Condition Assessment Manual

Appendix 1.10 – Guide for Exciter Condition Assessment

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1.0 General

The excitation system is a critical component in the powertrain of a hydropower plant. A failure of the exciter or its components can result in an extended outage and extensive repairs. For purposes of this guide the excitation system will include the source of the field current and components required for its control (regulator). These components will be referred to interchangeably as the "excitation system" or "Exciter". Failure or degradation of the exciter or its control components may result in operation at reduced output or may result in catastrophic failure. While operation with a degraded condition such as excessive brush wear, low insulation resistance, failed electronic components may continue undetected, a thorough condition assessment may avert a costly forced outage and the results can be used to justify upgrades and improvements. Exciter reliability can decline with time while the annual cost of repairs and maintenance increases with time. Thus, rehabilitation and possible replacement of aging exciter (or exciter components) may become more economical and less risky than maintaining the original excitation system, especially considering the potential reliability improvements possible with state-of-the-art excitation design. Yet, excitation system condition assessment is essential to estimate the economic lifespan and potential risk of failure, and to evaluate the benefits and cost of exciter upgrades.

For any excitation system, the following three step analyses are necessary to arrive at an exciter condition indicator:

1) What parts should be included for an excitation system condition assessment and which parts are more important than others (parts and their weighting factors)?
2) What metrics/parameters should be investigated for quantitative condition assessment and which ones are more important than others (condition parameters and their weighting factors)?
3) How to assign numerical scores to the excitation system parts (rating criteria)?

This Appendix provides guides to answer the above questions, which can be applied to the excitation system and its various subcomponents. The condition assessment is performed on individual exciters/regulators in a plant, because even the originally identical units may have experienced different Operation & Maintenance (O&M) stories and would arrive at different values of condition indicators. Due to the uniqueness of each individual excitation system, the guides provided in this Appendix cannot quantify all factors that affect individual system condition. Mitigating factors not included in this Guide may trigger testing and further evaluation to determine the final score of the excitation system condition and to make the decision of exciter/regulator replacement or rehabilitation.

This Appendix is not intended to define excitation system maintenance practices or describe in detail inspections, tests, or measurements. Utility-specific maintenance policies and procedures must be consulted for such information. Exciter performance is a function of exciter type, and North American Electric Reliability Corporation NERC related performance testing and evaluation are not included in this assessment.

2.0 Constituent Parts Analysis

Excitation systems and their constituent parts are analyzed and listed in Table 1 (reference to HAP Taxonomy). The excitation system can be broadly divided into a power section and a control (regulator) section. IEEE standards have identified 19 different configurations of DC, AC and static exciters for purposes of power system stability studies. The power section includes all components not electrically isolated from the exciter output. For purposes of this assessment guide the exciter power circuits will stop at the collector rings (or rotating diodes for a brushless unit). The ability to function at rated capacity with some degradation of either section depends on the design. For example, a solid state power section with a failed power rectifier bridge may function at rated capacity if there is a redundant bridge. The same is true for a solid state control (regulator) section that includes installed redundancy. Among all the system parts, a power source or collector ring failure would have the most impact on capacity and availability. If any part does not exist in a particular excitation system, this part will be excluded from scoring mechanism by inputting "NA" into the Table. The effect of one part exclusion is usually insignificant to the entire assessment, which may not justify any adjustment of the weighting factors for other parts of the excitation system.

3.0 Metrics for Excitation System Condition Assessment

For excitation system condition assessment, it is recognized that the physical condition cannot be properly and sufficiently evaluated based on the visual inspections only while the results from some routine or available tests are more critical as indication of the exciter condition. Although these testing results can be categorized into the Physical Condition, they are listed separately in addition to the visual condition to emphasize the importance of these metrics. Thus, as listed in Table 1, the following six condition parameters are considered for condition assessment of excitation system.

- The Visual Condition
- The Age
- The Installed Technology Level
- The Operating Restrictions
- Exciter Electrical Tests (excluding performance testing)
- The Maintenance Requirement

These six condition parameters are scored based on the previous testing and measurements, historical O&M records, original design drawings, previous rehabilitation feasibility study reports if conducted, interviews with plant staff, and some limited inspections or previous inspections. It is noticed that there are certain level of relevance between the age and physical condition, maintenance needs, or some operating restrictions. However, as a benchmarking condition assessment without specific new testing and measurements conducted on site, these six parameters are regarded as providing the basis for assessing the condition of excitation components. If any type of tests or metrics are not applicable for some parts input "NA" into the cells of irrelevant parts for this metrics.

