IEEE Guide for the Rehabilitation of Hydroelectric Power Plants

Sponsor
**Energy Development and Power Generation Committee of the
of the
IEEE Power Engineering Society**

Approved June 27, 1991

IEEE Standards Board

Abstract: This guide is directed to the practicing engineer in the field of hydroelectric power plant design for the purpose of providing guidance in the decision-making processes and design for the rehabilitation of hydroelectric power plants. It covers general assessment considerations, rehabilitation of waterways, and rehabilitation of equipment. An extensive bibliography is included.
Keywords: hydroelectric power plant, rehabilitation

The Institute of Electrical and Electronics Engineers, Inc.

345 East 47th Street, New York, NY 10017-2394, USA

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Library of Congress Cataloging in Publication Data will be found on the following page.

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IEEE guide for the rehabilitation of hydroelectric power plants /
sponsor, Energy Development and Power Generation Committee of the
IEEE Power Engineering Society.
p. cm.
"Approved June 27, 1991, IEEE Standards Board."
Includes bibliographical references.
ISBN 1-55937-150-1
1. Hydroelectric power plants — Maintenance and repair.
2. Hydroelectric power plants — Reliability. I. IEEE Power Engineering Society. Energy and Power Generation Committee.
II. IEEE Standards Board.
TK1081.I44 1992
621.31 ' 2134' 0288 — dc20

92-3347
CIP

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Foreword

(This Foreword is not a part of IEEE Standard 1147-1991, IEEE Guide for the Rehabilitation of Hydroelectric Power Plants.)

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 redevelopement of the site. Redevelopment will not be treated in detail in this guide.

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

The Working Group on Hydroelectric Power (P1147) was formed at the 1986 IEEE Summer Power Meeting. Its members represent a cross-section of the hydroelectric power industry that includes power plant owners, engineers, and equipment manufacturers.

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IEEE Guide for the Rehabilitation of Hydroelectric Power Plants

1. Scope and Introduction

1.1 Scope

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

1.2 Introduction

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

1) Retirement
2) Continuation of operation as-is
3) Redevelopment
4) Rehabilitation

The first two options are self-explanatory. Option (3), *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 (4), *rehabilitation*. Rehabilitation should result in extended life, improved performance, increased reliability, reduced maintenance, and improved operations. This guide covers all equipment up to and including the main transformer.

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

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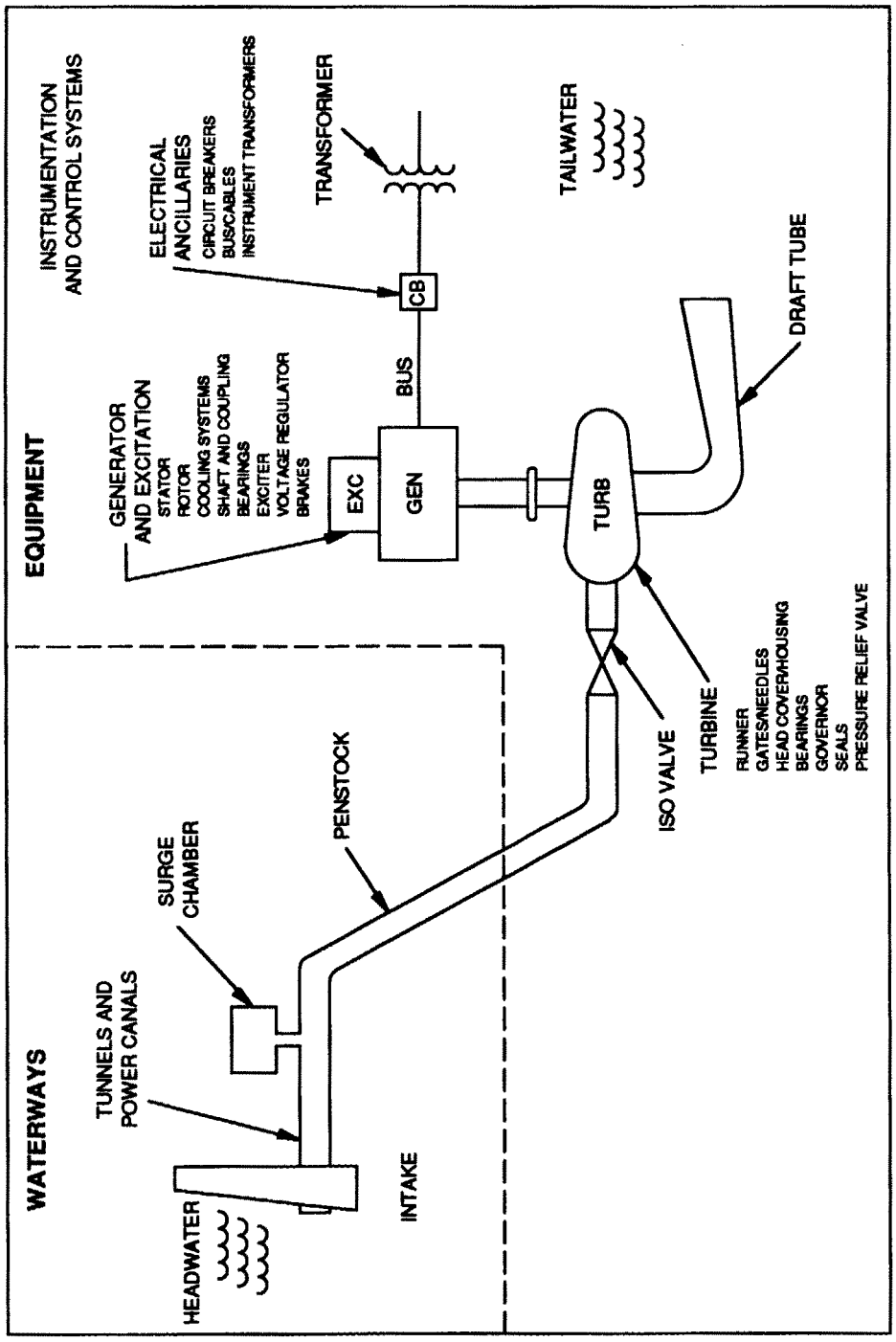


Figure 1—Typical Power Plant Systems Considered for Rehabilitation

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

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 regulating agency. The owner should also investigate historical preservation regulations that may impact the rehabilitation program.

This guide contains a bibliographical 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 is not complete, but is meant to be an aid in starting the review process.

2. General Assessment Considerations

2.1 General Conditions for Rehabilitation

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

1) Declining unit availability
2) Potential for improved performance
3) Changes in plant or unit operating conditions
4) Opportunity for plant automation
5) Reduced output capabilities
6) Failure of major equipment
7) Inability to withstand the effects of seismic forces during earthquakes

It is desirable to perform an appraisal of each of the above conditions as they apply to all major equipment in hydroelectric power plants. Inspection and testing is an integral part of this appraisal process. A tabulation of suggested items to be evaluated is given in Table 1.

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Table 1—Items to be Considered in Assessment of Plant and Equipment

The following is a list of items that should be considered in the assessment of equipment. The left column lists general items, and the right column gives more specific factors to be considered.	
Operating Conditions	Factors
Availability of water	Expected changes in water flows could have major effect on rehabilitation.
Addition of new unit(s)	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.
Need for increased capacity	Experience shows that increasing capacity by uprating requires minimum capital and produces the lowest cost in dollars per kW for increase.
Review Operating Records	Factors
Plant/unit flows, head, and energy production	Look for trends that could indicate degradation in performance, such as reduction in head due to high penstock losses or less energy produced by the same water.
Forced outages	Reveals major problem areas, types of outages, and their frequency.
Equipment operating data	Loadings, flows, temperatures, and cooling — all of which have an effect on life expectancy.
Review Maintenance Records	Factors
Past and present maintenance programs	Reveals if equipment has been maintained, which can influence the condition of equipment.
Repairs — what and when	Identifies problem areas if repairs are frequent. For example, frequent turbine runner repairs due to cavitation could indicate the need to change runner design or material or tailwater elevation. Another example would be frequent generator thrust bearing repairs, which could mean that a high-pressure lubrication system should be added, or an effort should be made to reduce the hydraulic thrust.
Equipment Design Data	Factors
Age and materials	Can be useful in predicting expected life.
Design performance and ratings	Is original consistent with present use? (For example, the turbine was designed to have a maximum efficiency rating at 80% rating, but is now operating at 110%; or, the unit was designed for 50 Hz, but is now operating at 60 Hz.)
Inspection of Equipment	Factors
General condition	Dirt, corrosion, leaks, cracks, cavitation, loose wedges, tape separation, etc.
Obvious problem areas	Leaks, vibration, high operating temperatures, lack of cooling, etc.
Equipment Tests	Factors
Test Data	Comparison of previous test data with new tests that can identify degradation in performance and reliability. Some tests are Turbine — efficiency tests Generator — insulation tests Switchgear — insulation tests Transformer — oil tests for degradation

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2.1.1 Declining Unit Availability

This causes increased costs and reduced revenues. Declining unit availability can be recognized by the occurrence of the following conditions:

1) 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.
2) Poor reliability of equipment may be evidenced by frequent outages. Outages and their frequency should be analyzed to determine the real cause; and corrective actions should be undertaken to improve the performance.
3) Maintenance activity that is over and above the routine activity necessary to keep the equipment in reasonable operating condition is another indicator. Causes for the increased maintenance activity should be investigated.

2.1.2 Potential for Improved Performance

The performance of major equipment such as output and efficiency was determined by the technology and state-of-the-art available at the time that the equipment was designed and built. Since significant advances in engineering and materials have occurred, older equipment can now be rehabilitated to obtain important gains in performance.

2.1.3 Changes in Plant or Unit Operating Conditions

Major equipment is designed to provide optimum performance for a specific set of operating conditions. The fact that these operating conditions can change with time often will justify rehabilitation of the equipment to improve its performance for a new set of operating conditions. Some examples are

1) Changes in water usage and availability for the generation of power can result in the need to increase the power output requirements of the turbine, generator, and anciliary equipment.
2) Changes in the method of operation of the unit can result in the need for higher outputs.

