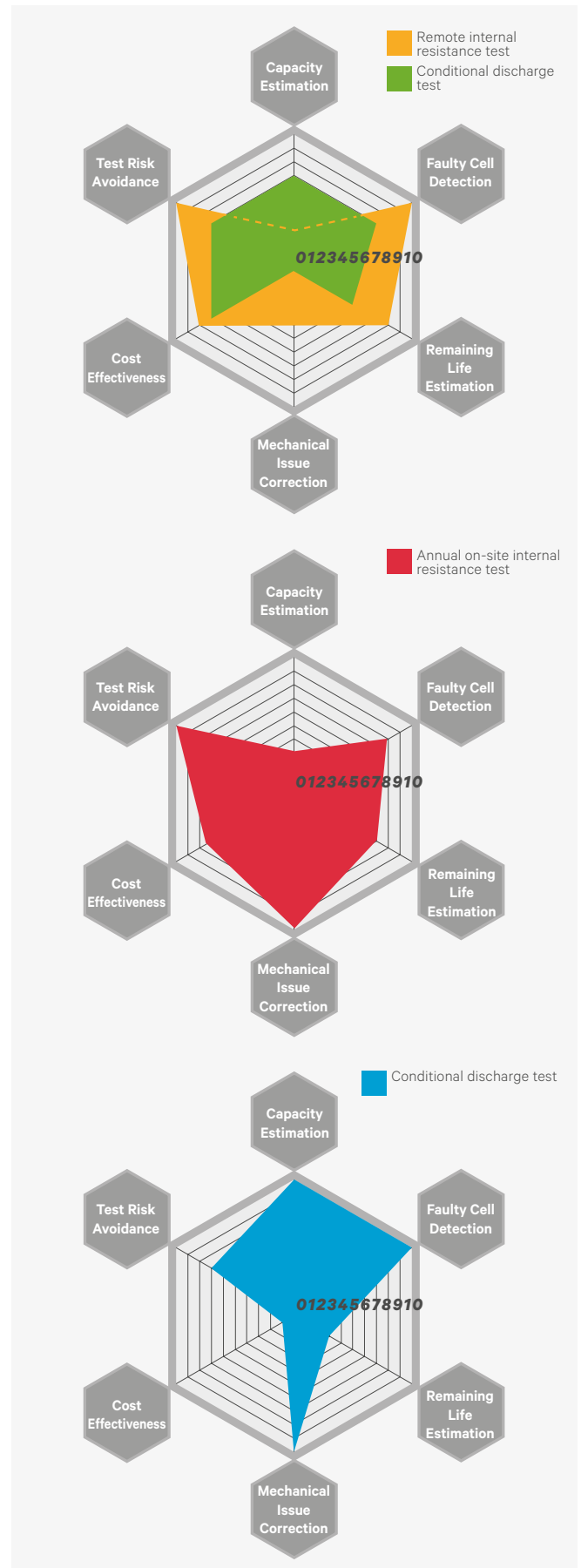


Figure 7. Remote Discharge and Internal Resistance with On-Site Internal Resistance and Condition Based Discharge

Optimized Corrective Maintenance

The predictive and preventive elements of an optimized battery maintenance program are an essential part of a complete package but for maximum effectiveness, corrective maintenance elements should be added to form part of the overall maintenance program.

A single faulty cell/monobloc can prevent a string from working or accelerate aging or degradation of other cells in the string, so it is important to remove those cells when detected. Of course, as a battery ages, failure is more likely to be caused by factors affecting all the cells in the string. A decision to replace larger numbers of cells needs to be based on the remaining service life of the healthy cells weighed against the cost of replacing the whole string - understanding that new cells inserted into old strings tend to age faster than existing cells. Typically, if more than a quarter of the cells are at end of life, the whole string should be replaced.

Cell failures in a large installation of batteries can be at very low failure rates, e.g. approximately 2% of the total cell count, however if these cell or bloc faults develop across multiple strings the load could be exposed to drastically reduced battery back-up. The risk of reduced battery performance can be in excess of 50% below par strings, (e.g. 10 strings of 24 cells, at 2% failure rate 5 faulty cells can affect 5 strings or 50% of the installed battery strings). In certain circumstances it is advisable to consolidate all healthy blocs into contiguous strings and then remove or isolate all faulty or 'suspect' blocs in string groups. Managing healthy and suspect blocs in this way improves battery reliability and helps prevent premature failure of battery installations.

Connectors and Torque Settings

Over time, battery connections loosen, increasing contact resistance at the connector to post interface and eventually reducing battery performance and increasing the potential for damage from overheated hardware. Occasionally re-tightening to maintenance torque values is not enough, especially if the surface has become contaminated and oxidized. For best results, the link and connecting hardware must be stripped, cleaned and re-assembled using the installation torque value.

CAUTION: Battery manufacturers often specify one torque value for installation and another lower value for maintenance, if maintenance personnel routinely re-torque to the higher installation setting, the posts may become distorted and damaged.

Cell Leakage

Cell or monobloc leaks or other external deposits of electrolyte, sulfates or just a general accumulation of dirt can create conductive paths where parasitic currents can flow between the battery and ground through the rack or shelves. This can cause excessive current to flow through all series connected cells, leading to overcharging, overheating and accelerated aging and, occasionally, thermal runaway. Replacing single damaged blocs can prevent premature failure of the entire battery.

Cleanliness

Cleaning batteries is an essential step in any maintenance regime. Apart from the potential for oxidized links and poor connections, there is a real possibility of ground current faults occurring if regular maintenance does not include a wipe down with a clean cloth dampened with water (with a solution of sodium bicarbonate to neutralize any acid leaks).

Conclusions

Most networks rely on large numbers of batteries of various types, age, capacity and condition often assigned to applications of varying criticality and operating under different temperature and cycling conditions. These batteries need regular maintenance and inspection; however, all of the aforementioned variables impact battery performance and lifespan. Adding another layer of complexity, there are several different battery testing techniques, all focused on different things and with their own strengths and weaknesses. It all adds up to gaps and inefficiency in battery testing and performance.

It does not have to be that way. The various testing methods may be packaged in different combinations, leveraging the optimal technique(s) for the site with regard to cost and accuracy. An optimal battery management program will be reached when the tests are applied in a dynamic way over the battery life based on earlier test results, age of the batteries and the criticality of the site. This gives the user a clear indication of the battery condition, a forecast of remaining life and recommendations for corrective action to ensure battery reliability.¹

In short, a protocol of new and existing testing methods applied more strategically and with the battery life cycle in mind, can provide the foundation for an effective battery optimization program that delivers improved battery reliability in a cost effective manner.

References

- 1) Battery Optimization Services – A technical Paper on battery maintenance – Peter Shore, Vertiv; Dr. G. May – FOCUS Consulting

