



IEEE Guide for the Rehabilitation of Hydroelectric Power Plants

IEEE Power Engineering Society

Sponsored by the
Energy Development & Power Generation Committee

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Abstract: This guide is intended for the hydroelectric power industry to assist hydroelectric power plant owners, operators, and designers in the economic (feasibility) and technical evaluation (electrical aspects) of existing hydroelectric installations for rehabilitation. It addresses conventional hydropower. Portions of this guide are relevant to pumped storage but the unique features of pumped storage are not covered. Feasibility study results may indicate redevelopment of the site. Redevelopment will not be treated in detail in this guide.

This guide covers all generating equipment up to and including the main transformer and typical auxiliary equipment.

Keywords: cable and raceway, compressed air, control, crane, drainage, excitation, fire protection, generator, governor, grounding heating, hydroelectric, lighting, lubrication, machine shop, plant security, protection, rehabilitation, telephone, transformer, turbine, UPS, ventilating and air conditioning, water

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Introduction

This introduction is not part of IEEE Std 1147-2005, IEEE Guide for the Rehabilitation of Hydroelectric Power.

This introduction provides some background on the rationale used to develop this guide. This information is meant to aid in the understanding and usage of this guide. This version of the guide is a revision of the original published in 1992. The P1147 Working Group reviewed the original guide and revised it by adding new sections on plant staffing and cold weather. The working group also revised the clause on governors, excitation systems, and transformers to enhance them with the most current experience of the working group. Bibliographic references were added and the entire guide was reorganized to conform with the format of the latest IEEE Style Manual. Numerous editorial changes and minor technical improvements were done to enhance clarity and understanding.

This document is a guide for the hydroelectric power industry to assist hydroelectric power plant owners, operators and designers in the economic (feasibility) and technical evaluation (electrical aspects) of existing hydroelectric installations for rehabilitation. Feasibility study results may indicate redevelopment of the site. Redevelopment will not be treated in detail in this guide.

The guide is intended to be used as a reference document for practicing engineers in the hydroelectric power industry.

Owners of hydroelectric power plants have four options to consider after evaluating the performance and operation of plants and individual units in the plant. These options are:

- a) Retirement
- b) Continue operation as-is
- c) Redevelopment
- d) Rehabilitation

The first two options are self-explanatory. Option c), redevelopment, involves the construction of an essentially new plant by replacement of all or a major part of the plant equipment and structures in order to make optimum use of the hydro resource.

This guide will address option d), rehabilitation. Rehabilitation should result in extended life, improved performance, increased reliability, increased availability, reduced maintenance, and improved operations. This guide covers all generating equipment up to and including the main transformer and typical auxiliary equipment.

All aspects of the power plant should be considered for rehabilitation including the typical structural, electrical, and mechanical systems shown in Figure 1. For example, improved performance can be achieved by replacement of the turbine runner with a modern design, or by upgrading the generator or improving auxiliary support systems. Increased reliability, reduced maintenance, and improved operations can be achieved by rehabilitation of appurtenant electrical equipment such as exciters, regulators, governors, transformers, and control systems. These and related subjects are addressed in this guide.

Although this document covers civil, structural, mechanical, and hydraulic aspects of a hydroelectric power plant, they are not covered in great detail. The intent is to provide sufficient information from these other disciplines to assist the reader of this document in the understanding of how the electrical aspects relate to or are affected by these other features.

As an historical note, the initial first drafts of this guide were coordinated with the ASCE Hydro Power Development Committee and the ASME Hydro-Power Technical. During the latest revision of the guide, it

was reviewed and commented upon by the ASME Hydropower Technical Committee (HPTC). The Working Group would like to thank the HPTC for their time and helpful contributions made to this guide.

This guide addresses conventional hydropower. Portions of this guide are relevant to pumped storage, but the unique features of pumped storage are not covered in the guide.

The plant owner should be aware of current safety codes and standards during the plant assessment and rehabilitation.

The plant owner should be aware that the rehabilitation of his plant may require the need for amending the license with the appropriate regulating agency. The owner should also investigate historical preservation and environmental regulations that may impact the rehabilitation program.

