September 2006

Hydro Plant Risk Assessment Guide

Appendix E7: Surge Arrester Condition Assessment

E7.1 GENERAL

Surge arresters are key components in the power train at hydroelectric powerplants and are appropriate for analysis under a condition assessment program. Surge arresters protect other electrical equipment from high-energy surges caused by lightning strikes and circuit switching. Failure of an aging and ineffective arrester can leave critical and expensive equipment, such as transformers, exposed to the damaging effects of these surges. Power equipment cannot be operated safely without effective surge arresters.

Surge arrester failure can be hazardous to staff and other equipment should the arrester fail explosively. Although procurement cost and time for arresters is not significant, the replacement cost and outage time for equipment collaterally damaged from an arrester explosion may be large. The economic impact from an extended outage resulting from an arrester explosion can be enormous. A strategy for dealing with ineffective or defective surge arresters is important to improving the reliability of the powerplant.

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

E7.2 SCOPE / APPLICATION

The surge arrester condition assessment methodology outlined in this appendix applies to station-class arresters currently in operation. It addresses both gapped, silicon-carbide type and metal-oxide varistor (MOV) type arresters.

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

E7.3 CONDITION AND DATA QUALITY INDICATORS AND SURGE ARRESTER CONDITION INDEX

This appendix describes different methods for obtaining condition indices for both silicon-carbide and MOV type arresters. In the case of silicon-carbide type, the Surge Arrester Condition Index will always be zero, as described in the section below entitled “Tier 1 -

Inspections, Tests, and Measurements." In the case of metal-oxide type arresters, the primary condition indicator is thermal imaging. This indicator is evaluated using Tier 1 inspections, tests, and measurements conducted by utility staff or contractors over the course of time. A numerical score is assigned to the condition indicator and used to arrive at an overall Surge Arrester Condition Index for MOV type arresters.

An additional stand-alone indicator is used to reflect the quality of the information available for scoring the Surge Arrester Condition Index. In some cases, data may be missing, out-of-date, or of questionable integrity. Any of these situations could affect the validity of the overall 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 Surge Arrester Condition Index.

The appendix also describes one Tier 2 test that may be applied to MOV type arresters depending on utility practice. 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 Surge Arrester 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.

After review by a surge arrester expert, the Condition Index is suitable for use as an input to the risk and economic analysis model or may be used directly to determine replacement options.

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

E7.4 INSPECTIONS, TESTING, AND MEASUREMENTS

Inspections, tests, and measurements should be conducted and analyzed by staff suitably trained and experienced in surge arrester diagnostics and on a frequency that provides the accurate and current information needed by the assessment.

E7.5 SCORING

Condition indicator scoring is based on extensive experience by surge arrester maintenance staff and engineers over a significant period of time and on recognized practices in the hydroelectric industry. 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.

E7.6 WEIGHTING FACTORS

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

E7.7 MITIGATING FACTORS

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

E7.8 DOCUMENTATION

Substantiating documentation is essential to support findings of the assessment, particularly where surge arrester replacement is indicated. Test results should accompany the Surge Arrester Condition Assessment Summary Form at the end of this document.

E7.9 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 Surge Arrester Condition Index.

Reasonable efforts should be made to perform inspections, tests, and measurements. However, when data is missing to properly score a Condition Indicator, it may be assumed that the score is "Good" or numerically some mid-range number such as 2. Caution: this strategy should be used judiciously to prevent misleading results. In recognition of the potential impact of poor or missing data, a separate Data Quality Indicator is rated as a means of evaluating and recording confidence in the final Surge Arrester Condition Index.

E7.10 TIER 1 – INSPECTIONS, TESTS, AND MEASUREMENTS

Surge arrester design and construction has undergone major transformation in recent years. Prior to about 1985, arresters were of the gapped, silicon-carbide type. The condition of this type of arrester is difficult to determine through diagnostic testing and the arrester may fail without warning. Explosive arrester failure can be disastrous to other equipment. Many cases of unexpected arrester failure from undetected internal conditions have been experienced in recent years, causing significant damage to adjacent equipment and expensive forced outages. Older arresters may not have venting means, which makes them more vulnerable to failure. Gapped arresters also become more vulnerable after several operations.

The general practice is to preemptively replace gapped, silicon-carbide type arresters based on age. Therefore, condition indicator scoring for these arresters intentionally arrives at an automatic Condition Index of zero, indicating a need to replace the arresters regardless of other test results.

