Hydro Plant Risk Assessment Guide

Appendix E8: Battery Condition Assessment

E8.1 GENERAL

Plant or station batteries are key components in hydroelectric powerplants and are appropriate for analysis under a condition assessment program. Plant batteries provide essential backup power for circuit breaker tripping and protective relay operation. Plant batteries often provide power for emergency lighting, fire detection / protection systems, and critical pumps and valves. Upon failure of either the normal alternating-current power or the battery chargers, the plant battery is the only remaining supply of energy to protect the plant and the power system during abnormal conditions.

Failure of the plant battery can be catastrophic to powerplant equipment and systems, as well as a risk to the power system. If the battery cannot provide the needed energy when required, protective action cannot remove sources of fault energy or isolate the plant from the power system. Equipment in the power train may be damaged or destroyed, thus causing significant outage time and costs. Power system stability may be jeopardized if the plant cannot be disconnected from the system. The powerplant cannot be safely operated without a healthy plant battery.

Many abnormal battery conditions detected through regular maintenance can be corrected. Under certain circumstances, individual cells may be replaced. However, some conditions indicate complete battery replacement. A strategy for detecting and dealing with failing plant batteries is important to improving the reliability of the powerplant.

Determining the present condition of plant batteries is an essential step in analyzing the risk of failure. This appendix provides a process for arriving at a Plant Battery Condition Index which may be used to develop a business case addressing risk of failure, economic consequences, and other factors.

E8.2 SCOPE / APPLICATION

The powerplant battery condition assessment methodology outlined in this appendix applies to multi-cell, vented lead-acid (VLA) (often called “flooded” or “wet cell”) type and valve-regulated lead-acid (VRLA) type. This methodology may be used to determine alternatives for continued maintenance or battery replacement.

This appendix is not intended to define plant battery maintenance practices or describe in detail plant battery condition assessment inspections, tests, or measurements. Utility maintenance policies and procedures must be consulted for such information.

E8.3 CONDITION AND DATA QUALITY INDICATORS AND PLANT BATTERY CONDITION INDEX

The following three condition indicators are generally regarded by hydro powerplant engineers as providing a sound basis for assessing plant battery condition:

- Visual Inspection
- Age
- Routine testing

These condition indicators are initially evaluated using Tier 1 inspections, tests, and measurements, which are conducted by utility staff or contractors over the course of time and as a part of routine maintenance activities. Numerical scores are assigned to each condition indicator, which are then weighted and summed to determine the Plant Battery Condition Index.

In addition, a stand-alone indicator is used to reflect the quality of the information available to score the Plant Battery Condition Index. In some cases, data may be missing, out-of-date, or of questionable integrity. Any of these situations could affect the accuracy of the associated condition indicator scores as well as the validity of the condition index. Given the potential impact of poor or missing data, the Data Quality Indicator is used as a means of evaluating and recording confidence in the final Plant Battery Condition Index.

The appendix also describes Tier 2 inspections, tests, and measurements that may be applied depending on the specific problem being addressed. Tier 2 tests are considered non-routine. If Tier 2 data is readily available, it may be used to supplement the Tier 1 assessment. Alternatively, Tier 2 tests may be deliberately performed to address Tier 1 findings. Results of the Tier 2 analysis may either increase or decrease the score of the Plant Battery Condition Index. The Data Quality Indicator score may also be revised during the Tier 2 assessment to reflect the availability of additional information or test data.

The methodology described in this appendix is valid only if a study of battery capacity versus present load has been performed and that the capacity is adequate. If capacity is not adequate, replacement is warranted and the condition methodology described herein is not applicable.

Note: A severely negative result of ANY inspection, test, or measurement may be adequate in itself to require immediate replacement regardless of the Plant Battery Condition Index score.

E8.4 INSPECTIONS, TESTING, AND MEASUREMENTS

Inspections, tests, and measurements should be conducted and analyzed by staff suitably trained and experienced in plant battery diagnostics and on a frequency that provides the accurate and current information needed by the assessment. More complex inspections and measurements may require a battery diagnostics "expert".

Results of the battery condition assessment may cause concerns that justify more frequent monitoring. Utilities should consider the possibility of taking more frequent measurements or installing computerized battery monitors that will continuously track critical quantities and automatically perform tests. This will provide additional data for condition assessment and may provide a certain amount of reassurance in continuing to operate the battery as maintenance / replacement alternatives are being explored.

