



IEEE Guide for the Rehabilitation of Hydroelectric Power Plants

STANDARDS

IEEE Power and Energy Society

Developed by the
Energy Development and Power Generation Committee

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Developed by the

Energy Development and Power Generation Committee
of the
IEEE Power and Energy Society

Approved 23 September 2021

IEEE SA Standards Board

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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: arc-flash, cable and raceway, compressed air, control, crane, drainage, excitation, fire protection, generator, governor, grounding heating, hydroelectric, IEEE 1147™, 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 1147-2021, IEEE Guide for the Rehabilitation of Hydroelectric Power Plants.

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 stator core rebuilds, arc flash mitigation, plant staffing, and cold weather. The working group also revised the clause on governors, excitation systems, and transformers to reflect current industry practices as identified by the working group. Bibliographic references were added and the entire guide was reorganized to conform to 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 as follows:

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

The first two options are self-explanatory. Option c), redevelopement, 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 refers to the 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 a 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 the plant may require the need for amending the license with the appropriate regulatory 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.

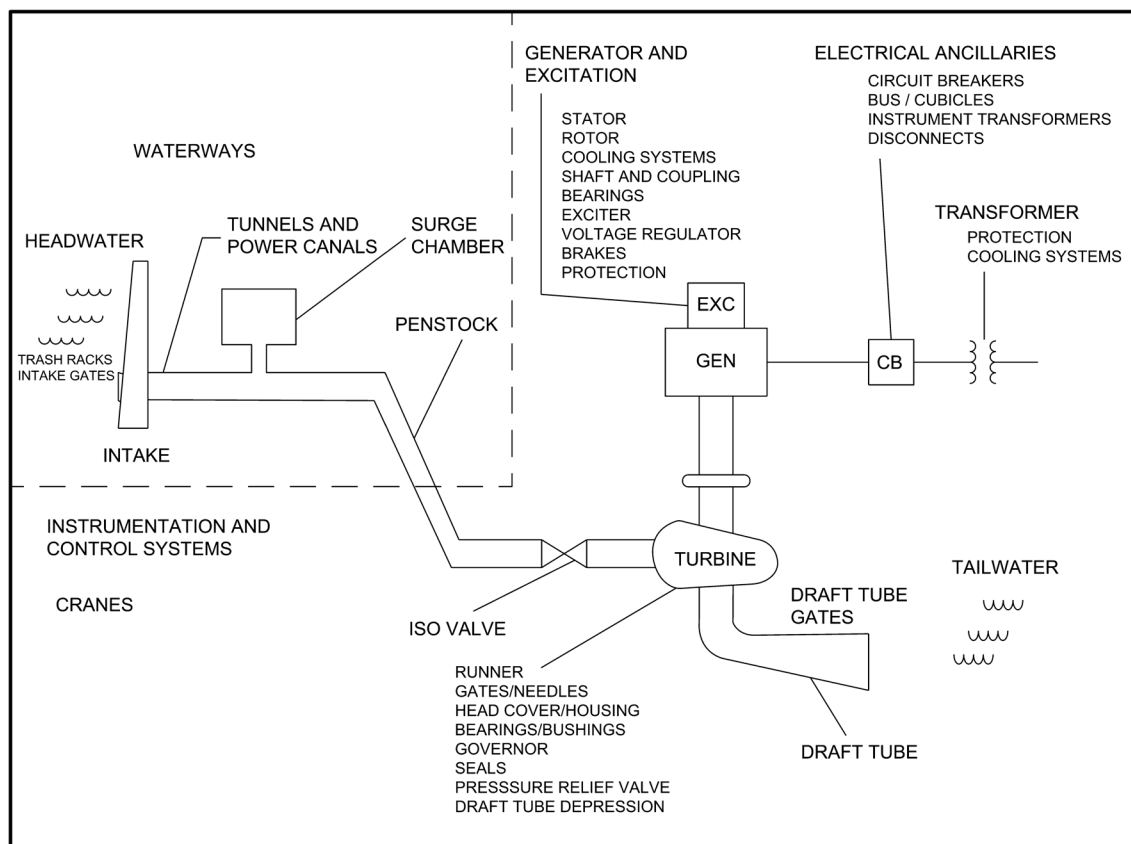


Figure 1—Typical major hydroelectric power plant systems

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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 [electrical systems within 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.