Subsequent to 1985, arresters were manufactured using metal oxide varistor (MOV) technology. MOV arresters do not experience the same kind of failure as the silicon-carbide arresters. However, MOV-type arresters can be affected by moisture ingress. Like the silicon-carbide type, it is difficult to determine the condition of MOV arresters through diagnostic testing. Currently, there is no known relationship between age and failure for MOV-type arresters. The following Condition Indicators only apply to MOV-type arresters.

Condition Indicator 1 – Thermal Imaging (MOV-Type Arresters)

Thermal imaging of arresters using infrared scanning equipment can detect abnormal heating patterns from leakage current, which may indicate imminent arrester failure. Infrared images are compared to previous images or to images of other arresters of similar age and construction. Differences in heating patterns or temperature differences between phases are of particular concern.

Apply the thermal imaging measurements to Table 1 to arrive at the condition indicator score.

Table 1 – Thermal Imaging Scoring

Results	Condition Indicator Score
Normal compared to previous or similar units.	3
Minor to moderate variation from previous tests or similar units.	2
Significant variation from previous tests or similar units.	0 (May indicate a serious problem requiring immediate evaluation, consultation, and remediation prior to re-energization.)

E7.11 TIER 1 – SURGE ARRESTER CONDITION INDEX CALCULATIONS

Enter the condition indicator scores from the tables above into the Surge Arrester 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 Surge Arrester Condition Index. This Index may be adjusted by the Tier 2 inspections, tests, and measurements described below. Suggested alternatives for follow-up action, based on the Surge Arrester Condition Index, are described in the Surge Arrester Condition-Based Alternatives (Table 4).

E7.12 SURGE ARRESTER DATA QUALITY INDICATOR

The Surge Arrester Data Quality Indicator reflects the quality of the inspection, test, and measurement results used to evaluate the arrester condition under Tier 1. 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 2 to arrive at a Surge Arrester Data Quality Indicator score.

Table 2 – Surge Arrester Data Quality Scoring

Results	Data Quality Indicator Score
All Tier 1 inspections, tests and measurements were completed within the normal testing frequency and results are reliable.	10
One or more of the Tier 1 inspections, tests and measurements were completed ≥ 6 and < 24 months past the normal testing frequency and results are reliable.	7
One or more of the Tier 1 inspections, tests and measurements were completed ≥ 24 and < 36 months past the normal testing frequency, or some of the results are not available or are of questionable integrity.	4
One or more of the Tier 1 inspections, tests and measurements were completed ≥ 36 months past the normal frequency, or no results are available or many are of questionable integrity.	0

Enter the Surge Arrester Data Quality Indicator Score from Table 2 into the Surge Arrester Condition Assessment Summary form at the end of this document.

E7.13 TIER 2 – INSPECTIONS, TESTS, AND MEASUREMENTS

Tier 2 inspections, tests, and measurements generally require specialized equipment or expertise, may be intrusive, or may require an outage to perform. A Tier 2 assessment is not considered routine. Tier 2 inspections are intended to affect the Surge Arrester Condition Index established using Tier 1 tests as well as confirm or disprove the need for more extensive maintenance, rehabilitation, or surge arrester replacement.

For Tier 2 assessments performed, apply only the appropriate adjustment factors per the instructions above and recalculate the Surge Arrester Condition Index using the Surge Arrester

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: AC Insulation Tests (MOV-Type Arresters)

AC insulation tests (Doble tests) for surge arresters include dielectric power (watts) loss and charging current. Such tests may provide some information regarding arrester condition but they cannot detect certain internal conditions that could lead to failure. Poor insulation test results indicate arrester replacement; fair or good insulation results do not necessarily mean arresters are reliable. Problems with arresters of similar design, construction, and age are important when considering replacement.

Apply surge arrester test results to Table 3 to arrive at the Surge Arrester Condition Index adjustment.

Table 3 – AC Insulation Test Scoring

Results	Adjustment to Arrester Condition Index
Normal.	No Change
Minor to Significant Degradation; minor increase in power (watts) loss or charging current compared to prior tests or similar units.	Subtract 2.0
Severe Degradation; significant increase in power (watts) loss or charging current compared to prior tests or similar units.*	To be determined by a surge arrester specialist.

*May indicate a serious problem requiring immediate evaluation, consultation, and remediation prior to re-energization.