2.1.4 Plant Automation

Plant automation programs that are intended to achieve unattended operation of a unit or to convert from local to off-site control often require extensive modifications to equipment. Although plant automation is beyond the scope of this guide, it is recommended that rehabilitation of equipment be included as part of the automation studies.

2.1.5 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 conditions are candidates for rehabilitation. Examples of operating restrictions are

1) Reduction in available water flow
2) Temporary repairs to maintain limited equipment operation

2.1.6 Failure of Major Equipment

Unscheduled outages due to failure of major equipment during operation often result in substantial economic losses, especially if water can not be stored or diverted to other units. When the severity of the failure results in a prolonged outage, it is appropriate to consider the uprating of the failed equipment as an alternative to simple repair or replacement in kind. The following examples illustrate situations in which uprating could be considered:

1) *Failure of a main unit transformer*. Procurement of a new transformer that has lower losses and is designed for current and future operating conditions could be appropriate.
2) *Failure of a turbine runner such that its repair is not feasible*. Upgrading the runner with a new design that features improved performance under the current and future operating conditions could be appropriate.

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2.1.7 Seismic Considerations

It is appropriate to review the capability 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, 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.

Examples of modernizations that improve seismic withstand capabilities are

1) Automatic flow shut-off by unit shutdown or intake gate closure initiated by seismic triggers
2) Anchoring of critical equipment necessary for safe and reliable shutdown, such as battery racks, governor equipment, and control and protection switchboards
3) Strengthening of control and protection switchboards to prevent buckling or collapse
4) Reinforcement of structures near critical equipment to prevent damage from falling debris
5) Installation of flexible metal hose in place of rigid pipe for governor pressure piping
6) Modifications to control and protection circuits to ensure safe shutdown in the event of failure of dc power supply during a seismic event

2.2 Systems Approach to Rehabilitation

In the above text, general conditions were reviewed that could lead to the 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.

To illustrate this point, consider a case in which a turbine runner is uprated to produce greater power output and to operate at improved efficiency. Such improvements are not uncommon, but the impact on other parts of the plants should be considered, such as

1) Passing greater water flows 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. Changes in governor stroke and timing and changes in pressure regulating valves (if applicable) are often required.
2) The increase in turbine shaft output power requires an assessment of the shaft coupling, generator shaft, and rotor structure to safely transmit the increased torque.
3) The increase in generator power output requires an assessment of the stator winding, stator core, and field to determine their ability to generate the increased power and the possible need to uprate. The ability of the excitation system to provide the required field current, to provide the necessary voltage control, and to meet reactive power requirements should also be determined.
4) The capability of the generator leads and circuit breaker (if applicable) to carry the increased current should be evaluated.
5) The main unit transformer and associated transmission lines should be evaluated to determine if they can carry the increased power.
6) The rating of the current transformers and associated metering and protective equipment should be evaluated based on the upgraded capacity of the generator.
7) The generator cooling system and components should be evaluated for adequacy.

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

1) 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 power and energy production from that water could be lost, which would have an important economic impact on the feasibility of the rehabilitation.
2) A prolonged unit outage also results in the loss of generating capacity on the electrical power system. If this loss in capacity occurs during system peak loads, then the loss of capacity could have an economic effect on the feasibility of the rehabilitation.

The above examples illustrate the importance of planning major rehabilitations so that they will have a minimal impact on the water and power systems associated with the plant.

2.3 Feasibility Study

2.3.1 Introduction

A feasibility study of the various alternatives is performed to determine a possible course of action for plant rehabilitation. Consideration is given to project staffing, operation, and maintenance of the plant. Alternatives are developed for repair, replacement, rehabilitation, modernization, and automation, as well as the addition of functionally new equipment. The alternatives are then studied and compared for performance and economic justification. The resultant mix of most favorable alternatives is then incorporated into a program for plant rehabilitation.

This section does not discuss the details of making a feasibility study but does emphasize the need for one. A concise plan for the anticipated work is a product of the study, and is a very useful tool in implementing any rehabilitation.

A rehabilitation project should result in an economic benefit. Other projects implemented for safety, environmental, or regulatory reasons may have little, if any, economic benefit.

The feasibility or benefit-to-cost analysis may be very simple or quite sophisticated, depending on the size of the project and the number 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 delete those that fail the economic justification.

The feasibility analysis is essential to the development of an informed basis for action and a concise scope of work.

2.3.2 Anticipated Benefits

2.3.2.1 Increased Plant Output

The means of increasing output, either capacity or energy, cover practically every aspect of the plant. Some cost more than others, and some have greater benefits than others. The need, during the feasibility review, 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 like a significant expense to rewind a 40 year old stator. However, 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.

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2.3.2.2 Reduced Manpower Requirement

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

2.3.2.3 More Efficient Water Use

Increased efficiency in the hydraulic equipment and water passages is a topic that should be subjected to critical review with the intention of obtaining long-term gains. Improved designs for turbines, gates, seals, governors, and controls offer an opportunity to make more efficient use of the water. Small efficiency gains turn into substantial economic benefits when evaluated over the life of the plant.

2.3.2.4 Improved Operation and Increased Availability

Benefits can be realized by reducing the forced outage rate and increasing the unit availability, thereby improving the reliability of the plant. 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 will result in improved revenues for the plant.

2.3.2.5 Reduced Operating and Maintenance Costs

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

2.3.3 Costs

Feasibility studies cover the costs associated with rehabilitation. The costs fall into several categories.

2.3.3.1 Direct Costs

1) Cost to purchase and install new equipment or modify existing equipment
2) Loss of revenues during outages caused by the rehabilitation program

2.3.3.2 Indirect Costs

1) Costs for planning, engineering, purchasing, etc.
2) Supervision and inspection

2.3.3.3 Investment-Related Costs

1) Depreciation and salvage
2) Return on capital
3) Taxes
4) Insurance
5) Cost of funds used during construction

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The feasibility stage of hydroelectric plant rehabilitation quite 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 are necessary before an economic evaluation can be completed and a program can be defined.

3. Rehabilitation of Waterways

3.1 General

Energy losses in the waterways system of the hydroelectric power plant are due to wasted water flow and loss of head. These losses are associated with the operating practices of the plant and with the physical equipment included in it'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 (ASCE[1] and ASME[2]) guides can be referred to for consideration and in-depth treatment of the rehabilitation of many of these components. Items such as spillway and intake gates are of paramount concern to a power plant owner because major plant and facility safety issues are involved.

3.2 Leakage Losses

Leakage from various power plant components decreases available flow to the turbines. The leakage is usually minor in nature. EPRI EM-2407 [B126][3] estimates the average leakage loss at a typical plant at less than 0.5 % of available stream flow. Leakage, for purposes of classification, can originate from three general sources: intake gate systems, flood control systems, and structural sources such as foundations, power tunnels, and penstocks. Leakage from sources up to the turbine shut-off valve, together with their causes, are discussed briefly in the following paragraphs.

3.2.1 Intake Gate Systems

3.2.1.1 Gate Seals

The intake gates may lack gate seals or have defective seals.

3.2.1.2 Gate Position Indication Systems

Some plants have remote indication systems that allow intake gates to be controlled from the power plant control room or other remote locations. Miscalibration or inherent design limitations of the indication system may give false indication of gate closure.

3.2.1.3 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 4.22 are applicable to the electrical systems of the gates and hoists.

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[1]American Society of Civil Engineers, 345 East 47th Street, New York, NY 10017, USA.
[2]American Society of Mechanical Engineers, 22 Law Drive, Fairfield, NJ 07007, USA.
[3]The numbers in brackets, when preceded by the letter “B,” correspond to the Bibliography in Section 5.

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3.2.2 Flood Control Systems

3.2.2.1 Flashboards

Flashboards are usually installed as a means to increase marginally reservoir capacity and reduce the need for inadvertent spill. Flashboards may be susceptible to leakage losses due to combinations of design, construction, operation, or flashboard deterioration.

3.2.2.2 Spillway Gates and Hoists

Spillway gates and associated hoist systems, position indication systems, and gate seal systems can contribute to water leakage in the same manner as do the intake gate systems previously described. If rehabilitation of spillway gate systems is being considered, many of the items discussed in 4.22 are applicable to the electrical systems of the gates and hoists.

3.2.2.3 Spillways

Spillways can contribute to leakage due to deterioration or erosion of the spillway crest.

3.2.3 Structural Leakage

In addition to the spillway structure, leakage may occur in dam abutment structures, the foundations of either the dam or the powerhouse, the penstock, the power canal, or the power tunnel.

3.3 Head (Hydraulic) Losses

3.3.1 Trash Rack Systems

Trash rack systems can be sources of hydraulic system losses and may contribute to high maintenance costs due to inadequate design. Detection systems, which measure differential head across the trash rack, are employed frequently for providing remote indication of the accumulation of debris on the power plant's trash rack. Structural requirements due to increased flow loading should be evaluated.

3.3.2 Surge Tank Systems

Some surge tanks (or chambers) have hydraulic loss devices, such as orifice plates, installed in the surge tank riser to enhance the hydraulic stability of the surge tank. The operation of the surge tank system should be evaluated.

3.3.3 Penstock, Power Canal, and Power Tunnel

3.3.3.1 Penstocks

Penstocks can be major contributors to power plant hydraulic system losses. Older power plants may employ either wooden or riveted steel penstocks, which are contributors to high head loss. Other sources of hydraulic system losses in the penstock include

1) Corrosion and accumulation of mineral or organic deposits on the inner surface
2) Sharp penstock radii
3) Penstock reducers
4) Penstock inlet valves and valve bodies, or both

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3.3.3.2 Power Tunnels

Unlined power tunnels used to supply water to the turbines can be sources of high hydraulic system losses. The installation of concrete or steel liners or the painting of existing liners could reduce losses.

