IEEE
Std 1129-1992

IEEE Recommended Practice for Monitoring and Instrumentation of Turbine Generators

Sponsor

Electric Machinery Committee
of the
IEEE Power Engineering Society

Approved June 18, 1992

IEEE Standards Board

Abstract: A basic philosophy and guidelines are established for the design and implementation of monitoring systems for cylindrical-rotor, synchronous turbine generators. Monitoring systems are used to display the status of the generator and auxiliary systems while these systems are operating on line. The basic information needed to choose monitoring schemes best suited for each application is provided. This standard does not specify actual equipment or instrumentation, but it does indicate some critical areas where it is important to provide monitoring capability.

Keywords: cylindrical-rotor, synchronous turbine generators; turbine generators

The Institute of Electrical and Electronics Engineers, Inc.
345 East 47th Street, New York, NY 10017-2394, USA

Printed in the United States of America

ISBN 1-55937-233-8

IEEE Standards documents are developed within the Technical Committees of the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Board. Members of the committees serve voluntarily and without compensation. They are not necessarily members of the Institute. The standards developed within IEEE represent a consensus of the broad expertise on the subject within the Institute as well as those activities outside of IEEE that have expressed an interest in participating in the development of the standard.

Use of an IEEE Standard is wholly voluntary. The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE Standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard. Every IEEE Standard is subjected to review at least every five years for revision or reaffirmation. When a document is more than five years old and has not been reaffirmed, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE Standard.

Comments for revision of IEEE Standards are welcome from any interested party, regardless of membership affiliation with IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments.

Interpretations: Occasionally questions may arise regarding the meaning of portions of standards as they relate to specific applications. When the need for interpretations is brought to the attention of IEEE, the Institute will initiate action to prepare appropriate responses. Since IEEE Standards represent a consensus of all concerned interests, it is important to ensure that any interpretation has also received the concurrence of a balance of interests. For this reason IEEE and the members of its technical committees are not able to provide an instant response to interpretation requests except in those cases where the matter has previously received formal consideration.

Comments on standards and requests for interpretations should be addressed to:

Secretary, IEEE Standards Board
445 Hoes Lane
P.O. Box 1331
Piscataway, NJ 08855-1331
USA

Foreword

(This foreword is not a part of IEEE Std 1129-1992, IEEE Recommended Practice for Monitoring and Instrumentation of Turbine Generators.)

This document is intended to establish a basic philosophy and guidelines for the design and implementation of monitoring systems for large turbine generators. Monitoring systems are used to display the status of the generator and auxiliary systems while on line. This document does not include automatic protective devices or relays.

At the time this standard was completed, the Working Group on Monitoring and Instrumentation of Turbine Generators had the following membership:

Ronald J. Corkins, *Chair*

Robert F. Gray
M. Lewis
P. I. Nippes
J. V. Pospisil
H. C. Sanderson
J. Spiegl
J. Timperly
I. Trebincevic
S. D. Umans
J. J. Wilkes

The following persons were on the balloting committee that approved this standard for submission to the IEEE Standards Board:

V. Aare
J. A. Aradillas
M. Balanson
F. C. Brockhurst
G. W. Buckley
M. V. K. Chari
R. J. Corkins
P. L. Dandeno
N. A. O. Demordash
J. S. Edmonds
A. M. El-Scrafi
E. W. Fuchs
N. K. Ghai
G. L. Godwin
B. E. B. Gott
R. F. Gray
D. R. Green
T. J. Hammons
M. H. Hesse
H. H. Hwang
P. S. Johrdo
G. Karolyi
G. K. M. Khan
J. L. Kirtley, Jr.
S. B. Kuznetsov
D. Lambrecht
P. R. H. Landrieu
C. W. Lawrence
M. Lewis
T. A. Lipo
F. A. Lotte
J. A. Mallick
D. McLaren
J. R. Michalec
S. H. Minnich
T. W. Nehl
G. J. Neidhoefer
N. E. Nilsson
P. I. Nippes
D. W. Novotny
J. A. Oliver
M. Pilote
J. V. Pospisil
D. G. Ramey
S. Rao
S. J. Salon
H. C. Sanderson
M. S. Sarma
J. Spiegl
J. Stein
J. F. Szablya
J. Timperly
I. Trebincevic
S. D. Umans
P. D. Wagner
T. R. Wait
D. L. Walker
P. A. Weyant
J. C. White
E. C. Whitney
J. J. Wilkes

When the IEEE Standards Board approved this standard on June 18, 1992, it had the following membership:

Marco W. Migliaro, *Chair* **Donald C. Loughry**, *Vice Chair*
Andrew G. Salem, *Secretary*

Dennis Bodson
Paul L. Borrill
Clyde Camp
Donald C. Fleckenstein
Jay Forster*
David F. Franklin
Ramiro Garcia
Thomas L. Hannan
Donald N. Heirman
Ben C. Johnson
Walter J. Karplus
Ivor N. Knight
Joseph Koepfinger*
Irving Kolodny
D. N. "Jim" Logothetis
Lawrence V. McCall
T. Don Michael*
John L. Rankine
Wallace S. Read
Ronald H. Reimer
Gary S. Robinson
Martin V. Schneider
Terrance R. Whittemore
Donald W. Zipse