In addition, the Data Quality Indicator, as an independent metrics, is to reflect the quality of available information and the confidence on the information used for the condition assessment. In some cases, data may be missing, out-of-date, or of questionable integrity, and any of these situations could affect the results of condition assessment. The scores of data quality are determined by the on-site evaluators for each assessed part/item to indicate the data availability, integrity and accuracy and the confidence on the given condition ratings.

4.0 Weighting Factors

There are two categories of weighting factors in Table 1. It is recognized that some condition parameters affect the exciter condition to a greater or lesser degree than other parameters; also some parts are more or less important than other parts of the excitation system. These weighting factors should be pre-determined by consensus among experienced hydropower electrical engineers and plant O&M experts. Once they are determined for each system, they should be largely fixed from plant to plant except for special designs found in a system where the weighting factors have to be adjusted. In this case, the adjustment of weighting factors must be conducted by HAP core process development team. The range of absolute values of weighting factors won't affect the Condition Indicator of an excitation system which is the weighted summation of all scores that assigned to the system parts and six condition parameters.

Table 1: Typical Exciter Condition Assessment & Scoring

- XXX Hydropower Plant (Unit #)

Exciter for Unit___	Taxonomy ID	Visual Condition Score	Age Score	Installed Technology Score	Operating Restrictions Score	Exciter Electrical Tests	Maintenance Requirement Score	Data Quality Score	Weighting Factors for Parts
Rotating Armature/Stationary Field	4.1.4.1								2.5
Collector / Commutator / Brushes	4.1.4.2								2.5
Power Potential Transformer	4.1.4.3								2.5
Alternate Power Source	4.1.4.4								2.5
Rheostats	4.1.4.5								1.0
AC Input Breaker	4.1.4.6								1.0
DC Field Breaker	4.1.4.7								1.0
Regulator / Electronics	4.1.4.8								1.5
SCR / Rectifier Bridge / Rotating Diodes	4.1.4.9								2.0
Fans / Sensors / Relays / Auxilliaries	4.1.4.10								1.0
Weighting Factors for Condition Parameters		1.0	2.0	2.0	1.0	1.5	1.5	Data Quality -->	*0.00*
								Exciter Condition Indicator -->	*0.00*

5.0 Rating Criteria

Visual Condition - Rating Criteria for Excitation System Parts

Visual Condition of excitation system parts refers to those features that are observable or detected through visual inspections. Collector, commutator and brush rigging condition, motor operated rheostats contacts, AC input and field breaker conditions, wiring, and overall cleanliness are all factors to consider in a visual assessment.

For HAP site assessment, it is important to review previous inspection records and interview and discuss with plant personnel to score the visual condition of the excitation system. The results of all related information are analyzed and applied to Chart 1 to assign the condition scores of the excitation system.

Chart 1 Exciter Visual Condition Rating Criteria		
Visual Condition Rating Scale		Visual Condition Score
Excellent	No noticeable defects. Some aging or wear may be noticeable. Very clean and well maintained.	**9 – 10**
Very good	Only minor deterioration or defects are evident, and function is full. Normal amount of carbon dust. None of the conditions cited under "very poor."	**7 – 8**
Good	Some deterioration or defects (see "very poor") are evident, but function is not significantly affected.	**5 – 6**
Fair	Moderate deterioration (see "very poor"), function is still adequate, but the unit operating flexibility may be affected.	**3 – 4**
Poor	Serious deterioration (see "very poor") in at least some portions, function is inadequate, unit operating flexibility or availability significantly affected.	**2**
Very poor	Extensive deterioration. Barely functional. Excessive carbon dust and contamination in collector/brush area, collector or commutator issues, brush issues, some regulator components out of service. Rheostat and breaker contacts corroded, pitted. Signs of overheating, insulation deterioration, physical damage, environmental damage.	**1**
Failed	Excitation System is non-functional.	**0**

Age - Rating Criteria for Excitation System Components

Age is an important factor to consider for excitation system reliability and upgrade potential. Electrical insulation critical to the system will irreversibly age and its remaining life will be a function of the original design and operating and maintenance history. When the system ages, the electrical insulation is more likely to develop grounds, particularly in the presence of excessive carbon dust or other contaminates. Age scoring is relatively more objective than other condition parameters. The detailed scoring criteria developed in Chart 2 allows the age score be automatically generated in the HAP Database by the actual years of the installed part.