1.3 General

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

1.4 Word usage

[The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted \(*shall* equals *is required to*\).^{1,2}](#)

¹ [The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.](#)

² [The use of *will* is deprecated and cannot be used when stating mandatory requirements; *will* is only used in statements of fact.](#)

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ASME PTC 29, Speed-Governing Systems for Hydraulic Turbine-Generator Units.^{3,2}

IEEE Std 125™, IEEE Recommended Practice for Preparation of Equipment Specifications for Speed-Governing of Hydraulic Turbines Intended to Drive Electric Generators.^{3,4,5}

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

^{3,2} ASME publications are available from [the American Society of Mechanical Engineers \(https://www.asme.org/\)](https://www.asme.org/) ~~their catalog web site at <http://members.asme.org/catalog/>.~~

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

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

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

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

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

IEEE Std 1249™ [/IEC 62270](#), IEEE Guide for Computer-Based Control for Hydroelectric Power Plant Automation.

[IEEE Std C50.12™, IEEE Standard for 50 Hz and 60 Hz Synchronous Generators and Generator/Motors Coupled to Hydraulic Turbines and Rated 5 MVA and Above.](#)

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this [document guide](#), the following terms and definitions apply. The ~~Authoritative Dictionary of IEEE Standards~~ [Dictionary Online Terms \[B146\]](#)⁵ should be [consulted](#) ~~referenced~~ for terms not defined in this clause.⁶

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.

⁶ [IEEE Standards Dictionary Online is available at: http://dictionary.ieee.org. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.](#)

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

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

3.2 Acronyms and abbreviations

<u>GSU</u>	<u>generator step-up</u>
<u>HMI</u>	<u>human-to-machine interface</u>
<u>HPSS</u>	<u>hydraulic pressure supply system</u>
<u>ISO</u>	<u>independent system operator</u>
<u>PMG</u>	<u>permanent magnet generator</u>
<u>RTD</u>	<u>resistance temperature detectors</u>
<u>RTO</u>	<u>regional transmission organization</u>
<u>SCADA</u>	<u>Supervisory Control and Data Acquisition</u>
<u>UPS</u>	<u>uninterruptible power supply</u>
<u>VAR</u>	<u>volt-ampere reactive power</u>

4. General assessment conditions 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
- 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 hydroelectric power plants. Inspection, testing, and continuous monitoring of significant data, where available, are 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	Notes and consideration
Operating conditions Examples—availability of water and storage capacity; addition of new units; need for increased capacity.	Changes in water flows or loss of storage capacity. 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. Dredging may be required to mitigate loss of storage capacity.
Review operating records Examples—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 Examples—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 Examples—Age and materials; design performance and ratings; original equipment manufacturer (OEM) data.	Can be useful in predicting expected life. Is original design consistent with present use?
Drawings and documentation	Drawings and documentation should be current and complete.
Inspection of equipment Examples—General condition; obvious problem areas.	Dirt, corrosion, leaks, cracks, cavitation, loose wedges, and tape separation. Leaks, vibration, high operating temperatures, and lack of cooling.
Equipment tests Examples—Startup test data; preoperational test data; outage test data.	Comparison of previous test data with new tests that can identify degradation in performance and reliability. Example tests are as follows: Turbine—efficiency tests, relative or absolute Generator—insulation tests Switchgear—insulation tests Transformer—oil tests for degradation
Safety and security	Can the equipment be inspected, handled, and maintained safely and does it fulfill current safety requirements? Do fire protection systems require upgrade in light of changing standards?

(New)

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

(Deleted)

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 ~~may often can~~ change with time ~~and may therefore 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 volt-ampere 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 1249^{6, z}).