3.3.4 Tailrace and Draft Tube

Sources of hydraulic system losses in the tailrace and draft tube include

1) Tailrace obstructions such as rocks or sedimentation accumulation
2) Poor flow transition at the end of the tailrace

3.4 Fishery Considerations

3.4.1 General

Fish passage systems exist for the purpose of transporting migratory fish around the dam and powerhouse. These systems can address both the fish migrating upstream as well as those migrating downstream. The upstream migrant systems contend with transporting the fish over the structure itself. The downstream migrant systems deal with diverting the fish from entering the turbine intake. Rehabilitation in these areas could result in greater efficiency of operation.

3.4.2 Screens

These devices are designed to separate or otherwise direct the fish out of the turbine water flow and into a diversion system. They are in the turbine intake structure and consequently produce a head loss. Alternate means of diversion may result in reductions in operating and maintenance costs.

3.4.3 Barriers

Fish ladders constitute the traditional approach to transporting the fish over the dam. These devices require that water from the forebay be used for attraction and transporting purposes. This water represents energy that could otherwise have been used to generate power. Development of this water for power production as well as for fish purposes is possible. More efficient systems that use less water might also be worth investigating.

3.4.4 Behavioral (Light and Sound) Barriers

These systems are designed primarily by marine biologists. Various attempts are made to encourage, trick, and direct the fish along desired paths. A comprehensive examination of the intent and execution of these designs could result in more efficient systems.

3.5 Water Quality

3.5.1 Tailrace Aeration

Tailrace water quality has become a recent concern. Oxygen depletion in the reservoir is the principal cause of poor water quality, which has an adverse effect on aquatic life. Aeration of the water is a solution. Aeration will place additional burden on the operation of the plant either by placing greater demands on the auxiliary power system or by reducing turbine efficiency.

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3.5.2 Temperature Control

Water withdrawal from the reservoir for power production is usually made at depth. Therefore, the discharge from the plant has the characteristics of the stratified layer of the reservoir from which the withdrawal is made. This discharge may create unnatural environmental effects, particularly when the temperature of the discharge is much lower than the temperature experienced in "run of the river" conditions. To mitigate this effect, selective withdrawal structures can be utilized to allow the plant operator to control the withdrawal depth.

4. Rehabilitation of Equipment

4.1 Turbines

4.1.1 Introduction

All hydroelectric power plant rehabilitation studies should include a review of the following major components, as applicable, in order to determine the necessary scope of work to be carried out.

1) Runner
2) Main shaft
3) Bearings
4) Wicket gates and linkages
5) Shaft packing box or mechanical seal
6) Blade or deflector servomotor
7) Head cover and bottom ring
8) Bearing lubrication and cooling systems
9) Stay vanes
10) Draft tube
11) Turbine shut-off valve
12) Pressure relief valve

The following discussion addresses the electrical auxiliaries that support the above listed mechanical components and systems.

4.1.2 Cooling and Seal Water

The supply of water for both the turbine seal and bearing lubrication heat exchanger may require the supply of the following auxiliary systems:

1) Water booster pumps with necessary motor starters
2) Water flow and pressure switches for pump control
3) Water flow switches for seal and heat exchanger supply lines
4) Motorized or solenoid operated control valves to terminate the cooling water flow as the unit comes off line
5) Water sump pumps for mounting on the turbine head cover to remove water leaking out of the turbine seal; necessary motor starters and level switches to control the sump pump motors
6) Water filters either manual or automatic self-cleaning with necessary differential pressure switches
7) Temperature control valves to modulate the cooling water flow to each oil heat exchanger

Many of the above listed items that are contained in the powerhouse water supply system may need to be upgraded to handle the water requirements of the rehabilitated turbine. When the water inlet supply is taken directly from the penstock, the requirement of water pressure to the turbine seal or packing should be reviewed with the turbine supplier. The supply of an automatic, self-cleaning strainer in rehabilitated plants can eliminate the need for manually operated basket strainers, which require periodic servicing.

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4.1.3 Turbine Protection and Control Instrumentation

The application of protection and control instrumentation used on the turbine will vary primarily with the type and size of the rehabilitated turbine. The final selection of instrumentation employed on the turbine should be based on the following criteria:

1) Reliability
2) Ruggedness
3) Sensitivity
4) Accuracy

The functional requirements for the instrumentation, such as switch contact rating or type of resistance temperature detectors (RTD), should be coordinated with the unit's control equipment. Protection and control of the unit is referenced in IEEE Std 1010-1987 [B105]. The amount of equipment needed to protect and control a turbine and auxiliary equipment will vary based on the size and type of turbine considered.

4.1.4 Turbine-Greasing Equipment

Adequate lubrication of the turbine mechanical components is necessary to ensure longevity of moving components, such as wicket gate stems and linkages, and auxiliary components like the wicket gate ring lock. Primarily, larger hydro turbine installations or plants that run unattended can justify the added costs of an automatic turbine-greasing system.

The most common form of automatic greasing system is controlled by a series of cams used to control the frequency and duration of greasing for a component. Pressure switches are used to verify the presence of grease in grease lines for equipment that is located furthest away from grease pump.

The addition or rehabilitation of the turbine-greasing equipment can affect the size of the motor starter required for the grease pump as well as increase the amount of controls that need to be coordinated. The need for a grease lubrication system can be eliminated with the implementation of self-lubricated wicket gate stem bushings. Either oil impregnated or synthetic bushing materials can be installed in a rehabilitated turbine head cover design.

4.1.5 Bearing Lubrication System

A properly designed bearing lubrication system is crucial for a reliable and fail-safe operation of both the turbine and generator bearings. A detailed description of the mechanical aspects of the design requirements of the oil system for lubrication is presented in ASME LOS-5D1 [B125]. For flooded lubricated bearing designs, a thorough investigation should be conducted to verify

1) Requirement and availability of a reliable (fail-safe) power supply to the lube-pump motors
2) Proper lube-pump capacity and motor sizing
3) The need for a lube oil leakage detection system to alarm in the event that oil leaks into the cooling water system

4.1.6 Shear Pin Failure Equipment

Shear pins or friction couplings are provided on the turbine wicket gate linkages to enable the wicket gate assembly to close when debris becomes lodged between wicket gate passageways. A shear pin detection system senses when one or more wicket gate shear pins have failed. This condition results in an alarm condition that is used to initiate the closure of the turbine shut-off valve. Turbine manufacturers supply several different types of shear pin detection systems that result in the same basic output. The addition of a shear pin detection system can be implemented on upgraded Francis or Kaplan turbine designs that utilize a gate operating ring and wicket gate lever linkage arrangement.

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The pneumatic type of shear pin detection system utilizes a differential pressure switch and orifice to detect the flow of air through a broken shear pin. The switch only trips when a sufficient air flow occurs across the supply line orifice. Another type of system utilizes a spring-loaded gate linkage on each wicket gate with individual gate linkage switches. The spring-loaded linkage system is used on smaller turbines.

4.2 Governors

4.2.1 Introduction

Older governors for large hydro units can be of the mechanical-hydraulic cabinet actuator type. They consist of the governor head (ballhead motor, ballhead, dashpot, and compensating, gate limit, and speed droop adjusting mechanisms), the hydraulic amplification equipment (pilot valve and distributing valve), and the oil pressure system (oil pumps, sump, pressure tank, and associated controls). The lifetime of some governor components can be less than the lifetime of the associated turbine. The governor should be considered for rehabilitation when it becomes too expensive to maintain or when there are changes in the operational mode of the project. Governors become costly to maintain when there is excessive maintenance; frequent adjustment; a high failure rate; or when spare parts become expensive, hard to procure, or unavailable. Whether or not the original manufacturer still supports the equipment should also be considered. Operational changes that could create a need for rehabilitation are faster control, automatic controls, remote control, joint load control, higher efficiency, improved stability, or unusual control algorithms.

4.2.2 Rehabilitation

The most basic type of governor rehabilitation is the addition of devices to allow for new operational modes. These may include speed switches and limit switches for automatic control, remote indicating devices, automatic blade angle control on Kaplan turbines, net head comparator, and creep indication. The advantages of this approach are low cost, short outage time, and the likelihood of doing the work with available labor.

4.2.3 Electrical Conversion

The next level of governor rehabilitation is the electrical conversion. This consists of replacing the mechanical governor head with equipment of the type found in modern electric-hydraulic governors. Normal devices to be removed include the upper and lower floating levers, the dashpot and linkage, the ballhead and ballhead motor, the speed droop fulcrum, and, sometimes, the PMG (permanent magnet generator used for speed sensing). Equipment added includes a pilot control assembly, gate limit and restoring shaft linkages, speed and power set changer (synchronizing motor), pressure-reducing valve and strainers, flow regulator, speed-sensing equipment, and electronic devices such as the proportional, integrating, and differential control operational amplifiers, and a watt transducer for feedback. Electric conversion will be able to accomplish almost all changes in governor operating mode and can be accomplished with short down-time. Recent advancements in the development of microprocessor-based digital governors, frequently used in small hydroelectric applications, have made it possible to utilize this class of equipment for electrical conversions instead of more traditional electronic devices.

4.2.4 Partial Replacement

When the governor is no longer supported by its manufacturer, or when there are significant maintenance problems, a partial replacement might be considered. This includes not only an electric conversion but also the replacement of the control column and the main distributing valve. Only the existing oil system is retained.

4.2.5 Complete Replacement

Complete replacement of the governor may be necessary when the existing oil pressure system is no longer acceptable or when the maximum pressure is increased.

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4.3 Generators

4.3.1 Introduction

Rehabilitation of generators frequently includes uprating. This makes sense economically as it increases revenues, improves reliability, and extends life.

Certain parts such as collector rings, brake shoes, and oil-to-water and air-to-water heat exchangers will deteriorate with time. These are relatively minor parts, and the correction of their problems may be classified as repair or maintenance.

The stator winding is a component that deteriorates with time and temperature. A large percentage of outages are caused by stator winding failures. Because of the many improvements in insulating materials and advanced design methods, a new stator winding will result in a significant form of rehabilitation.

The stator core, the rotor winding, or both may be replaced during rehabilitation, but this is not frequently required. Older field and stator windings may contain asbestos. The hazards and legislation pertinent to this material should be considered when disturbing these windings.