E8.5 SCORING

Battery condition indicator scoring is somewhat subjective, relying on battery condition experts. Relative terms such as “Results Normal” and “Degradation” refer to results that are compared to industry accepted levels; or to baseline or previous (acceptable) levels on this equipment; or to equipment of similar design, construction, or age operating in a similar environment.

E8.6 WEIGHTING FACTORS

Weighting factors used in the condition assessment methodology recognize that some Condition Indicators affect the Plant Battery Condition Index to a greater or lesser degree than other indicators. These weighting factors were arrived at by consensus among plant battery maintenance personnel and engineers with extensive experience.

E8.7 MITIGATING FACTORS

Every plant battery is unique and, therefore, the methodology described in this appendix cannot quantify all factors that may affect individual battery condition. It is important that the Plant Battery Condition Index arrived at be scrutinized by engineering experts. Mitigating factors specific to the utility may determine the final Plant Battery Condition Index and the final decision on replacement.

E8.8 DOCUMENTATION

Substantiating documentation is essential to support findings of the assessment. Test results should accompany the Power Battery Condition Assessment Summary Form.

E8.9 CONDITION ASSESSMENT METHODOLOGY

The condition assessment methodology consists of analyzing each condition indicator individually to arrive at a condition indicator score. The score is then weighted and summed with scores from other condition indicators. The sum is the Plant Battery Condition Index.

Reasonable efforts should be made to perform Tier 1 inspections, tests, and measurements. However, when data is unavailable to properly score a condition indicator, it may be assumed that the score is “Good” or numerically equal to some mid-range number such as 2. This strategy must be used judiciously to prevent erroneous results and conclusions. In recognition of the potential impact of poor or missing data, a separate Data Quality Indicator is rated during the

Tier 1 assessment as a means of evaluating and recording confidence in the Plant Battery Condition Index.

E8.10 TIER 1 – INSPECTIONS, TESTS, AND MEASUREMENTS

Tier 1 inspections, tests, and measurements are routinely accomplished as part of normal operation and maintenance, or are readily discernible by examination of existing data. Tier 1 test results are quantified below as condition indicators that are weighted and summed to arrive at a Plant Battery Condition Index. Tier 1 inspections, tests, and measurements may indicate abnormal conditions that can be resolved with standard corrective maintenance solutions. Tier 1 test results may also indicate the need for additional investigation, categorized as Tier 2 tests.

Battery Condition Indicator 1 – Visual Inspection

Visual inspection is an easy yet effective way to begin assessing battery condition. Battery cells should be in good condition even if the battery has been in service for many years.

In the case of vented lead-acid batteries, inspection may include levels and colors of sedimentation at the bottom of the cells; condition of plates; level of electrolyte; condition of flame arresters; leaks, cracks, and corrosion of cell casing and terminals.

For valve-regulated, lead-acid batteries, inspection should include looking for bulges, leaks, and cracks in cell casings and corrosion of cell terminals.

Results of visual inspection are applied to Table 1 to arrive at an appropriate Condition Indicator Score.

Table 1 – Visual Inspection Scoring

Results	Condition Indicator Score
Inspection normal.	3
Minor degradation – no cracks or leaks, minimal corrosion; minimal sedimentation; normal electrolyte level.	2
Significant degradation – no cracks; few if any unrepairable leaks; moderate corrosion; moderate sedimentation; normal electrolyte level or needing minimal replacement.	1
Extreme degradation – cracks, leaks, or corrosion leaching into cell or cable; heavy sedimentation (quantity or size), consistently low electrolyte.	0

Battery Condition Indicator 2 – Age

Battery age is important as an indicator of remaining life. VLA batteries have life expectancies of about 20 years if properly maintained.[1] VRLA batteries have significantly less life – typically 5 to 7 years[2] – and must be maintained much more diligently than VLA batteries. Therefore, many utilities do not use VRLA batteries as plant batteries.

Apply the battery age to either Table 2 or Table 3 to arrive at the Condition Indicator Score.