4.1.5 Reduced output capabilities

Major equipment or components that have restrictions preventing ~~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 tailwater elevation or a severely cavitated and unrepairable runner.
- c) Reduced capacity of air admission or tailwater depression systems.
- d) Remedial repairs limiting equipment operation such as the ~~—An example would be—~~ cutting out of stator coils.
- e) Metal-enclosed bus, main circuit breaker, generator step-up transformer, and neutral equipment ratings, temperature ratings, and condition.
- f) Reduced capacity caused by general equipment degradation over time.
- g) Minimum flow requirements.
- h) Ramping rates.
- i) Consumption rates of upstream water users.

^{z6} Information on references can be found in Clause 2.

~~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.
- b) Anchoring of critical equipment necessary for safe and reliable shutdown, such as, [generator step-up transformer](#), battery racks, governor equipment, [and](#) control and protection switchboards.
- c) Strengthening of control and protection switchboards to prevent buckling or collapse.
- d) Reinforcing of structures near critical equipment to prevent damage from falling debris.
- e) Installation of flexible isolation sections in place of rigid pipe for governor pressure piping.
- f) [Installation of metal-enclosed bus flexible joints](#).
- g) Modifications to control and protection circuits to ensure safe shutdown in the event of failure of dc power supply during a seismic event.

4.2 [System](#) ~~Systems~~ approach to rehabilitation

In 4.1, general conditions were reviewed that can lead to rehabilitation of major equipment. It is important to realize that changes in external system parameters or criteria, or the rehabilitation of one major piece of equipment can have a significant impact on other systems in the plant. A systems approach is needed to fully evaluate most rehabilitation. An example is outlined in the EPRI [CS-6419 \[B168\]](#).⁸ ~~Hydropower Plant Modernization Guide [B149]~~.

To illustrate this point, consider a case where a turbine runner is uprated to produce greater power output with improved efficiency. Such improvements are not uncommon but the impact on other parts of the plant should be considered, such as [the following](#):

- a) Increasing water flow through the turbine can have an impact on the penstock in that larger flows will produce higher pressure transients due to load acceptance and rejection.

^{8, 5} The numbers in brackets correspond to those of the bibliography in Annex A.

- b) Changes in governor stroke and timing and changes in pressure regulator valves (if applicable) are often required.
- c) The increase in turbine power requires a design assessment of such items as the shaft coupling, turbine shaft, rotor structure, and generator structure to safely transmit or handle the increased torque.
- d) An increase in turbine output requires a design assessment of the generator stator windings, stator core, and field to determine their ability to generate the increased power and the possible need to uprate the generator as well.
- e) The excitation system's steady state and transient ability ~~is~~ to provide the required field current and the necessary voltage control, and to meet reactive power requirements should also be determined.
- f) The capability of the generator leads and circuit breaker (if applicable) to carry the increased current should be evaluated.
- g) The main unit transformer and associated transmission lines should be evaluated to determine that they can carry the increased power.
- h) The rating of the current transformers and associated metering and protective equipment should be evaluated based on the upgraded capacity of the generator. Generator protection settings should be reassessed.
- i) The generator cooling system and components should be evaluated for adequacy.
- j) Possible environmental impacts should be evaluated along with the costs of related mitigation.

Because rehabilitation of major equipment in the plant can involve prolonged unit outages, the impact of the outage on the water system and on the electrical power system should also be considered. ~~Three~~ ~~Two~~ examples of the impact due to outages are as follows:

- A prolonged unit outage for rehabilitation could mean that water must be stored or diverted to other units or plants. If this cannot be accomplished, then the lost power and energy production should be taken into consideration as an economic impact on the feasibility of the rehabilitation.
- A prolonged unit outage also results in the loss of revenue and generating capacity on the electrical power system.
- [A prolonged unit outage may also impact system stability if the unit is relied upon for ancillary services such as reactive power support, spinning reserve, or black start restoration.](#)

The previous examples illustrate the importance of planning major rehabilitation programs so that they have a minimum impact on the water flow and power systems associated with the plant.