There exists a particularly promising opportunity to modernize and uprate hydro turbines and, consequently, generators for the following reasons:

1) Many major generator components can be used without change. Since the most common turbine modification is a new, higher-performance runner with increased capacity, a new stator winding, and, occasionally, a new stator core or new rotor winding will be required.
2) The application of modern technology will usually increase the turbine and generator efficiencies and ratings.

The following is a general discussion of the opportunities for uprating that are now possible due to technological advances. Most generators built before 1960 can be modified and uprated by at least 15%. However, the designer should be thorough and should consider all parts of the machine as if they were being designed for the first time.

Table 2 is provided to ensure that all aspects of generator design are reviewed.

4.3.2 Electrical

Technical advances have led to possibilities for substantial increases in rating. Developments in the following areas have done the most to lead the advances in ratings:

1) Stator coil insulation
2) Ventilation and cooling
3) Thermal analysis
4) Computer analysis

Table 3 illustrates one case and the results obtained. In this case, both the stator and rotor windings were replaced while the exciter was retained.

Uprating may involve changes to the inertia, the reactances, or the time constants. In each case, machine parameters should be assessed, along with the capability of the existing design, given new turbine characteristics.

Turbine overspeed is one of the most important areas of concern. Changes in rated speed are possible with varying degrees of equipment replacement.

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Table 2—Generator Rehabilitation Checklist

Component	Stator Foundation	Stator Frame	Stator Core	Stator Winding	Rotor Pole Body	Rotor Pole Coil	Rotor Damper Winding	Rotor Rim	Rotor Spider	Rotor Keys	Shaft
Check											
Roundness	—	X	X	—	—	—	—	X	—	—	—
Welds/Brazes	—	X	—	X		X	—	—	X	—	
Radial Freedom	—	X	—	—	—	—	—	X	—	—	—
Fastener Torques	X	X	X	—	—	X	—	X	X	—	X
Concrete Integrity	X	—	—	—	—	—	—	—	—	—	—
Cracks in Plates and Castings	—	X	—	—	X	—	—	X	X	—	X
Nonuniform Waves	—	—	X	—	—	—	—	X	—	—	—
Gaps or Crushing at Splits	—	—	X	—	—	—	—	—	—	—	—
Hot Spots	—	—	X	—	X	X	X	—	—	—	—
Upset Laminations	—	—	X	—	X	—	—	X	—	—	—
Fretting Corrosion	—	X	X	—	—	—	X	—	—	X	—
Losses	—	—	X	X	X	X	—	—	—	—	—
Insulation Resistance	—	—	—	X	—	X	—	—	—	—	—
Corona Extinction Voltage	—	—	—	X	—	—	—	—	—	—	—
Temperature Class	—	—	—	X	—	X	—	—	—	—	—
Service Record	—	—	—	X	—	X	—	—	—	—	—
Deformation	X	X	X	X	X	X	X	X	X	X	—
Mechanical Strength	X	—	—	—	X	X	—	X	X	X	X
Safety Factor	X	—	—	—	X	X	—	X	X	X	X
Down Time Cost	X	X	X	X	X	X	X	X	X	X	X
Cleanliness	—	—	X	X	—	X	—	—	—	—	—

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Table 2A —

	Thrust Bearing	Guide Bearing	Ventilation System	Bracket Foundation	Bracket Structure
Fretting Corrosion	X	X	—	—	—
Operating Temperature	X	X	—	—	—
Losses	X	X	X	—	—
Loading	X	X	—	—	—
Safety Factor	X	X	—	—	X
Welds	—	—	—	—	X
Mechanical Strength	—	—	—	—	X
Deformation	X	X	—	—	X
Air Utilization for Cooling	—	—	X	—	—
Concrete Integrity	—	—	—	X	—
Fastener Troques	—	—	—	X	X
Down Time Cost	X	X	—	X	—
Cracks in Castings and Plates	X	X	—	—	X
Cleanliness	X	X	X	—	—
Leakage	X	X	—	—	—

Table 2B —

	Heat Exchangers	Brakes and Jacks	High Pressure Oil Lift	Controls
Cleanliness	X	—	X	—
Leakage	X	X	X	—
Capability	X	X	X	—
Service Record	X	X	X	—
Down Time Cost	X	X	X	X
Adequacy of Protection	—	—	—	X
Productivity Improvements	—	—	X	—

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Table 3—Example of Uprated Results

Characteristic	Original	Uprated
Rotor winding	Class B strap	Class F strap
Stator winding	Class B asphalt	Class F epoxy
Rating	125 MVA .95 pf	173.6 MVA .95 pf
	13.8 kV	13.8 kV
Overload	15%	None
Exciter	655 kW 500 V	Same
	750 V ceiling	
SCR	1.18	0.885
Field current at maximum load	1040 A dc	1036 Adc
Maximum rotor winding temperature rise at maximum load	80°C	80°C
Maximum stator winding temperature rise at maximum load	80°C	80°C
Efficiency at maximum lead	98.11%	98.39%
Rotor coil copper	20 412 kg	31480 kg
Stator coil copper	12 788 kg	17 092 kg
Maximum lead torque	9 011 250 N·m	10 880 250 N·m

Since field current increases with load, the capacity of the rotor winding, the exciter, or both may be exceeded. In such a case, the rated power factor may be altered toward 1.0 (to lower rated load field current requirements), the rotor winding may be changed, or the exciter may be changed depending on individual requirements.

The following discussions explain how each of the four technical advances can be applied to existing generators.

4.3.2.1 Coil Insulation

Newer insulation systems for stator coils are both thinner and more heat conductive than the older, asphalt-based systems. Load-carrying capability is thereby increased due to the extra copper that can be added and due to superior heat transfer. Transposition and stranding dimensional changes can be made to reduce eddy current loss in the coil. Due attention should be paid to specifying the new insulation system because many insulation tests are now common for coils that were not contemplated for asphalt insulation systems.

4.3.2.2 Ventilation

Ventilation tests on older generators have shown that many generators do not have the airflow patterns contemplated by their designers. In some cases, only design margins have allowed satisfactory operation of the unit. Tests of airflow and ventilation performance are therefore recommended to ensure confidence in the ability of the unit to support the uprate. Such tests include pressure taps and flow measurements in critical areas of the machine. Ventilation system effectiveness may be improved by

1) Addition or redesign of rotor fan blades
2) Addition or redesign of baffles to control airflow
3) Cleaning of surface coatings or contaminants from heat transfer surfaces such as rotor coils

Total airflow may not be the most significant parameter. The cooling air should be appropriately distributed in the various passages in proportion to the heat generated in each passage.

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4.3.2.3 Thermal Analysis

Reviews of performance tests of older machines show that many had substantial temperature margins with respect to their guarantees. Rewinding these units with epoxy mica insulation systems may achieve up to a 15% uprate within the original temperature guarantees. Computerized solutions of heat transfer models relating the coils, teeth, core, and ventilating air coupled with more exact loss calculations enable designers to predict temperatures more accurately. This minimizes the built-in margins and the possibility of exceeding the guarantees.

The original rotor windings are likely to have more margin and are therefore more likely to be able to carry the increased current associated with the uprate. Because of relatively simple construction and low operating stresses, rotor windings suffer little deterioration and are seldom replaced.

Once the thermal and loss performance of the design are established at the uprated load, the capability of the air cooler system should be checked to ensure that sufficient heat removal capacity exists. Again, older, more liberal margins minimize the likelihood of this problem.

4.3.2.4 Computer Analysis

Calculation methods for electrical parameters have improved. Manufacturers have additional analytical tools and procedures backed up by more experience. Finite element analysis can now be used to verify previously empirically-derived formulae. The number and complexity of design rule checks has grown. The generator may require detailed examination to acquire the necessary information.

4.3.3 Mechanical

The following discussion will point out certain mechanical areas that should be considered in the initial planning stages of an uprating as well as some of the problems a designer will face when reviewing these items. Table 4 provides a general check list for the mechanical review.

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Table 4—Areas of Concern for Mechanical Integrity

Major Components	Torque	Speed	Short Circuit	Magnetic Pull	Thrust
Frame	x	x	x	x	x
Stator Foundation	x	x	x	x	—
Core/Frame Connection	x	x	x	x	—
Spider	x	x	—	—	—
Spider/Rim Connection	x	x	—	x	—
Rim	—	x	—	—	—
Pole Tip and Dovetail	—	x	—	—	—
Field Coil	—	x	—	—	—
Shaft	x	x	—	x	—
Shaft/Spider	x	x	—	—	—
Shaft Coupling	x	x	—	—	—
Bearings	—	x	—	x	x
Brackets	—	x	—	x	x

4.3.3.1 Design Practices

Early hydroelectric generators were mechanically designed to what appeared to be relatively safe levels; and the margins of safety, as calculated, were rather large, in many cases, when compared to modern practice. There are four reasons for caution that should be considered when using these earlier calculations.

1) *Analytical methods*. The earlier methods were rather limited, and most of the analyses were very basic. The computerized and more technically accurate calculations of today were not available. The larger margins permitted this and proved to be acceptable.
2) *Materials*. Material quality and quality assurance have improved. Certain materials, such as castings, are of immediate concern. A cast spider, for example, may have serious hidden defects that never caused failure only because of the high safety factor. Other materials may be susceptible to shock loads, brittleness, or corrosion over a period of time.
3) *Manufacturing processes*. Quality control, inspection, tooling, and manufacturing methods and tolerances were not as highly developed.
4) *Experience*. The backlog of historical data and experience gained while designing, building, and operating units at ever increasing ratings and speeds was not available. More data at extreme loadings gives today's designers an edge over their predecessors.

A fundamental problem in reviewing the design for the mechanical uprate on the older machines is the lack of original material requirements, calculated stress levels, quality checks, or manufacturing and other early recorded data. It would be expected that the drawings showing configurations and materials would be available; however, exceptions to the drawings during manufacture, modifications made during installation and operation, and original expected design loadings versus actual loadings may not be so easy to obtain.