Table 2 – Age Scoring – Vented Lead-Acid

Age	Condition Indicator Score
< 12 years (< 60% of expected life)	3
≥ 12 and < 16 years (≥ 60 and < 80% of expected life)	2
≥ 16 and < 20 years (≥ 80 and < 100% of expected life)	1
≥ 20 years (≥ 100% of expected life)	0

Table 3 – Age Scoring – Valve Regulated Lead-Acid

Age	Condition Indicator Score
< 3 years (< 60% of expected life)	3
≥ 3 and < 5 years (≥ 60 and < 80% of expected life)	2
≥ 5 and < 7 years (≥ 80 and < 100% of expected life)	1
≥ 7 years (≥ 100% of expected life)	0

Battery Condition Indicator 3 – Routine Testing

Utilities conduct routine testing of batteries as part of a scheduled maintenance program. Test types and frequency vary between utilities but often include the following tests and measurements:

Vented Lead-Acid:

- Impedance or internal resistance test
- Battery and cell float voltages
- Specific gravity readings

[1] The manufacturer should be consulted for life expectancy values for specific batteries.
[2] Experience has shown that manufacturers' VRLA life expectancy data may be overly optimistic.

- Temperature readings
- Connection resistance

Valve-Regulated Lead-Acid:

- Impedance test or internal resistance
- Battery and cell float voltages
- Temperature readings
- Connection resistance

Qualified personnel should make a subjective determination of scoring that encompasses as many operation and maintenance factors as possible under this indicator.

Results of Routine Testing are analyzed and applied to Table 4 to arrive at an appropriate Condition Indicator Score.

Table 4 – Routine Testing Scoring

Results	**Condition Indicator Score**
Results Normal: {Impedance/Internal Resistance: Less than 105% of baseline for multi-cell VRLA jars OR Impedance/Internal Resistance: Less than 115% of baseline for single-cell VLA or VRLA jars} AND Float Voltages: Less than +/- 0.5% difference from manufacturer's data AND Specific Gravity: Less than - 0.005 difference from manufacturer's data AND Temperature: Cell variance less than +/- 2 °F AND Connection Resistance: Less than 110% of baseline (VLA or VRLA) excluding long jumpers.*	3
Minimal Deviation from Normal: {Impedance/Internal Resistance: Less than 115% of baseline for multi-cell VRLA jars OR Impedance/Internal Resistance: Less than 125% of baseline for single-cell VLA or VRLA jars} AND Float Voltages: Less than +/- 1% difference from manufacturer's data	2

AND Specific Gravity: Less than - 0.010 difference from manufacturer's data AND Temperature: Cell variance less than +/- 4 °F AND Connection Resistance: Less than 120% of baseline (VLA or VRLA) excluding long jumpers.*	
Significant Deviation from Normal: {Impedance/Internal Resistance: Less than 125% of baseline for multi-cell VRLA jars OR Impedance/Internal Resistance: Less than 135% of baseline for single-cell VLA or VRLA jars} AND Float Voltages: Less than +/- 2% difference from manufacturer's data AND Specific Gravity: Less than - 0.015 difference from manufacturer's data AND Temperature: Cell variance less than +/- 5 °F AND Connection Resistance: Less than 150% of baseline (VLA or VRLA) excluding long jumpers.*	1
Extreme Deviation from Normal: {Impedance/Internal Resistance: Greater than or equal to 125% of baseline for multi-cell VRLA jars OR Impedance/Internal Resistance: Greater than or equal to 135% of baseline for single-cell VLA or VRLA jars} OR Float Voltages: Greater than or equal to +/- 2% difference from manufacturer's data OR Specific Gravity: Greater than or equal to - 0.015 difference from manufacturer's data OR Temperature: Cell variance greater than or equal to +/- 5 °F OR Connection Resistance: Greater than or equal to 150% of baseline (VLA or VRLA) excluding long jumpers.*	0

* Connection resistance is not an indicator of battery capacity unless the resistance cannot be

reduced by cleaning and re-torquing to manufacturer's recommendations.

The impedance test is a primary indicator of battery capacity. Regardless of the results of other routine tests (or age or visual inspection) or the Tier 1 Plant Battery Condition Index score, if the impedance test shows degradation per utility standards then an immediate capacity test as described in Tier 2 is indicated.