4.3 Feasibility study

4.3.1 Introduction

A feasibility study of the various alternatives should be undertaken to determine the most favorable course of action for plant rehabilitation. Consideration of project staffing, operation, and maintenance of the plant should be included in the study. Alternatives include repair, replacement, rehabilitation, modernization, and automation as well as the addition of functionally new equipment. [The feasibility stage often requires testing of the equipment, water passage losses, and river levels and flows to confirm the existing conditions prior to plant modifications. The establishment of benchmark values is necessary before an economic evaluation can be completed and a program defined.](#) The alternatives are then studied and compared for performance and economic justification and a final decision is made.

The feasibility or benefit-to-cost analysis may be very simple or quite sophisticated depending on the size of the project and the number and complexity of optional features involved. The study evaluates the various options, most often using a present-worth computation, to include those features that show favorable economics and to delete those that fail the economic justification.

The feasibility analysis is essential to the development of a concise scope of work. ~~The discussion in~~
This subclause does not discuss the details of making the feasibility study, but it does emphasize the need for one.

4.3.2 System impact

If a plant rehabilitation includes an uprate in unit or plant capacity, or an upgrade to systems integral to unit operation and protection—such as exciters, governors, and protective relays—then its impact to the interconnecting transmission/distribution system must be investigated. The procedure for assessing the system impact is highly site-specific and depends on many factors such as ownership of the transmission/distribution system, the size of the plant/uprate and the voltage at the point of common coupling. Therefore, it is vital that the entity having jurisdiction for interconnection of the plant be identified and that the procedure for preparing a system impact study be determined during the early stages of the rehabilitation process, preferably during the feasibility study.

A system impact study could result in a requirement to make upgrades to the transmission/distribution system that adds significant cost to the rehabilitation. Typical upgrades for small projects connecting to a distribution system can include, among others, additional switching, changes in feeder protection, reconductoring, increases in switchgear current ratings, addition of voltage support devices, and addition of remote telemetry for metering and control. For large projects, it may be necessary to perform both steady state and dynamic analyses of the interconnection to determine what, if any, system upgrades are needed to accommodate the changed units. Potential upgrades may include, among others, reconductoring, switchgear replacements to achieve higher thermal ratings, higher short-circuit ratings or faster clearing times, addition of voltage control equipment, and enhancements to Supervisory Control and Data Acquisition (SCADA).

The extent and cost of interconnecting transmission/distribution system improvements that may be associated with a plant rehabilitation project should be factored into any planned rehabilitation.

4.3.3 Anticipated benefits

4.3.3.1 Increased plant output

The means of increasing output, either capacity or energy, covers practically every aspect of the plant. Some modifications for increased output cost more than others, and some have greater benefits than others. The need, during the feasibility study, is to determine those modifications that are economically justifiable. The present-day expense of modernization should be balanced against the long-term gains. For example, it may seem as if it is a significant expense to rewind a forty-year-old stator, but if the gain in output, which may be small, is evaluated over the future life of the plant, it may be a highly desirable expenditure. Similarly, increased operating head or water storage should be evaluated with the intent of increasing plant output or load factor.

4.3.3.2 Reduced labor requirement

When evaluating rehabilitation programs, substantial returns often emerge after an analysis of the labor requirements. A “before and after” review of personnel requirements can show dramatic economic benefits. This is particularly evident in those cases where 24-hour staffed positions can be eliminated or reduced to one shift requirements.

4.3.3.3 More efficient water use

Improved designs of equipment and systems offer an opportunity to make more efficient use of the water. Increased efficiency in the hydraulic turbine equipment and water passages is an area that should be subjected to critical review with the intention of obtaining long term gains. Even small efficiency gains turn into substantial economic benefits when evaluated over the life of the plant.

4.3.3.4 Improved operation and increased availability

Benefits can be realized by reducing the forced outage rate and increasing the unit availability thereby improving plant reliability. Fiscal values can be assigned to these improvements and used in the feasibility analysis when weighing costs against benefits.

Operation can be improved by incorporating modern control schemes, reducing the number of control devices, eliminating unnecessary recording functions, or similar methods. Unit availability can be increased by replacing or refurbishing equipment that has become or will soon become failure prone. Reliability improvements can be equated to better operation and result in improved revenues for the plant. A plant condition monitoring system can provide the means for accurately monitoring and documenting plant equipment and plant system conditions allowing the change from event-driven maintenance to a condition-based maintenance.