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4.3.3.2 Torque Effects

A change to the loading of mechanical parts is due to the increase in torque. Torque is directly proportional to the product of kVA and power factor, and is inversely proportional to speed and efficiency. Since projected upratings run anywhere from a few percent to well over 50%, torque effects are significant.

Comparisons should be made between the original and the new parameters. Some owners operated units well above rated load, and such overload performance can be used to see how the unit operates at higher than design values.

The components most affected by the torque change are

1) *Shaft*. The shaft will see the full change in torque. The basic design, configuration, and analysis, however, make it somewhat easier to evaluate than the spider. If necessary, a relatively complete ultrasonic test of the shaft can be performed in the field to verify its integrity. The couplings should also be considered in the review.
2) *Spider*.The spider carries the full load torque from the shaft. Variations of design are numerous, and the analysis can be complex. It is probably the most difficult component to evaluate with respect to increased torque. Torque stresses are only part of the total stress distribution in the spider. Stresses due to centrifugal force, weights, and rim shrinkage should also be considered. Therefore, an increase in torque does not necessarily mean a proportional maximum stress increase in the spider.
3) *Rim-to-Spider and Spider-to-Shaft Connections*. These will transmit the full value of a change in torque, but there is usually little difficulty in allowing increased loads.
4) *Stator*. Depending on the electrical changes made, the stator may be subjected to a change in the short-circuit torque. Often, it will not be affected at all since, without changes to the electromagnetic design, the short-circuit torque is not proportional to rated torque. The frame-to-foundation and core-to-frame connections should also be reviewed.

4.3.3.3 Unit Stability and Magnetic Pull

There are electrical changes that can be made in the stator that effect the dynamic stability of the unit. The unbalanced magnetic pull between the rotor and stator can change due to changes in air gap flux density and the arrangement of the stator circuits. A unit with a new stator core and winding design can have a significantly different magnetic pull. Such a change can effect guide bearing loadings, critical speeds under load, shaft dynamic movements during operation, and stator behavior.

4.3.3.4 Turbine Effects

The uprate may or may not involve a change in the turbine. If a new turbine is specified, the generator designer will need to contend with a number of possible changes. A new rated speed, new maximum overspeed, new turbine weight, and new hydraulic thrust need to be considered because they cause a significant change in the loading of certain parts.

Changes in speed are the exception rather than the rule and are not considered in detail here. A change in rated speed or maximum overspeed will effect most major components. The time for review will be lengthened if an increase in overspeed or a change in rated speed is contemplated.

The turbine characteristics, such as thrust, may change even if the existing turbine is used. The designer should obtain the design loads to be used in reviewing the generator from the turbine manufacturer.

A thrust change will have a direct effect on the thrust bearing and bearing support structure. A thorough analysis of the existing bearing can be made for increased load capacity. If changes need to be made because of thrust considerations, minimal component changes quite often will accomplish the desired result. Care should be taken when comparing the original design values against the new loading.

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A bearing that has satisfactorily run over the years may have done so because the design loadings were never reached. The mechanical support system should be analyzed for increased stress and deflection. The effect of the thrust on the axial stress in the shaft is usually checked and found to be small.

4.3.4 Cleaning, Inspection, and Testing

Uprating cannot be accomplished reliably by just rewinding the stator, for example, without having a detailed knowledge of the condition of the generator and its performance. Many owners or manufacturers have records of performance tests made when the generator was new. If no ventilation modifications have been made on the original machine, the original temperature tests can provide very useful information to be factored into the design of an uprated machine. An old machine may have increased core and tooth loss as a result of aging of the silicon steel and degradation of interlaminar insulations. Therefore, if a substantial uprating is planned using the old stator core, new loss tests should be made because higher core loss will adversely influence the winding temperature.

A thorough cleaning of the generator is a necessary part of modifying and uprating. This should be done before the uprate is designed to permit a very detailed inspection of the mechanical parts. This is especially important when any of the major parts of the generator are castings. An inspection should include a thorough visual check (see Table 2). It may be wise to check some highly-stressed areas with penetrating dye, magnetic particle, or ultrasonic methods.

Rotating exciters and collector rings should be inspected thoroughly. These, along with the rotor winding, should have a dc megger test if they are to be used without modification on the uprated machine. If static exciters are a part of the rehabilitation program, the generator manufacturer should be contacted concerning allowable ceiling voltage and possible insulation damage.

Upon completion of the generator uprate work, a new set of tests may be desirable to establish a baseline for future operation. They should include tests specifically aimed at longterm characteristics such as dc ramp testing, partial discharge analysis, and operational air gap measurement, if the appropriate equipment has been installed.

4.4 Excitation Systems

4.4.1 Introduction

The excitation system associated with the synchronous generator provides the field current requirements of the machine as well as a means of voltage or reactive control. Many excitation systems installed prior to 1960 consisted of a rotating exciter feeding the main field of the generator, a rotating pilot exciter feeding the main exciter field, and a regulator controlling the pilot exciter output. Sometimes, a motor-generator set with mechanical regulator was used instead of a pilot exciter. Static excitation systems using thyristor bridge rectifiers have been used most commonly since 1960. Another common excitation system for smaller high-speed machines is a brushless exciter with a rotating ac generator and rotating rectifiers. Both the older rotating excitation systems as well as the newer static excitation systems easily lend themselves to rehabilitation.

4.4.2 Rehabilitation

The reasons for considering rehabilitation of excitation systems are those common to most other equipment: improved efficiency, reliability, and performance, and reduced maintenance. The major efficiency improvements are accomplished by elimination of the mechanical and magnetic losses of the rotating exciter and the elimination of the exciter field rheostat. Rotating excitation systems have an efficiency of about 88% compared with an efficiency of up to 95% for static excitation systems. Reliability is greatly improved because older, worn equipment is more likely to fail when subjected to loads near its original design limits. Modern static systems have high availability. Rotating-type excitation systems may have too slow a response to function properly with present automatic control requirements and may not perform as needed during system transients. When rehabilitating machines with brushes and slip rings, brushless or static excitation systems should be considered. Maintenance is then improved because of the elimination of mechanical components that wear and need frequent adjustment as well as the replacement of equipment for which spare parts are no longer available.

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4.4.3 Accessories

The simplest form of modernization of excitation systems is the addition of accessories to the existing equipment. This is done more commonly on older static excitation systems rather than rotating systems. Possible auxiliary devices include maximum and minimum excitation limiters, active and reactive droop compensator, power system stabilizer, field ground relay, static field temperature indicator, and var or power factor controller. Although these auxiliaries provide additional capabilities, they do not address the possible improvements that can be achieved by replacement of all or part of the excitation system.

4.4.4 Partial Replacement

A partial replacement usually consists of replacement of the voltage regulator and pilot exciter with a modern solid-state voltage regulator that directly feeds the main exciter field. The exciter field rheostat is normally eliminated in a partial replacement. This type of rehabilitation has the advantages of relatively low cost and improved performance and reliability, but does not maximize the efficiency increase and sluggish response when compared with a full static system.

4.4.5 Full Replacement

Replacement with a full static excitation system provides the best improvements, but also has the highest associated costs and the longest unit outage time. Furthermore, floor space is frequently a restriction in this type of a replacement. Brushless exciters are available for high-speed generators with ratings up to 25 MVA maximum output. The existing rotating exciter may be replaced, resulting in a marginal increase in generator efficiency.

4.5 Generator Main Leads and Switchgear

The unit main leads and switchgear are two areas that are sometimes overlooked when undertaking a station rehabilitation program. Both of these should be evaluated carefully when any changes in unit ratings are being considered.

The unit main leads may be cable or busbar. The unit switchgear may be oil-filled, airmagnetic, or air blast. The steps to be taken for evaluating the adequacy of the existing installation are

1) Inspect the system for any visual damage, such as signs of arcing or degradation of insulation. The physical condition alone may dictate replacement of the equipment.
2) Obtain, if possible, maintenance and repair records for the station to determine if the installation has had a record of failure.
3) Obtain, if possible, nameplate data, drawings, catalog information, ratings sheets, test reports, and other documentation that may contain the following equipment ratings:
   a) Maximum voltage
   b) BIL level
   c) Continuous current
   d) Short-circuit withstand current
   e) Maximum current interrupting rating (for switchgear)
4) Compare the main leads and switchgear ratings against those of the machine. Perform short-circuit system studies to determine system fault levels, and compare to equipment ratings.
5) Study the personnel safety aspects. Can the equipment be inspected, handled, and maintained safely, and does it fulfill modern safety requirements?

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Based on the results of the above evaluations, it is recommended that the main leads and switchgear be replaced for any one of the following reasons:

1) Physical damage or deterioration
2) History of frequent failure and repair
3) Ratings inadequate for intended machine
4) Ratings inadequate for system conditions
5) Modern safety requirements

Furthermore, it is recommended that consideration be given to replacing the equipment on the basis of its age. Organic insulation systems gradually deteriorate over a period of time. For this reason, it is recommended that, when replacing or rewinding the generator, unit-related cable systems, and oil-filled switchgear older than 25 years should also be replaced.

4.6 Generator Neutral Grounding Equipment

The generator neutral grounding system should be reviewed as part of the rehabilitation study.

The neutral grounding recommendations depend on the manner in which the generators are connected to the system. High-impedance neutral grounding is most often recommended for unit-connected generators. This is where one generator is either directly connected or connected through a circuit breaker to a step-up transformer such that there is no interconnection of zero sequence current or voltage. Selective ground fault relaying or unbalanced load applications use other neutral grounding methods. These include applications in which generators are connected at generator voltage to other generators or overhead lines and power distribution systems.

When new generator stator windings are being installed as part of the rehabilitation, the neutral grounding and protection system may be upgraded in line with current IEEE recommendations. Details of grounding may be found in IEEE C62.92-1989 [B107] and IEEE C37.101-1985 [B54]. These recommended systems are designed to minimize damage caused by a generator single-phase ground fault and to limit transient overvoltages.