The bibliography is a listing of industry standards, recommended practices, and guides that may be used as a resource by the engineer engaged in power plant rehabilitation. The review of those documents that apply to the desired area of rehabilitation is encouraged. The listing may not be the most recent edition but is meant to be an aid in starting the review process. If the referenced publications are superseded by an approved revision, the revision shall apply.

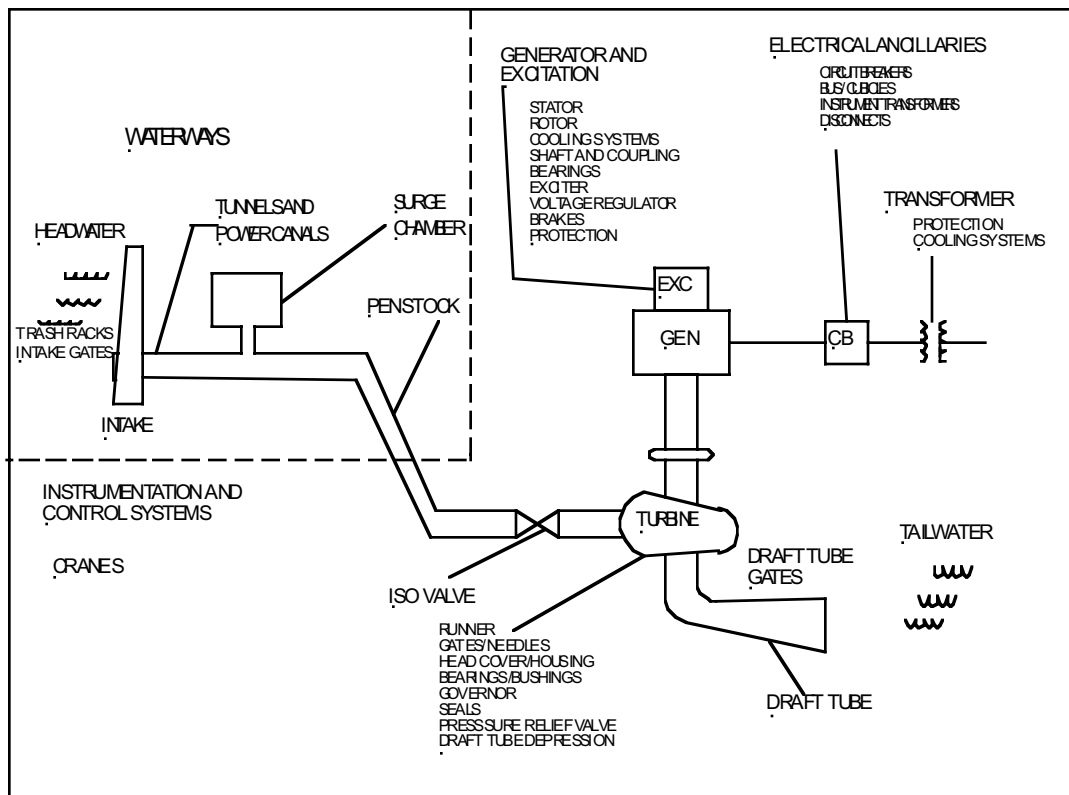


Figure 1—Typical hydroelectric power plant systems

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Participants

The Working Group on Hydroelectric Power Plant Rehabilitation (P1147) was originally formed at the 1986 Summer Power Meeting. Its members represented a cross-section of the hydroelectric power industry at that time that included power plant owners, consulting engineers, and equipment manufacturers.

The persons listed below were members of the original Working Group:

S. R. Brockschink, *Chair*

F. L. Brennan	J. H. Gurney	P. Micale
E. Bilstein	R. D. Handel	A. Mickevicius
H. Butz	R. E. Howell	D. McLaren
H. E. Church	P. S. Johrde	G. D. Osburn
R. F. Cleven	J. H. Jones	D. J. Parker
J. Coyne	R. Karlicek	L. Pereira
R. S. Coleman	D. L. Kornegay	J. Quinn
H. R. Davis	J. E. LeClair	D. B. Seely
R. A. Dent	S. O. Lindstroen	A. Tseng
D. L. Evans	D. R. McCabe	K. Vik
		B. Zarlenga

The persons listed below are the members of the Working Group that revised the 1992 guide:

Steven R. Brockschink, *Chair*

Dave Apps	Larry Long	Bill Terry
Horst Butz	Paul Micale	John Yale
Don Evans	Hans Naeff	Jerry Gibson
Russ Fostniak	Dave Parker	Matthew Davis
Tony Griffiths	Bernard Poulin	Terry Deckman
Randy Groves	Jack Quinn	Jay Anders
Jim Gurney	Doug Seely	George Girgis
Bob Handel	Phil Spotts	Tommy McEntyre
Bob Howell	Winfried Stach	Chris Shultz
Dave Kornegay		Brent Zarlenga

The following members of the ASME Hydropower Technical Committee contributed to this guide:

D. Jones	S. Peabody	J. Sinclair
J. Kerr		T. Spicher

The following members of the individual balloting committee voted on this standard. Balloters may have voted for approval, disapproval, or abstention.

William Ackerman
Jay Anders
Sabir Azizi-Ghannad
Michael Baldwin
William Bartley
Thomas Bishop
Steven Brockschink
William Cantor
Tommy Cooper
Matthew Davis
Guru Dutt Dhingra
Jerome DiSciullo
Neal Dowling
James Edmonds
Amir El-Sheikh
Gary Engmann
Jorge Fernandez-Daher
Rabiz Foda

Russ Fostiak
Trilok Garg
Randall Groves
Bal Gupta
James Gurney
Thomas Hammons
Robert Handel
William Hopf
Edward Horgan, Jr.
David W. Jackson
Reinhard Joho
Innocent Kamwa
David Kornegay
David Krause
Lawrence Long
Gregory Luri
Don McLaren
John Merando

James Michalec
Gary Michel
Krsti Najdenkoski
Nils Nilsson
Bernard Poulin
Madan Rana
Lori Rux
Douglas Seely
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James Stoner
William Terry
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Hugh Zhu
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IEEE Guide for the Rehabilitation of Hydroelectric Power Plants

1. Overview

This guide contains clauses for references and definitions. Clauses on assessing conditions and rehabilitating waterways and equipment are included. A bibliography is attached as an informative annex, organized into equipment subgroups.

1.1 Scope

This guide describes alternatives that hydroelectric power plant owners should consider when undertaking a rehabilitation of the facilities. It is useful in ensuring that potential improvements are not overlooked in the owner's process.

1.2 Purpose

This guide is directed to the practicing engineer in the field of hydroelectric power for the purpose of providing guidance in the decision-making processes and design for rehabilitation of hydroelectric power plants.

2. Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ANSI C50.10-1990, American National Standard for Rotating Electrical Machinery—Synchronous Machines.¹

¹ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

ASME PTC 29, Speed-Governing Systems for Hydraulic Turbine-Generator Units.²

IEEE Std 125TM, IEEE Recommended Practice for Preparation of Equipment Specifications for Speed-Governing of Hydraulic Turbines Intended to Drive Electric Generators^{3, 4}.

IEEE Std 810TM, IEEE Standard for Hydraulic Turbine and Generator Integrally Forged Shaft Couplings and Shaft Runout Tolerances.

IEEE Std 1010TM, IEEE Guide for Control of Hydroelectric Power Plants.

IEEE Std 1020TM, IEEE Guide for Control of Small Hydroelectric Power Plants.

IEEE Std 1095TM, IEEE Guide for Installation of Vertical Generators and Generator/Motors for Hydroelectric Applications.

IEEE Std 1207TM, IEEE Guide for the Application of Turbine Governing Systems for Hydroelectric Generating Units.

IEEE Std 1248TM, IEEE Guide for the Commissioning of Electrical Systems in Hydroelectric Power Plants.

IEEE Std 1249TM, IEEE Guide for Computer-Based Control for Hydroelectric Power Plant Automation.

3. Definitions

For the purposes of this guide, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms* [B146]⁵ should be referenced for terms not defined in this clause.

3.1 rehabilitation: The process of programmatically replacing, modifying, or adding equipment to an existing hydro facility to restore functionality of safety, reliability, maintainability, or operability of the facility.

3.2 upgrade: The process of replacing, modifying, or adding equipment to an existing hydro facility to improve equipment performance.

3.3 uprate: The process of increasing equipment rating (capacity) or improving equipment performance (efficiency) to increase overall energy production.