4.3.3.5 Reduced operating and maintenance cost ~~costs~~

The use of supervisory control and automated data acquisition can reduce many of the manual operations that are normally associated with the older plants. Also, improved monitoring of operating and maintenance data can assist in determining maintenance requirements and reduce forced outages.

4.3.4 Cost ~~Costs~~

The feasibility studies should include an economic analysis of ~~cover~~ the ~~economic~~ costs associated with rehabilitation. The costs fall into three ~~several~~ categories as described in 4.3.4.1, 4.3.4.2, and 4.3.4.3. ~~The feasibility stage of hydroelectric plant rehabilitation often requires testing of the equipment, water passage losses, and river levels and flows to confirm the existing conditions prior to plant modifications. The establishment of benchmark values is necessary before an economic evaluation can be completed and a program defined.~~

4.3.4.1 Direct cost ~~Costs~~

Direct costs are expenses that are completely attributable to the production of specific goods and services associated with the rehabilitation. These costs are usually allocated on an item-by-item basis and include the following:

a) Cost of studies, engineering, project management, licensing and permitting, procurement, demolition, installation, witness factory testing, site testing/commissioning, and training. Some rehabilitation projects may also include hazardous materials remediation and historic preservation.

Depending on the breakdown of the work, these costs may be borne by the owner's personnel or contracted out to suppliers, contractors, or consultants. However, services such as operation of material handling equipment; safety and security compliance; environmental compliance; and outage management are generally performed by the owner's personnel.

b) Owner's infrastructure costs. Large rehabilitation projects may warrant on-site facilities such as office trailers; furniture; communications systems and equipment; water and sanitary systems; parking; and site lighting.

c) Insurance. Costs for insurance specifically written against work of the rehabilitation project should be included as a direct cost.

d) Legal costs.

e) Property taxes. Any changes in property taxes caused by a revaluation of the project due to its rehabilitation should be factored into the direct cost of the work.

~~a) Cost to purchase and install new equipment or modify existing equipment~~

~~b) Costs for planning, engineering, purchasing, environmental studies, factory test witnessing, on-site commissioning, training, etc.~~

~~c) Field supervision and inspection~~

4.3.4.2 Indirect costs

An expense that is incurred as a corporate function and thereby difficult to assign to the rehabilitation project is considered an indirect expense and often defined as a General and Administrative (G&A) cost.

These costs typically include back-office services such as public relations, network maintenance, general management, purchasing, reproduction, advertising, rent, office supplies, utilities, and other costs incurred by a business in its day-to-day operations. Any changes in indirect costs resulting from the rehabilitation project should be included in the economic analysis.

~~a) Office supervision~~

~~b) Engineering positions and support such as copy machines, supplies, lights, rent, telephone, and computers~~

~~c) General management~~

4.3.4.3 Investment-related costs

Investment-related costs are those costs associated with the economic analysis and viability of the project that are not specifically associated with direct or indirect costs.

a) Salvage value. Owners typically evaluate the economic feasibility of a proposed rehabilitation project on a strictly 'going-forward' basis. The net book value of the existing asset is treated as a sunk cost and not included in the economic evaluation—unless the salvage value is negative. If the salvage value is negative, it is typically treated as an avoided cost and included in the economic analysis as a benefit in the year the decommissioning cost would have been incurred.

~~a) Depreciation and salvage~~

~~b) Return on capital~~

b) Forgone revenue during outages caused by the rehabilitation program.

c) Changes in the depreciation schedule. An existing asset that is being considered for rehabilitation typically has been in service a number of years and its book value reflects the original investment less the sum of accumulated depreciation and salvage value. The rehabilitation project will likely extend the service life of the asset triggering a new depreciation schedule for rate making purposes. The accounting process for the new depreciation schedule can be quite complicated and typically unnecessary for the economic analysis, which considers the rehabilitation project on a going forward basis.

d) Source of funds and analysis. The economic analysis is typically a straightforward year-by-year accounting of costs and benefits. Some owners prefer a 'Cash on Cash' analysis where the investment is treated as all equity in year 1 of the study. Other owners opt for a levered analysis where the investment is covered by a combination of equity and debt. The equity portion is accounted for in year 1 and the debt is amortized over the life of the loan. Depending on the owner's preference the analysis may be 'pre-tax' or include applicable income taxes. An analysis that includes income taxes also usually includes depreciation of the investment cost of the rehabilitation over a set period per the tax code and any incentives that may be in effect.