The existing generator neutral grounding equipment will most often involve current transformers, resistors that are either directly in the neutral or on the secondary of a distribution transformer in the neutral, and potential transformers. Ground protection consists of voltage and current relays connected to instrument transformers.

Replacement of oil-filled transformers in the neutral grounding scheme is desirable to avoid a fire hazard or PCB problem.

Any revision of the neutral grounding that increases the voltage stress at the neutral end of an existing aged generator stator winding should require review of the generater insulation at the neutral. A change in stress at this point on an old winding could precipitate an incipient generator ground fault.

Low resistance or reactor neutral grounding to permit ground fault protection coordination is found where power is distributed at generator voltage.

Resistors, distribution transformers, instrument transformers, and protection schemes should be reviewed and checked as part of the rehabilitation process. The generator protection system should include two ground fault relay systems.

4.7 Main Transformers

Transformer rehabilitation or improvement, in conjunction with power plant rehabilitation, is somewhat limited. Transformer rehabilitation may be necessitated by increased capacity or improved reliability. Rewinding is one approach to increasing capacity, but is probably not the most economical. If the transformer has provisions for forced cooling, the addition of oil pumps and fans can be considered as a means of increasing its rating. Existing transformers

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with water cooling (OW) can be evaluated for replacement by transformers with OA, OA/FA, FOA, or other cooling schemes. If the transformer rating is increased by rewinding or additional cooling, the capability of the bushings to withstand the increase should be carefully investigated.

Rehabilitation is an opportune time to evaluate the insulating oil and reprocess it to improve its insulating quality. If the oil contains PCBs, it would be advantageous to replace the oil and decontaminate the transformer. The contaminated oil must be disposed of following applicable regulations.

Consideration should be given to containing oil leakages. In conjunction with the containment or isolation, fire protection and oil contamination of the environment should also be considered.

Rehabilitation is also an opportune time to reevaluate and improve transformer protection (see 4.9).

The review should evaluate if it is economically advantageous to replace a transformer rather than perform extensive rehabilitation. Replacement can provide increased capacity and improved efficiency.

4.8 Control and Instrumentation Equipment

Rehabilitation of a hydroelectric plant's control and instrumentation equipment can improve plant performance, increase plant availability, reduce maintenance, and reduce plant operating costs. Plant performance can be improved by controlling the turbines to make optimum use of available water. Plant availability can be enhanced through the use of comprehensive logs and accurate data for tracking and anticipating problems. Maintenance can be reduced by replacing high-maintenance instrumentation such as strip chart recorders with data logging equipment. Operating costs may be reduced by automating the controls to enable unattended operation of the plant or by centralizing controls to reduce the number of operators.

The lack of availability of replacement parts for existing systems becomes a significant factor to both operating costs and unit availability. The maintenance task becomes increasingly challenging as well. Maintaining an adequately trained technical staff as well as the parts and test equipment necessary to maintain the control and instrumentation systems within the plant can become difficult and costly. This can result in greater reliance upon purchased services from control equipment vendors and control service organizations.

The following items should be reviewed when considering the rehabilitation of plant control and instrumentation equipment:

1) The turbine/generator start-stop sequencing logic and the control systems for various plant subsystems should be reviewed. If the logic is performed with relays, it should be determined if replacing the relays with programmable controllers could enhance plant operation and reduce equipment maintenance.
2) The location and arrangement of existing controls should be reviewed to determine if improvements in plant operation could be achieved by automation, extension to a centralized location, or by the consolidation of these controls.
3) The overall plant control systems should be reviewed to determine if off-site control could reduce operating costs and improve plant performance by enabling unattended plant operation. Centralizing and automating the controls could be achieved by several methods, including a computer based control system, hard wired logic, or programmable controllers.
4) Equipment devices such as pressure, temperature, and level sensors should be reviewed to determine if replacement with newer instrumentation could provide more accurate and reliable data for plant operation and protection.
5) The plant instrumentation and recorders should be reviewed to determine if improvement in quantity or presentation format could be achieved. This improvement could reduce operator confusion and errors.
6) The annunciation system should be reviewed to determine if operators are provided with enough information to know what action to take in response to an alarm and how to correct any nuisance alarms that may exist.
7) The unit synchronizing scheme should be reviewed to determine if automatic synchronizing is desirable.
8) Instrument transformer burdens, ratios, and accuracies should be reviewed to determine if their present application is correct.

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4.9 Protection

Electrical relaying systems are designed to offer protection to personnel and equipment during unusual loading and fault conditions. The costs for these systems are often classified as “insurance premiums” because the expense is not justified until a fault occurs. At that time, damage is either eliminated or minimized by the relay operation. The extent of the relaying system, accordingly, is limited by the system designer's perception of the loss potential, the cost for the protective system, and the willingness to incur the expense of preventing or minimizing the loss.

All protective relay applications should be reviewed. Some examples are

1) Power transformers
2) Generating equipment
3) Station-service transformers
4) Station-service switchgear
5) DC systems
6) Motor circuits
7) Feeder circuits

During a hydroplant rehabilitation, it is necessary to analyze each of the protective relaying devices and systems. This is very important in older stations to determine if

1) The existing relays are maintainable and satisfactory for continued use.
2) Additional protection may be justified due to the advanced age of equipment.
3) Enhanced performance can be obtained by use of new devices.
4) Present system criteria are met.

If equipment ratings are being changed in the rehabilitation, it is particularly important to reevaluate the relay application; recalculate the settings; field test the devices; and review the instrument transformers burdens, ratios, and accuracies.

Although seldom installed in old plants, breaker failure relaying may be a desirable addition. This should be a consideration in all rehabilitated hydroplants.

Improvements in the generator excitation system, particularly if a potential source static excitation system supplied from the generator terminals is utilized, may result in need to reevaluate generator overcurrent relaying. Impedance or voltage restraint relays may be required to provide adequate overcurrent protection.

4.10 Auxiliary Power Equipment

The station service equipment usually will not require any modifications or upgrading, provided that the equipment was properly sized initially and no serious maintenance problems have been encountered. If plant unit sizes are uprated or new auxiliary equipment is installed, the overall station service requirements should be carefully reviewed. Also, loads may have been added to the point where equipment is seriously overloaded. It is suggested that short circuit, load flow, and voltage regulation studies be performed.

At the existing plant, the following station service equipment should be checked, and the plant operating methods should be reviewed for possible improvements in efficiencies and implementation of changes as required due to plant rehabilitation.

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1) Determine if the station-service transformers are properly sized for new conditions of the plant. A substantial unit uprating and other plant improvements may increase auxiliary loads and may require changes in the transformer cooling system, or even replacement of the transformer.
2) If the existing station-service transformer is a PCB type, a replacement should be considered.
3) Review station-service transformer operating methods for improved efficiency (for example, deenergization of the unit-auxiliary transformer during the unit shutdown period).
4) Verify that the station-service switchgear is in satisfactory operating condition, and, if necessary, refurbish or replace the equipment. Circuit breaker contacts, arc chutes, etc., should be inspected. Review current interrupting capability. If increased auxiliary power is required, verify that the existing equipment has the required maximum current carrying capability.
5) Verify that station service voltage levels remain within acceptable limits during all operating conditions.
6) Determine the operating power factor of the auxiliary power system. Low power factor means larger losses. If required, shunt capacitors should be considered to improve the power factor.
7) Investigate the need for adding automatic bus transfer facilities to improve auxiliary system reliability and, in some cases, to reduce losses.
8) If it does not already exist, verify the need for a plant standby diesel generator.
9) Recommend methods for improving equipment maintenance.
10) Review loading on lighting panels, load centers, motor control centers, etc., to verify that they are not overloaded.
11) Investigate replacing existing electric motors with high-efficiency motors.

4.11 Batteries, Chargers, and DC Distribution Equipment

During the plant rehabilitation process, an examination of the station dc system should be performed to assess its adequacy for continued plant operation. Among the factors to be considered are dc system loading, equipment age, and fault clearing coordination.

Over the years of plant operation, the dc system loading is likely to have changed. Increased loading could have resulted from additional equipment, such as the following:

1) Emergency lighting
2) Protective relaying and fault monitoring equipment
3) Additional switchgear
4) Additional substation breakers
5) Remote terminal units for off-site control and monitoring
6) Automatic unit control systems
7) Field flashing for static excitation systems
8) Fire detection systems
9) Security systems
10) Bearing lubrication systems

A battery sizing calculation should be performed to determine if the station battery is capable of supplying not only existing loads but also those loads that result from the rehabilitation of other plant systems. The reduction in output capability of the battery with age should be factored in. The combination of increased load and battery age may indicate that replacement is in order.

Procedures for testing station batteries and for performing the sizing calculations are available in the industry standards listed in 5.8.

Increased dc system load will also impact the battery charger. A charger sizing calculation should be performed to determine if a higher-capacity charger is needed.

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The dc distribution panelboards should be examined. Breakers should be inspected and replaced, if necessary. Additional breakers, or perhaps an additional panelboard, may be required to supply direct current to new or modified systems that result from the powerhouse rehabilitation. Finally, a fault clearing study should be performed to ensure coordination between panelboard breakers and the battery and distribution cabinet protection.

4.12 Emergency Power Equipment

Aside from the station battery, the most common source of emergency power at a powerhouse is the engine-driven generator. It is sized to supply essential loads, such as the following, for a specified number of hours.

1) Governor oil pump
2) Guide bearing oil pump
3) High-pressure bearing oil lift pump
4) Powerhouse sump pumps
5) Battery chargers
6) Emergency lighting
7) Spillway gates
8) Fire protection equipment
9) Cooling water pumps (turbine, generator, etc.)

Engine generator capacity should also be adequate to support abnormal plant operating conditions, such as black start.

If additional essential loads result from the plant rehabilitation, a study should be performed to ensure that the existing engine generator will adequately supply them. If a larger motor load is to be supplied, a voltage drop study should be performed. These studies, as well as the overall mechanical condition of the engine generator, may indicate that replacement is in order.