Test T2.2: Other Specialized Diagnostic Tests

Additional tests may be applied to evaluate specific surge arrester problems. Some of these diagnostic tests may be considered to be of an investigative research nature. When conclusive results from other diagnostic tests are available, they may be used to make an appropriate adjustment to the Surge Arrester Condition Index.

E7.14 TIER 2 – SURGE ARRESTER CONDITION INDEX CALCULATIONS

Enter the Tier 2 adjustments from the tables above into the Surge Arrester Condition Assessment Summary form at the end of this guide. Subtract the sum of these adjustments from the Tier 1 Surge Arrester Condition Index to arrive at the Net Surge Arrester 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.

E7.15 SURGE ARRESTER CONDITION-BASED ALTERNATIVES

After review by a surge arrester expert, the Surge Arrester 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 surge arrester alternatives, in which case the Surge Arrester Condition Index may be directly applied to Table 4.

Table 4 – Surge Arrester Condition-Based Alternatives

Condition Index	Suggested Course of Action
≥ 7.0 and ≤ 10 (Good)	Continue O & M without restriction. Repeat condition assessment as needed.
≥ 3.0 and < 7 (Fair)	Continue operation but accelerate re-evaluation and plan for arrester replacement.
≥ 0 and < 3.0 (Poor)	Replace surge arrester immediately.*

**** Surge arresters should be replaced as a set, i.e., all three phases should be replaced simultaneously. Surge arresters on opposite ends of a transmission line or on opposite sides of a transformer should be replaced simultaneously with arresters of the same material composition. This strategy will prevent voltage wave reflections due to dissimilar construction or the over dependence on the metal-oxide arresters.***

SURGE ARRESTER
TIER 1 CONDITION ASSESSMENT SUMMARY

Date: _____ Location: _____

Arrester Identifier: _____ Phase: _____

Manufacturer: _____Yr. Mfd.: _____

Silicone Carbide Gapped: _____ or Metal Oxide: _____ Voltage: _____ BIL: _____

Surge Arrester Condition Summary* *(For instructions on indicator scoring, please refer to condition assessment guide)*				
No.	**Condition Indicator**	**Score** ×	**Weighting Factor** =	**Total Score**
1	Thermal Imaging* *(Score must be 0, 2, or 3)*		3.333	
	Tier 1 Surge Arrester Condition Index (Sum of individual Total Scores) *(Condition Index should be between 0 and 10)*			

*Condition indicators are used to score MOV type arresters only. For gapped, silicon-carbide type arresters, the Arrester Condition Index is zero (0).

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

Evaluator: _____ Technical Review: _____

Management Review: _____ Copies to: _____

(Attach supporting documentation.)

Surge Arrester Condition-Based Alternatives	
Condition Index	**Suggested Course of Action**
≥ 7.0 and ≤ 10 (Good)	Continue O & M without restriction. Repeat condition assessment as needed.
≥ 3.0 and < 7 (Fair)	Continue operation but accelerate re-evaluation and plan for arrester replacement.
≥ 0 and < 3.0 (Poor)	Replace surge arrester immediately.**

***** Surge arresters should be replaced as a set, i.e., all three phases should be replaced simultaneously. Surge arresters on opposite ends of a transmission line or on opposite sides of a transformer should also be replaced simultaneously with arresters of the same material composition. This strategy will prevent voltage wave reflections due to dissimilar construction or the over dependence on the metal-oxide arresters.***

SURGE ARRESTER
TIER 2 CONDITION ASSESSMENT SUMMARY

Date: _____ Location: _____

Arrester Identifier: _____ Phase: _____

Manufacturer: _____Yr. Mfd.: _____

Silicone Carbide Gapped: _____ or Metal Oxide: _____ Voltage: _____ BIL: _____

Tier 2 Surge Arrester Condition Summary (MOV type arresters only) *(For instructions on indicator scoring, please refer to condition assessment guide)*		
No.	**Tier 2 Test**	**Adjustment to Tier 1 Condition Index**
T2.1	AC Insulation	
T2.2	Other Specialized Diagnostic Tests	
Tier 2 Adjustments to Surge Arrester Condition Index (Sum of individual Adjustments)		

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

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

Tier 1 Surge Arrester Condition Index _____

minus **Tier 2 Surge Arrester Adjustments** _____ = _____

Net Surge Arrester Condition Index

Evaluator: _____ Technical Review: _____

Management Review: _____ Copies to: _____

*(*Attach supporting documentation.)