E8.11 TIER 1 – PLANT BATTERY CONDITION INDEX CALCULATIONS

Enter the condition indicator scores from the tables above into the Plant Battery Condition Assessment Summary form at the end of this document. Multiply each condition indicator score by the Weighting Factor, and sum the Total Scores to arrive at the Tier 1 Plant Battery Condition Index.

E8. 12 PLANT BATTERY DATA QUALITY INDICATOR

The Plant Battery Data Quality Indicator reflects the quality of the inspection, test and measurement results used to evaluate the battery condition. The more current and complete the inspections, tests, and measurements, the higher the rating for this indicator. The normal testing frequency is defined as the organization's recommended frequency for performing the specific inspection, test, or measurement.

Qualified personnel should make a subjective determination of scoring that encompasses as many factors as possible under this indicator.

Results are analyzed and applied to Table 5 to arrive at a Plant Battery Data Quality Indicator Score.

Table 5 – Plant Battery Data Quality Scoring	
Results	**Data Quality Indicator Score**
All Tier 1 inspections, tests and measurements were completed within the normal testing time interval and the results are reliable.	10
Tier 1 inspections, tests and measurements were completed < 150 percent of the normal testing time interval and the results are reliable.	7
Tier 1 inspections, tests and measurements were completed ≥ 150 and < 200 percent of the normal testing time interval, or some of the results are not available or are of questionable integrity.	4
Tier 1 inspections, tests and measurements were completed ≥ 200 percent of the normal testing time interval, or no results are available or many are of questionable integrity.	0

Enter the Plant Battery Data Quality Indicator Score from Table 5 into the Plant Battery Condition Assessment Summary form at the end of this document.

E8.13 TIER 2 – INSPECTIONS, TESTS, AND MEASUREMENTS

Tier 2 inspections, tests, and measurements generally require specialized equipment or training, may be intrusive, or may require an extended outage to perform. A Tier 2 assessment is not considered routine. Tier 2 inspections are intended to affect the Plant Battery Condition Index established using Tier 1 but also may confirm or refute the need for more extensive maintenance, rehabilitation, or battery replacement.

For Tier 2 assessments performed, apply the appropriate adjustment factor and recalculate the Plant Battery Condition Index using the Plant Battery Condition Assessment Summary form at the end of this document. An adjustment to the Data Quality Indicator score may be appropriate if additional information or test results were obtained during the Tier 2 assessment.

Test T2.1: Battery Capacity Test

The battery capacity or load test is generally regarded by hydro powerplant engineers as the only conclusive test for determining plant battery condition. The capacity test determines the battery's ability to provide power over a predetermined period of time. If the battery cannot pass the test, replacement of the entire battery should be considered, possibly even required, in the interest of preventing the problems described above. Replacement of a failing battery should take place ***before*** the battery is required to respond in an emergency.

The impedance test (see Tier 1) identifies batteries and cells that might not have sufficient capacity. The capacity test is clearly indicated for batteries that do not pass the utility's impedance test.

Despite popular myth, the capacity test in not destructive to the battery. A healthy battery will not be negatively affected by a load test. Capacity testing is supported by IEEE, NFPA, battery manufacturers, and most utility maintenance experts. It is the only effective way to measure the battery's ability to meet an emergency demand.

Whether the capacity test is regularly scheduled or triggered by Tier 1 tests, this guide assumes that test results are current and accurate. In some cases, it may be necessary to conduct the capacity test to complete this assessment. If Tier 1 tests score highly (i.e., a Tier 1 Condition Index of "Good") and Tier 1 tests are current (i.e., a high Data Quality Indicator) and a Capacity Test has been performed recently, conducting the Capacity Test may not be necessary. The utility's maintenance practice should be consulted.

Results of the Battery Capacity Test are applied to Table 6 to arrive at an appropriate Condition Indicator Score.

Table 6 – Battery Capacity Test	
Test Results	**Adjustment to Tier 1 Condition Index**
≥ 90% capacity	No Change
≥ 80 and < 90% capacity	Subtract 5.0
< 80% capacity	Subtract 10.0

Note: New batteries often start with a capacity that may be as low as 90% of rated. This capacity will increase to 100% over the first 1 to 3 years of charging. This must be taken into account when applying Capacity Test results to Table 6.