Enhancement of the engine generator control scheme and protective relaying may be beneficial. Automatic engine start, generator loading of essential loads, and load shedding of nonessential loads upon loss of station service may be desirable, especially if the plant is unmanned.

4.13 Uninterruptible Power Supply (UPS)

The rehabilitation of the plant's control systems may require the addition or replacement of the UPS.

A UPS furnishes frequency and voltage regulated ac power to certain plant systems during a loss of the normal power source.The UPS obtains its power from either a dedicated battery or the station battery if station ac power is lost.

The systems that are powered by a UPS tend to be those related to data collection and storage and, in some cases, control. These types of systems normally are microprocessor based and may therefore be sensitive to power interruptions. If such systems are added to the plant during a rehabilitation, the addition of a UPS system may be desired.

Guidelines for selecting a UPS may be found in IEEE Std 944-1986 [B71].

4.14 Lighting

During the plant rehabilitation, the station lighting system should be reviewed to assess the adequacy of the existing system and to study possible savings on energy consumption. The items listed below should be considered.

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4.14.1 Switching

In many older plants, the switching is performed directly from the lighting panels. As a consequence, most of the lights are left on continuously. Selective switching in the areas of use should be considered.

4.14.2 Automatic Control

In the areas in which extinguishing of lights may not create a hazard, automatic controls may be installed by use of photocells, timers, or clocks. This can provide considerable savings in energy. This is particularly true in the areas in which daylight is available.

4.14.3 Lighting Sources

A review should be made of existing lighting fixtures to assess if replacement of the lighting sources should be considered. Replacement of existing fixtures by more efficient sources may prove economically advantageous, as lighting source efficiencies vary considerably. The efficiency is measured by the amount of light (lm) obtained from the energy (W) used. The following is a list of lighting fixtures in descending order of efficiency:

1) Low-pressure sodium
2) Metal halide
3) Mercury vapor
4) Fluorescent
5) Incandescent
6) High-pressure sodium

4.14.4 Emergency Lighting

The emergency lighting system should be investigated to determine if an upgrade is required to meet accepted present standards.

4.15 Water Systems

4.15.1 General

The power plant main (raw) water supply is taken from the reservoir, usually via the penstock, or pumped from the tailrace. This main water supply is normally filtered before feeding the cooling water, fire protection, and potable water systems. Rehabilitation of these systems may be needed to match increased cooling requirements of power plant equipment, to increase reliability, and to meet applicable code requirements.

Evaluation of water systems for rehabilitation should include the following items:

1) Corrosion protection
2) Valve and fitting seals
3) Pipe vibration and expansion supports
4) Acoustic and thermal insulation and heat tracing
5) Pressure reduction and cavitation
6) Filtration or purification
7) Piping and valving arrangement for maintenance
8) Instrumentation for optimizing operation and initiating alarms

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4.15.2 Cooling Water

Cooling water is either taken directly from the main water supply or pumped from the tailrace. For economic reasons, the use of cooling water pumps should be considered for plants operating with heads exceeding 180 m. The cooling water system serves power plant equipment such as

1) Turbine components
   a) Bearing
   b) Shaft seal
   c) Runner wear seals
2) Generator components
   a) Bearing
   b) Air coolers
3) Electrical equipment
   a) Step-up transformers
   b) Exciters
   c) Isolated phase bus
4) Mechanical equipment
   a) Heating and ventilating air handling units
   b) Air compressors

Evaluation of the cooling water system for rehabilitation should include

1) Consideration of optimization of cooling water usage by temperature regulation of flow to generator air coolers.
2) Review of the filtration system to determine whether adequate or inadequate, and what improvements may be necessary. One consideration could be the use of duplex filters to permit automatic or manual backwashing without unit shutdown. Additional filtration or treatment may be required for special applications.
3) Need for additional instrumentation to monitor pressure, flow, temperature; to optimize system operation; and to alarm low-flow and high-temperature conditions.
4) Review of cooling requirements for uprated power plant equipment with increased power output.

4.15.3 Fire Protection

The fire protection water is normally taken from the power plant main water supply directly, then pressure regulated or boosted to the appropriate system operating pressure. The fire protection system is covered in 4.20.

4.15.4 Potable Water

Potable water is normally taken from the power plant main water supply, then regulated and treated before serving the plumbing fixtures. Treatment usually includes further filtration and chlorination. Automatic chlorination based on flow has not been satisfactory for low-flow applications, and consideration should be given to utilizing more recent methods such as ultraviolet treatment. Lead content resulting from sporadic demand of potable water using soldered tubing is an increasing concern, and the use of alternate pipe material should be reviewed.

4.16 Station Drainage

Over the life of a hydroelectric project, changes can occur that effect the quantity, source, and removal of station drainage water. Gallery drains, turbine pit drains, and foundation drains (particularly when the power plant structure is part of the dam) may become clogged by precipitates in the drain water and may require opening by reaming or the drilling of new drains. Rehabilitation may require the consideration of oil and water separators or the prevention of oil leakage from reaching the station sump to meet increased environmental regulation. The amount of leakage or drainage from gallery and foundation drains may also be changed from the original design quantity.

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Other sources of water to the station drainage system may be increased by leakage from wicket gate stems and turbine shaft seals.

New downstream conditions or peaking operation can result in a higher tailwater elevation. The higher tailwater elevation may effect the removal of station drainage quantities and sump pump efficiency if the tailwater elevation rises above the discharge line.

A review of the station drainage system, with the various drains collecting in a station sump and the pumping equipment, discharge lines, and check valves necessary to empty the station sump, is a necessary part of the rehabilitation project.

Pumping equipment changes that may be necessary include the following:

1) New pumps to restore efficiency or provide for additional capacity due to pumping head changes
2) New high-efficiency driving motors for energy conservation
3) New pump controls and alarms in the form of station sump level float switches, etc.
4) Rebuilding wearing parts of the pump systems and controls

The turbine and draft tube unwatering system can effect the capacity of standby or backup pumps if routed through the station sump.

4.17 Grounding System

The adequacy and proper use of the grounding system of a hydroelectric power plant is critical to the safe operation of the plant. The grounding system provides a low resistance path to ground for fault currents, thus reducing voltage rise of equipment and electrical circuits during faults. The grounding system provides a nearly equipotential reference point to connect plant equipment. This system includes the buried or embedded ground mat, risers, exposed ground cables, and connectors.

Because much of this system is inaccessible, rehabilitation of the existing system or modification to permit other plant rehabilitation may be difficult. Ideally, the system should be thoroughly inspected and tested to ensure its integrity and to verify that the grounding system resistance is not excessive for the available fault current. In reality, much of the grounding system in the plant itself may not be available for inspection because it is buried or embedded.

In places where part of the buried ground mat for the installation is reasonably accessible, such as in an associated switchyard, it may be desirable to inspect a sampling of the ground mat conductors and connectors in an attempt to verify the condition of the system. If there is a question about the effectiveness of the system, testing of the grounding system resistance is advised. Where grounding system resistance exceeds a defined maximum, it may be possible to reduce the overall ground mat resistance by connecting to accessible portions of the mat and extending the mat over a larger area, such as into the tailrace.

This may not solve the problem in situations in which individual conductors and connectors have deteriorated and, therefore, dangerously high voltages can exist on equipment during faults. Deteriorated conductor and connectors should be replaced wherever possible. In places where the grounding system has deteriorated and cannot be corrected, or where the available fault current has increased, consideration should be given to reducing ground fault current and the duration of faults to in order minimize the danger to personnel as an alternative to making major grounding system modifications. The duration of faults may be reduced by reducing the relay and circuit breaker operating times.

The original design of each installation and economic considerations will dictate what modifications are feasible. Exposed grounding system components should always be inspected and then replaced, where needed. All ground connections to existing equipment should be inspected. All new equipment should be properly grounded.

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4.18 Cables and Raceways

Cables and raceways may be effected in any rehabilitation of power plant equipment and systems, and may be candidates for extensive rehabilitation. For the purposes of this guide, the term “raceways” includes conduit, trenches, cable trays, and other electrical cable support systems.

Cable should be considered for replacement if any of the following conditions exist:

1) The cable has reached an age where it may be wise to replace the cable given that it will be in use for many years before replacement is again feasible.
2) The cable insulation or outer jackets may be deteriorated to the point where continued use would be unsafe or unreliable.
3) The cable may be constructed of flammable materials or other materials, such as lead, asbestos, varnished cloth, or rubber, that are no longer suitable for use.
4) The ampacity of the cable is not sufficient, or the voltage drop is excessive for the intended loads.
5) The cable has insufficient conductors for the needs of the modernized plant.

Any cables that have been disturbed during rehabilitation should be tested to ensure insulation integrity. If they fail the test, they should be replaced.

An inspection of the cabling system in an older plant will usually show that older cables are poorly identified; that the cables are possibly damaged; or that, over the years, additional cables of various types have been added for different purposes and the system has become confused and disorganized. Also, in light of more recent concerns about fire protection and prevention, it may become obvious that the existing cabling system presents unacceptable fire hazards.

For any of the above reasons, extensive rehabilitation may be justified. It is probable that total removal and replacement of the cables is more cost effective than selective replacement. Where cable runs through conduit, it should also be noted that removing and totally replacing the cable is probably more acceptable because it is virtually impossible to keep installation pulling tensions at an acceptable level when existing cables remain in the conduit. Furthermore, the existing cable may be damaged by the process of installing the new cable.

Raceways may have suffered abuse or misuse such as overcrowding or overloading and, therefore, should be inspected for possible rehabilitation. Their structural integrity should be verified and restored, where required. For maximum efficiency, this inspection and repair should take place when the cabling itself has been removed, as discussed above.

It may be necessary to modify or replace all or part of the raceway system. This could occur if

1) The raceway is structurally damaged beyond repair.
2) The cable trenches do not drain water properly.
3) The existing raceway system cannot support the load dictated by the needs of a more complex, rehabilitated plant.
4) The cable trays are constructed of material (e.g., plywood) that is unacceptable for reasons of fire hazard.
5) The cable trays are constructed such that good ventilation of the cables is not provided. For example, cable trays with solid bottoms do not provide the ventilation of the cables that open, ladder-type trays do.
6) Cable trays may not be properly grounded.
7) Existing cable trays will not extend to new or rehabilitated equipment.