4. General assessment considerations

4.1 General conditions for rehabilitation

Rehabilitation of equipment in a hydroelectric power plant may be appropriate when any of the following conditions prevail:

- a) Declining unit availability
- b) Potential for restored or improved performance

²ASME publications are available from their catalog web site at <http://members.asme.org/catalog/>.

³IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

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⁵The numbers in brackets correspond to those of the bibliography in Annex A.

- c) Changes in plant or unit operating conditions
- d) Opportunity for plant automation
- e) Reduced output capabilities
- f) Failure of major equipment
- g) Inability to withstand the effects of seismic forces during earthquakes
- h) No spare parts available
- i) Increasing maintenance costs
- j) High operating costs
- k) Undesirable safety and security concerns

It is desirable to perform an appraisal of each of the above as they apply to all major equipment in hydro-electric power plants. Inspection, testing, and continuous monitoring of significant data where available is an integral part of this appraisal process. A tabulation of suggested items to be evaluated is given in Table 1.

Table 1 lists items that should be considered in the assessment of equipment. The left column lists general items and the column at the right gives more specific factors to be considered.

Table 1—List of items for assessment of plant and equipment

Specific item	Factors
Operating conditions Availability of water Addition of new unit(s) Need for increased capacity	Changes in water flows A new unit at a plant could relegate operation of existing units to short-time peaking, which could affect the benefits of rehabilitation of the existing units. Increasing capacity by uprating is cost effective
Review operating records Plant/unit flows, head and energy production. Forced outages. Equipment operating data.	Look for trends that could indicate degradation in performance such as reduction in head due to high intake and penstock losses, or less energy produced by the same water. Reveals major problem areas, types of outages, frequency and duration. Loadings, flows, temperatures, cooling— all of which have an effect on life expectancy.
Review maintenance records Past and present maintenance programs. Repairs—what and when.	Reveals relationship between condition and equipment maintenance practices. Identifies problem areas if repairs are frequent. For example, frequent turbine runner repairs due to cavitation, or changed hydraulic conditions, could indicate need to change runner design or material. Frequent generator thrust bearing repairs that could mean a high pressure lubrication system should be added or an effort made to reduce the hydraulic thrust. Frequent unavailability of generating unit due to failures in the existing automation system, the sensors, or instrumentation may indicate the end of lifetime of the relevant component and/or system.
Equipment design data Age and Materials Design Performance and Ratings	Can be useful in predicting expected life. Is original design consistent with present use?
Drawings and documentation	Drawings and documentation should be complete and accurate.
Inspection of equipment General Condition Obvious Problem Areas	Such as dirty, corroding, leaks, cracks, cavitation, loose wedges, and tape separation. Such as leaks, vibration, high operating temperatures and lack of cooling.
Equipment tests Test Data	Comparison of previous test data with new tests that can identify degradation in performance and reliability. Some tests are: Turbine— efficiency tests, relative or absolute Generator— insulation tests Switchgear— insulation tests Transformer— oil tests for degradation
Personnel Safety	Can the equipment be inspected, handled and maintained safely and does it fulfill current safety requirements?
Environmental Impacts	Pollutants Hazardous materials

4.1.1 Declining unit availability

Declining unit availability causes increased costs and reduced revenues and should be evaluated. Plant records need to be examined to identify the following conditions that are indicative of poor unit availability:

- a) The end-of-life expectancy of the individual components should be analyzed and the expected timing, cost of replacement, and availability of spares should be included in the analysis.
- b) Outages and their frequency should be analyzed to determine the root cause and corrective actions that should be undertaken to improve performance.
- c) Maintenance work that is judged to be over and above routine maintenance activity necessary to keep the equipment in reasonable operating condition that can contribute to decreased unit availability. Causes for the increased maintenance above the norm should be identified for possible remedial action.

4.1.2 Potential for restored or improved performance

The performance of major equipment was determined by the technology and state-of-the-art technology available at the time that the equipment was designed and built. Significant advances in engineering, materials, and manufacturing have occurred so that the hydraulic turbines, generators, and related equipment can be rehabilitated to obtain important and, in some cases, significant gains in performance and capacity.

Equipment, such as turbine runners and related equipment, degrades over time and thus has less output and reduced performance.