Test T2.2: Other Specialized Diagnostic Tests

Additional tests may be applied to evaluate specific battery problems. When conclusive results from other diagnostic tests are available, they may be used to make an appropriate adjustment to the Plant Battery Condition Index.

E8.14 PLANT BATTERY CONDITION INDEX CALCULATIONS

Enter the Tier 2 adjustments from the tables above into the Plant Battery Condition Assessment Summary form at the end of this guide. Subtract the sum of these adjustments from the Tier 1 Plant Battery Condition Index to arrive at the Net Plant Battery Condition Index. Attach supporting documentation. An adjustment to the Data Quality Indicator score may be appropriate if additional information or test results were obtained during the Tier 2 assessment.

E8.15 PLANT BATTERY CONDITION-BASED ALTERNATIVES

After review by a battery expert, the Plant Battery Condition Index is suitable for use in a risk-and-economic analysis model. The condition index may be deemed sufficient in itself for decision-making regarding plant battery alternatives, in which case the Plant Battery Condition Index may be directly applied to Table 7.

Table 7 – Plant Battery Condition Index-Based Alternatives	
Plant Battery Condition Index	**Suggested Course of Action**
≥ 7.0 and ≤ 10 (Good)	Continue O & M without restriction. Repeat this condition assessment process as needed.
≥ 3.0 and < 7 (Fair)	Continue operation. Accelerate testing and plan for battery replacement.
≥ 0 and < 3.0 (Poor)	Replace battery immediately.

PLANT BATTERY
TIER 1 CONDITION ASSESSMENT SUMMARY

Date: ________________________ Location: ____

Battery Identifier: ______________ Type: _________________

Location: ___________________ Manufacturer: ____________________ Yr. Mfd.: _________

No. of Cells: ____________ Voltage: __________________

Tier 1 Plant Battery Condition Summary *(For instructions on indicator scoring, please refer to condition assessment guide)*				
No.	**Condition Indicator**	**Score ×**	**Weighting Factor**	**= Total Score**
1	Visual Inspection *(Score must be 0, 1, 2, or 3)*		0.833	
2	Age *(Score must be 0, 1, 2, or 3)*		0.833	
3	Routine Testing *(Score must be 0, 1, 2, or 3)*		1.667	
	Tier 1 Plant Battery Condition Index (Sum of individual Total Scores) *(Condition Index should be between 0 and 10)*			

Tier 1 Data Quality Indicator *(Value must be 0, 4, 7, or 10)*	

Evaluator: ___________________________ Technical Review: ___________________________

Management Review: _________________ Copies to: __________________________________

(Attach supporting documentation.)

Plant Battery Condition Index-Based Alternatives	
Condition Index	**Suggested Course of Action**
≥ 7.0 and ≤ 10 (Good)	Continue O & M without restriction. Repeat this condition assessment process as needed.
≥ 3.0 and < 7 (Fair)	Continue operation. Accelerate testing and plan for battery replacement.
≥ 0 and < 3.0 (Poor)	Replace battery immediately.

PLANT BATTERY
TIER 2 CONDITION ASSESSMENT SUMMARY

Date: ________________________ Location: ____

Battery Identifier: ______________ Type: _________________

Location: ___________________ Manufacturer: ____________________ Yr. Mfd.: _________

No. of Cells: ____________ Voltage: __________________

Tier 2 Plant Battery Condition Summary		
No.	**Tier 2 Test**	**Adjustment to Tier 1 Condition Index**
T2.1	Capacity Test (If capacity test is not required, enter zero)	
T2.2	Other Specialized Diagnostic Tests	
Tier 2 Adjustments to Plant Battery Condition Index (Sum of individual Adjustments)		

Tier 2 Data Quality Indicator *(Value must be 0, 4, 7, or 10)*	

To calculate the Net Plant Battery Condition Index *(Value should be between 0 and 10)*, subtract the Tier 2 Adjustments from the Tier 1 Plant Battery Condition Index:

Tier 1 Plant Battery Condition Index __________

minus **Tier 2 Plant Battery Adjustments** __________ = ________________

Net Plant Battery Condition Index

Evaluator: __________________________ Technical Review: __________________________

Management Review: _________________ Copies to: _________________________________

(Attach supporting documentation.)