Chart 2 Age Rating Criteria for Excitation System		
Age of the Excitation System Power Components	Age of the Excitation System Control Components	Age Score
< 5 years	< 5 years	**10**
5-10 years	5-10 years	**9**
10-15 years	10-15 years	**8**
15-20 years	15-20 years	**7**
20-25 years	20-25 years	**6**
25-35 years	25-35 years	**5**
35-40 years	35-40 years	**4**
40-45 years	40-45 years	**3**
45-50 years	45-50 years	**2**
> 50 years	> 50 years	**1**

Installed Technology Level – Rating Criteria for Excitation System Parts

The Installed Technology Level indicates levels of sophistication of the excitation system. Fully solid state inverting systems with redundant capacity and control channels represents the state of the art for excitation. At the other extreme will be varieties of rotating exciters with motor operated rheostats and rudimentary controls. The outdated technology may bring difficulties for spare parts supply and prolonged outage when it fails.

With the development of solid state silicon controlled rectifier (SCR) bridge circuits and electronic controls, overall control, response time and efficiency (reduction of losses) have been markedly improved. Older rotating systems usually have greater potential to gain efficiency and capacity by replacing and using the state-of-the-art fully solid state designs and materials.

The competence, professionalism and reputation of the original suppliers could also imply the installed technology levels. Compared with those from large and well-known manufacturers, the exciter parts supplied by small and unnamed companies whose industry track record shows history of reliability issues due to their design would get lower scores.

Chart 3 describes the ratings of exciter technology.

Chart 3 Exciter Technology Rating Criteria	
Technology Levels of the Parts/Items (as defined by IEEE 421.5 models)	**Score for Installed Technology Level**
ST (static excitation systems)	**8 - 10**
AC (alternator supplied rectifier excitation systems)	**4 - 7**
DC (direct current commutator exciters)	**1 - 3**

<u>Operating Restrictions - Rating Criteria for Exciter Parts</u>

The exciter operating restrictions refer to any limitations on the output of MVAR assuming sufficient excitation is available for Speed No Load (SNL). Operational limitations play a role in determining the serviceability of the excitation system.

To prevent rotor overheating, excitation (lagging or positive vars) may be limited; however, in this case the generator (rotor) would get a lower score and not the excitation system. If excitation was limited due to a failed bridge circuit or diodes then the excitation system rather than the generator would get lower score for the operating restrictions.

Chart 4 describes the ratings of exciter operating restrictions.

Chart 4 Exciter Operating Restrictions Rating Criteria	
Operating Restrictions or Off-Design Conditions	**Score for Operating Restrictions**
No operating resistrictions or limitations due to excitation. Exciter operates at full capacity. Limiters appropriately set (if applicable).	**8 - 10**
No operating resistrictions or limitations due to excitation. Exciter operates at full capacity. No limiters provided, requires operator intervention.	**5 - 7**
Moderate restraints: Temperature limitations, less than full output capacity from excitation system. Where redundancy exist in design, redundant feature lost.	**3 - 4**
Severe limitations: The exciter is undesirable to operate anymore or has failed. Restoration or repair required.	**0 - 2**

Exciter Electrical Tests

In conjunction with a thorough visual inspection electrical testing will reveal the most information about the power and control circuits. Basic tests include the insulation resistance (IR) test, polarization index (PI) test, pole drop and high-potential test. The high potential test establishes the adequacy of the insulation to withstand both normal operating and transient voltages. The test may be either an acceptance test (new equipment) at standard test voltages or a service test at 65% of the standard test voltage. Either AC or DC tests may be performed. Engineering judgment will be required to assign a score based on available test data and weighing of comparative test results.

Chart 5 describes the ratings of exciter testing.

Chart 5 Excitation System Electrical Test Scoring	
Test Results	**Score for Electrical Condition**
Insulation resistance of power section (IR) > 50 megohms, polarization index (PI) >2.0, withstood AC/DC or VLF hipot.	**8 - 10**
Insulation resistance of power section (IR) < 50 megohms, > 1 megohms, polarization index (PI) >2.0, withstood AC/DC or VLF hipot	**5 - 7**
Insulation resistance (IR) < 1 megohms, polarization index and (PI) >2.0, withstood AC/DC or VLF hipot.	**2 - 4**
Insulation resistance (IR) < 1 megohms, polarization index and (PI) < 2.0.	**0 - 1**

Maintenance Requirement – Rating Criteria for Exciter Parts

The amount of corrective maintenance that either has been or must be performed is an indication that how the exciter condition is. No corrective maintenance is an indication that the exciter is in good shape. Frequent and extensive corrective maintenance or failures typically requires a major outage and is indicative of severe duty and/or aging.

Other factors to consider for maintenance scoring include:

- The need of maintenance is increasing with time or problems are reoccurring;
- Deteriorating trend in insulation integrity test results;
- Previous failures related to the exciter parts;
- Industry experience with failures and problems with exciters of similar design;
- Availability of service and/or replacements parts.