~~d) Taxes~~

~~e) Insurance~~

~~f) Cost of funds used during construction~~

4.4 Plant staffing assessment

The rehabilitation of major hydroelectric power plant equipment or systems should include an evaluation of the existing staffing necessary to operate and maintain the plant. The replacement or rehabilitation of high-maintenance equipment and systems will often reduce the amount of time and effort expended by the staff in operating and maintaining the equipment to the point where staff reductions may be warranted.

When equipment and systems are replaced with newer technology it can result in a requirement for skilled people that are not presently available in the operation and maintenance staff. Retraining of existing staff or the hiring of [especially](#) ~~specialty~~ skilled individuals may be necessary if it is decided to avoid using resources outside the organization.

A major rehabilitation of a hydroelectric power plant is an opportune time to evaluate current staffing and skills based on the aforementioned considerations.

5. Rehabilitation of waterways

5.1 General

Energy losses in the hydroelectric power plant's waterways system are due to wasted water flow and loss of head. These losses are associated with the plant's operating practices and with physical equipment included in the plant's waterways systems. A brief discussion of these losses is contained herein. The discussion does not attempt to address possible improvements and their implementation unless significant electrical content is involved. Appropriate civil and mechanical engineering society ([e.g.](#), ASCE and ASME) guides can be referred to for consideration and in-depth treatment of rehabilitation of many of these components. Items such as spillway and intake gates are of paramount concern to a power plant owner since major plant and facility safety issues are involved. The *Guide to Hydropower Mechanical Design* [[B165](#) ~~B145~~] is a good reference for mechanical systems and equipment.

5.2 Leakage losses

Leakage from various power plant components decreases available flow to the turbines. The leakage is most often minor in nature; an industry survey (EPRI ~~report~~ EM-2407 [[B167](#) ~~B148~~]) estimates the average leakage loss at a typical plant at less than 0.5% ~~percent~~ of available stream flow. Leakage, for purposes of classification, can originate from intake gate systems, flood control systems, and structural sources such as foundations, power tunnels, penstocks including isolating valves, [canals](#), [flumes](#), and turbine units. Leakages from sources up to the turbine shutoff valve, together with causes, are discussed briefly in the following subclauses.

5.2.1 Intake gate systems

5.2.1.1 Gate seals

The intake gates may lack gate seals or have defective seals. The resulting leakage can create significant problems during unit shutdown for turbine inspection and maintenance. Additional pumping and associated electrical power supply to unwater equipment for maintenance or rehabilitation may be required.

5.2.1.2 Gate position sensor

Miscalibration of, or inherent design limitations of the gate position sensor will give false indication of gate position to the control system resulting in a failure to fully open or close the gate. This can result in an unsafe condition.

5.2.1.3 Gate hoist equipment

Erratic or unpredictable operation of gate hoist equipment can be a cause of gate leakage. If rehabilitation of intake gate systems is being considered, many of the electrical features discussed in 6.24~~23~~ are applicable to the electrical systems of the gates and hoists.

5.2.2 Flood control systems

5.2.2.1 Flashboards

Flashboards, if installed on the spillway are used to increase reservoir capacity and reduce spill from the dam. Flashboards may be susceptible to leakage losses due to combinations of design, construction, operation, or flashboard deterioration.

5.2.2.2 Spillway gates and hoists

Spillway gates and associated hoist systems, position indication systems, and gate seal systems may also contribute to water leakage. If rehabilitation of spillway gate systems is being considered, many of the items discussed in 6.24~~23~~ are applicable to the electrical systems of the gates and hoists.