4.1.3 Changes in plant or unit operating conditions

Hydroelectric generating equipment is designed to provide optimum performance for a specific set of operating conditions. These operating conditions often can change with time which will justify rehabilitation of the equipment to improve its performance for a new set of operating conditions. Although rehabilitation is traditionally undertaken to enhance plant power output or capacity, recent industry developments regarding the power plant interface with the transmission system requires additional considerations. As an example, in North America, the power plant interface with the transmission system may be controlled by an independent system operator (ISO) or a regional transmission organization (RTO). These entities may require that the plant contractually supply reactive power (VAR) support or provide spinning reserve capabilities to the power system. This could be implemented by providing synchronous condensing capability to existing units. In return for providing these capabilities to the ISO or RTO, the power plant operator may realize significant revenue streams from the RTO or ISO operator for these ancillary services. The following are examples of changed plant operating conditions:

- a) Changes in water usage and availability for power generation can result in the need to increase the power output of the turbine, generator and associated equipment.
- b) Changes in the method of operation of the unit can result in the need for higher outputs.
- c) Ancillary requirements in terms of reactive power support may require a coordinated approach for assessing the unit's reactive power output capabilities including a re-evaluation of the generator reactive power rating, the generator excitation system in terms of performance and rating, and the generator step-up (GSU) transformer rating in units of MVA, voltage and high-voltage tap ratings.
- d) Changes in the environmental requirements to the plant may require turbine runner changes or measures to control and improve the dissolved oxygen in the river and fish passage through the turbine.
- e) Environmental regulations require different control needs not available in the original equipment.

4.1.4 Plant automation

Plant automation programs that are intended to allow unattended operation of a unit or to convert from local to offsite control often require extensive modifications to equipment. Although plant automation is beyond the scope of this guide, it is recommended that automation rehabilitation feasibility studies include a review of offsite control and plant automation (see IEEE Std 1249⁶).

4.1.5 Reduced output capabilities

Major equipment that have restrictions that prevent operation of the unit at its full capacity or curtail its energy production due to changes in plant or equipment conditions are candidates for rehabilitation.

The following are examples of operating restrictions:

- a) Severe restrictions in the ability for the turbine to pass the flow.
- b) Excessive vibration due to “rough zones” in the hydraulic operation due to a change in head or tail-water elevation or a severely cavitated and unreparable runner.
- c) Remedial repairs limiting equipment operation. An example would be cutting out stator coils.
- d) Over time the degradation of the equipment causes reduced capacity.

4.1.6 Failure of major equipment

Unscheduled outages due to failure of major equipment during operation invariably result in substantial economic losses especially if water cannot be stored or diverted to other units. When the severity of the failure results in a prolonged outage, it is appropriate to consider either rehabilitation of the failed equipment as an alternative to repair or a replacement in-kind without an upgrade or uprate. The following examples illustrate where uprating could be considered:

- Failure of a main unit transformer. Procurement of a new transformer that has lower losses and improved through-fault withstand capability, and is designed for current and future operating conditions could be appropriate.
- Failure of a turbine runner such that its repair is not feasible. Upgrading the turbine runner with a new runner design that has improved performance under the current and anticipated operating conditions may be an economically viable step.
- Failure of the generator. Rewinding of the generator to increase the generation capability to better match turbine output is a possibility. However, this may result in a mismatch between the generator output and the generator-step-up transformer rating, which would limit the benefits from the generator rating increase.

4.1.7 Seismic considerations

Plant owner requirements or prevailing building codes may dictate that new equipment installations be capable of meeting more stringent seismic design criteria than the criteria used during initial plant design. In this case, it is appropriate to review the ability of plant structures and equipment to withstand the effects of earthquakes. This involves establishing ground motion levels (peak horizontal and vertical acceleration and velocity) for the maximum credible earthquake (MCE) for the area, and then assessing the ability of plant structures and equipment to withstand these levels. Assessments can be made using a combination of computerized (dynamic) and manual analysis techniques and physical inspections.

The following are examples of modernizations to improve seismic withstand:

- a) Automatic flow shutoff by unit shutdown or intake gate closure initiated by seismic triggers.

⁶Information on references can be found in Clause 2.