Proper grounding is important when rehabilitating the raceways. Metal portions of the raceways should be bonded together by bonding jumpers, and proper connections to the plant grounding system should be provided. Also, some older cable trays are constructed of asbestos. The hazards associated with asbestos should be considered when rehabilitating these systems.

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With increasing emphasis on fire prevention and containment, special consideration should be given to floor and wall penetrations so that appropriate fire stops can be provided. In some cases, it may also be desirable to provide fire containment in the raceways themselves in the form of fire retardant material sprayed on the cable or even fire retardant tape and blankets on or over the cables. Fire detection near some raceways may also be desirable. Safety standards, company policy, cost, criticality of the plant, and other considerations will determine the extent of the fire detection system.

4.19 Heating, Ventilating and Air-Conditioning Systems

4.19.1 General

The heating, ventilating, and air-conditioning (HVAC) systems of a hydroelectric power plant serve a variety of enclosed spaces within the power plant. Examples of enclosed areas in the plant cover such diverse functions as generator air housings, plant offices, control rooms, inspection galleries, cable tunnels, and personnel egress areas. Each of these enclosed areas has its own unique set of HVAC requirements and use patterns. Energy usage of power plant HVAC systems can be reduced by modifying the HVAC system itself or by making changes to components of the enclosed areas such as windows, doors, roof, walls, etc. An energy audit of the power plant is suggested for identifying, quantifying, and documenting measures that will produce required HVAC system performance commensurate with reduced energy demands. Because of site specifics of individual hydroelectric power plants, only a brief discussion of power plant building components and HVAC subsystems that can be evaluated for energy savings during rehabilitation studies follows. The user is referred to appropriate ASME[4] and ASHRAE[5] guides and standards for in-depth discussion of remedial and implementation measures.

4.19.2 Building Components

A number of measures employed in recent years to reduce HVAC energy demands in commercial and industrial buildings also have applicability to powerhouse structures. Building envelope components such as double-glazed windows, building weather-stripping, walls, floor, and roof insulation, and systems to mitigate building solar gains are examples of items to evaluate during an HVAC rehabilitation.

4.19.3 HVAC Systems Improvements

HVAC systems may consume disproportionate amounts of energy, that is, have high energy “budgets,” due to a variety of reasons. Some areas for possible improvement are

1) HVAC system distribution losses (leaks and poor performance of piping, pumping, duct, and fan systems)
2) Lack of HVAC system energy management controls (set-back thermostats)
3) Low HVAC system efficiency (poor refrigeration system coefficient of performance, use of multiple conditioning systems)
4) Poor HVAC system zoning and control
5) Lack of utilization of outside air and generator waste heat sources to enhance HVAC system performance
6) Overabundance of HVAC supply air
7) Inefficient electric motors

4.20 Fire Protection

When rehabilitating fire detection and protection systems and equipment, the existing installation should be evaluated in conjunction with current applicable codes and standards.

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[4]See footnote [2].
[5]American Society of Heating, Refrigerating, and Air Conditioning Engineers, 1791 Tulle Circle NE, Atlanta, GA 30329, USA.

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4.20.1 Detection

Some of the areas and equipment that should be evaluated for detection systems are

1) General power plant areas
2) Control building
3) Office areas
4) Flammable liquid storage and piping areas
5) Cable spreading rooms and tunnels
6) Generators
7) Governor actuator cabinets
8) Transformers

Detection systems can be automated to be self-monitoring for system faults, such as short circuits, ground faults, and open circuits. They can also be configured to function under faulted conditions. The detection system can also provide automatic initiation of protection systems. The extent of automation is dependent on company policy, cost, and applicable codes and standards.

4.20.2 Protection

Protection equipment and systems can range from hand-held extinguishers to automatic CO_2 or Halon[6] injection systems. Power plant areas, the control building, and office areas are most often protected by sprinkler systems with fusible link spray heads. Flammable liquid storage areas, cable spreading rooms and tunnels, and transformers can be protected by fixed spray systems that are initiated either manually or automatically by the detection system. Generators are usually protected by automatically-initiated CO_2, Halon, or water injection systems. Governor actuator cabinets may also be protected by $C0_2$ or Halon injection systems. As with detection systems, the extent and type of protection is dependent on company policy and applicable codes and standards.

Special consideration should be given to high degrees of fire detection and protection automation for unmanned facilities, underground facilities, and facilities with limited or restricted personnel egress. These automated systems can be expanded to include automatic door closure and ventilation system reconfiguration to exhaust or contain CO_2 or Halon, exhaust smoke, limit oxygen for combustion, or enhance personnel safety.

The protective systems for fire control should be evaluated and tested. The evaluation should include

1) For pumped systems, a 100% standby pump, preferably with a nonelectric prime mover
2) For pressure regulated systems, pressure relief provisions for valve leakage and 100% standby pressure regulator
3) Drainage provisions for full flow testing of deluge valves of generator and step-up transformer sprinkler systems
4) Provision of outside hydrants near the main entrance accesses used for fire fighting
5) Provision for on-off sprinkler heads to reduce extent of water damage
6) Integration of fire suppression systems activation signals with fire detection and equipment shutdown
7) Review the need to increase fire protection water capacity given that the power plant rehabilitation will likely add new equipment and facilities
8) Enhancements for personnel safety, such as generator air housing door interlocks
9) Additional stages of $C0_2$ injection to maintain adequate CO_2 concentration level
10) Coordination of fire detection and protection with generator protection

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4.21 Compressed Air System

Compressed air systems are especially important to the plant operation if the units are utilized as synchronous condensers. Some of the compressed air systems and their applications are listed in Table 5.

Table 5—Compressed Air Systems

System	Application
Governor air	Governor hydraulic oil supply
ISO valve air	Shut-off valve hydraulic oil system
Station Air	Tools, cleaning, generator brakes, instruments
Draft tube depression air	Synchronous condenser
Circuit breaker air	Unit breaker (if air-blast type)

The electric motors used for these compressors are some of the largest in a hydroelectric plant. In recent years, highly efficient electric motors have been developed that can replace the standard motor and thereby reduce the cost of operating plant auxiliaries. This possibility of operating cost reduction with improved reliability should be reviewed when a plant is considering rehabilitation. If the controls are to be replaced for improved reliability, then refer to 4.8.

If the air quality or volume size of the compressed air system is to be improved, then all of the components should be reviewed. These components would include the air receivers, the air dryers, drains, etc. If a compressed air system is used for control (instrument air), consideration should be given to drying, oil-free compressors, and oil-air separation.

4.22 Cranes

Rehabilitation of the cranes may be desirable or even necessary for several reasons.

1) Safety concerns due to deteriorated crane conditions or modern safety and health standards
2) Inability to maintain the crane properly due to lack of spare parts
3) Changes in lift requirements, operation, or maintenance practices

Since the cranes are required for other rehabilitation work in the plant (such as generator and turbine rehabilitation), it is important to schedule the timing of the crane modifications to avoid interference with other plant rehabilitation work.

Electrical features of older cranes may require rehabilitation. General areas to consider for electrical rehabilitation include

1) Replacement of the power conductors that connect the plant station-service system to the runway conductors. This may be needed if the power Cables are deteriorated.
2) Addition or modification of power disconnecting devices to meet present day standards.
3) Replacement of mechanical load brakes with electrical load brakes.
4) Repair or replacement of motors.
5) Replacement of the control system.
6) Replacement of control and power wiring or conductor and collector systems.
7) Replacement or upgrading of the lighting system.
8) Conversion from dc to ac power.

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During the rehabilitation, consideration may given to adding special features such as radio control, pendent control, scales, devices to detect overload or end-of-travel (limit switches), electrical operation of previously nonelectric functions, or tandem operation of hooks, trolleys, or bridges.

In all cases of major crane rehabilitation, a review of safety features is important as well as the retesting of the crane when the rehabilitation is complete.

4.23 Lubrication and Insulating Oil Purification Equipment

Lubrication and insulating oil purification equipment can reach a point in its life at which repair is uneconomical and replacement is necessary. New plant equipment can have more stringent requirements for purification that are not attainable by the older equipment. The rehabilitation program presents an opportunity to review these requirements and determine if replacement of the equipment is reasonable.

4.24 Telephone or Other Communication Equipment

Older telephone, radio, power line carrier, microwave, and other communication equipment tend to consume greater amounts of power, and can be replaced with more efficient and reliable equipment. The rehabilitation program might add requirements for new paths or stations for the existing equipment. In addition, recent advancements in digital plant control and communications applications may dictate changes to communication equipment requirements. Installation of fiber optic communication links may provide a more noise tolerant media when interconnecting new digital controllers with plant computer supervisory control and data acquisition systems. If changes to existing equipment are not economical, new equipment may have to be purchased.

4.25 Plant Security

Plant rehabilitation could result in the need to enhance the plant's security system. A change to unmanned plant operation may require the addition of intrusion detection equipment with alarms at the plant operator's location. In certain instances, the addition of video surveillance equipment may be warranted. The enhancements are likely to impact other plant systems such as communications, supervisory control, and data acquisition systems.

4.26 Machine Shop

The machine shop is an area that should be considered when undertaking a program of plant rehabilitation. Auxiliary systems (such as service water, compressed air, lighting, fire protection, HVAC, and station service power) that are being rehabilitated may effect this area. Changes in these auxiliary systems could cause changes in the layout or location of the machine shop.

Some consideration could be given to the machines within the shop, though usually the larger ones rarely need replacing. New technology in the equipment within the power plant can necessitate addition of new machine shop equipment but would not necessarily replace existing equipment. For this reason expansion of the shop area might be considered. Also, new equipment for new functions could require additional machine shop equipment.

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The following listing of industry standards, recommended practices, and guides is provided as a helpful resource to the engineer engaged in hydro power plant rehabilitation. The engineer is encouraged to review those documents that apply to the desired rehabilitation areas.

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