The results of exciter maintenance history (including routine maintenance and corrective maintenance) and trended test results are analyzed and applied to Chart 6 to score the maintenance demand of exciter components.

Chart 6 Exciter Maintenance Requirement Rating Criteria	
Amounts of Corrective Maintenance	**Maintenance Requirement Score**
Minimum Level (normal condition): A small amount of routine preventive maintenance, cleaning and routine testing is required and performed at the recommended frequency. Spare parts and service support readily available.	**9 - 10**
Low Level: Small amounts of corrective maintenance (e.g., less than 3 staff days per unit per year). Repairs that could be completed during a unit preventive maintenance outage that is scheduled on a periodic basis (e.g. rheostat cleaning, breaker maintenance). Some parts not readily available but still supported by a manufacturer.	**7 - 8**
Moderate Level: Some corrective maintenance that causes extensions of unit preventative maintenance outages (e.g., collector ring / commutator maintenance). Some parts not available and service not supported by OEM.	**5 - 6**
Significant/Extensive Level: Significant additional and corrective maintenance is required; forced outage occurs and outages are extended due to maintenance problems (e.g., parts and service not available, major component replacement).	**3 - 4**
Severe Level: Severe corrective maintenance that requires scheduled or forced outages. Repeated forced outages, frequent repairs, abnormal wear to components, and/or labor-intensive maintenance is required. Spare parts and service not available.	**0 - 2**

Data Quality – Rating Criteria for Exciter Parts

The Data Quality scores reflect the quality of the inspection, test, and measurement results to evaluate the condition of excitation systems. The more current and complete inspection, the more consistent the testing and trending, the higher the Data Quality scores. The frequency of normal testing is as recommended by the manufacturer, industry standards or dictated by operating organization's experience.

Reasonable efforts should be made to perform visual inspections and data collection (measurements, tests, operation logs, maintenance records, design drawings, previous assessment reports and etc.). However, when data is unavailable to score a condition parameter properly, it may be assumed that the condition is "Good" or numerically equal to some mid-range number 3-7. Meanwhile, the Data Quality score is graded low to recognize the poor or missing data. Qualified personnel should make a subjective determination for the Data Quality scores, considering as many factors as possible. The suggested criteria for scoring the Data Quality of excitation systems are developed in Chart 7.

Chart 7 Exciter Data Quality Rating Criteria

Data Availability, Integrity and Accuracy	Data Quality Score
High – The exciter maintenance policies and procedures were followed by the plant and the routine inspections, tests and measurement were performed within normal frequency in the plant. The required data and information are available to the assessment team through all means of site visits, possible visual inspections and interviews with experienced plant staff.	**8 - 10**
Medium – One or more of routine inspections, tests and measurement were completed 6-24 months past the normal frequency, or small portion of required data, information and documents are not available to the assessment team.	**5 - 7**
Low – One or more of routine inspections, tests and measurement were completed 24-36 months past the normal frequency, or some of results are not available.	**3 - 4**
Very Low – One or more of required inspections, tests and measurement were completed >36 months past the normal frequency, not completed or significant portion of results are not available.	**0 - 2**

6.0 Excitation System Condition and Data Quality Indicators

In Table 1 the final condition score of the excitation system, i.e., the Condition Indicator, *CI*, can be calculated as follows:

$$CI = \frac{\sum_{K=1,M}^{J=1,6} S_C(K,J) \times F(K) \times F(J)}{\sum_{K=1,M}^{J=1,6} F(K) \times F(J)} \qquad (1)$$

The excitation system Data Quality Indicator, *DI*, will be the weighted summation of all Data Quality scores received for its associated parts/items:

$$DI = \frac{\sum_{K=1,M} S_D(K) \times F(K)}{\sum_{K=1,M} F(K)} \qquad (2)$$

Here *M* = the total number of parts/items associated with an excitation system; *K* = the identification No. of excitation system Parts (from 1 to *M*); *J* = the identification No. of condition parameters (from 1 to 6, respectively for visual condition, age, installed technology,,….);$S_C(K, J)$ = the condition score of an excitation system part for one of 6 condition parameters; $S_D(K)$ = the data quality score for a part; *F*(*J*) = the weighting factor for a condition parameter; and *F*(*K*) = the weighting factor for an excitation system part.

The calculated Condition Indicator from equation (1) may be adjusted by the results of internal inspections and specific testing results that would be performed, since the specific excitation system testing, such as the hi pot and megger testing would more directly reveal the condition of excitation system insulation.

7.0 Reference

IEEE 421.1, Standard Definitions for Excitation Systems for Synchronous Machines.

IEEE 421.3, Standard for High Potential Test Requirements for Excitation Systems for Synchronous Machines.

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