*Member Emeritus

Also included are the following nonvoting IEEE Standards Board liaisons:

Satish K. Aggarwal
James Beall
Richard B. Engelman
David E. Soffrin
Stanley Warshaw

Kristin M. Dittmann
IEEE Standards Project Editor

Contents

SECTION PAGE

IEEE Recommended Practice for Monitoring and Instrumentation of Turbine Generators

1. Scope and References

1.1 Scope. This document is intended to establish a basic philosophy and guidelines for the design and implementation of monitoring systems for cylindrical rotor, synchronous turbine generators. Monitoring systems are used to display the status of the generator and auxiliary systems while these systems are operating on line. This document does not specify actual equipment or instrumentation, but it does indicate some critical areas where it is important to provide monitoring capability.

Generator-protection techniques are not discussed in this document. There is a fine line of distinction between instrumentation that is used for monitoring and instrumentation used for protection, and there are many instruments that play a dual role.

The purpose of monitoring is to provide information to the operator to guide appropriate action. This action may be maintenance planning, maintaining load, tripping the unit, or load reduction. The key distinction between monitoring and protection is that with monitoring, the action taken (if any) is not automatic but is initiated by the operator. Some users may choose to include some of the items listed here as part of the generator-protection scheme.

Monitoring of basic generator parameters is routinely performed on commercial generators. It is only recently, however, that the economics of power generation has created the need, and advancing technology provided the ability, to monitor nearly all aspects of generator operation. This should allow the operation of large-capacity machines with increased reliability and availability and with reduced downtime for outages. However, care must be exercised to avoid “overmonitoring.” While there is no doubt that great quantities of data may be useful to review when (and if) time permits, the operator should not be subjected to an overload of unessential data. The use of diagnostic systems may facilitate handling of multitudinous data to assist the operator.

This document provides the basic information needed to choose the monitoring schemes that are best suited for each application. Not all items discussed in this document are necessary for all generators. Some users may wish to add additional monitoring systems beyond those presented in this document. The user should refer to the manufacturer’s monitoring recommendations.

1.2 References. This recommended practice shall be used in conjunction with the following publications. When the following standards are superseded by an approved revision, the revision shall apply.

[1] ANSI C50.13-1977, American National Standard Requirements for Cylindrical-Rotor Synchronous Generators[1].

[2] ANSI C50.14-1977, American National Standard Requirements for Combustion Gas Turbine Driven Cylindrical Rotor Synchronous Generators.

---

[1] ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

[3] ANSI C50.15-1989, American National Standard Requirements for Hydrogen-Cooled Combustion Gas-Turbine-Driven Cylindrical-Rotor Synchronous Generators.

[4] IEEE Std 67-1990, IEEE Guide for Operation and Maintenance of Turbine Generators (ANSI).[2]

[5] IEEE Std 421.1-1986, IEEE Standard Definitions for Excitation Systems for Synchronous Machines (ANSI).

[6] IEEE Std 492-1974 (Reaff 1986), IEEE Guide for Operation and Maintenance of Hydro Generators (ANSI).

[7] IEEE Std C37.101-1985 (Reaff 1990), IEEE Guide for Generator Ground Protection (ANSI).

[8] IEEE Std C37.102-1987 (Reaff 1990), IEEE Guide for AC Generator Protection (ANSI).

2. Definitions

monitoring. The process of observing a system to verify that its parameters are within prescribed limits.

particulate. A small particle that is created by thermal decomposition of organic materials present inside the generator.

protection. The process of observing a system, and automatically initiating an action to mitigate the consequences of an operating condition that has deviated from the established acceptable performance criteria.

pyrolysate. A product of thermal decomposition.

stator bar. A unit of winding on the stator of a machine. *Also:* bar; stator coil.

3. Stator Frame and Core

Stator frames of turbine generators have been very reliable in making minimal contributions to forced outage rates. Some early-on problems with vibration and alignment have occurred, usually in conjunction with foundation, soleplate, and grouting deficiencies. The monitoring emphasis has been very low for this component of the generator. However, concerns for internal components occasionally arise with respect to core overheating, local overheating due to short circuits between adjacent core laminations, and excessive tooth vibration.

3.1 Frame

3.1.1 Presence of Liquids or Moisture. The presence of liquid in the generator may be evidence of a cooler leak, leak of a water-cooled stator winding component, or seal oil entry. Moisture-laden hydrogen gas supply could also be a source of the water, as well as simply the

---

[2] IEEE publications are available from the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, P. O. Box 1331, Piscataway, NJ 08855-1331, USA.

operation of a unit with a low cold gas temperature, which may cause condensation. Air-cooled units that use ambient air may be susceptible to condensation under some conditions. The biggest risk may be when the unit is in cold shutdown, and warm moist air enters the stator.

Moisture entering the lubricating oil system from the turbine gland steam seals may also be released into the generator from the hydrogen seal oil system.

Accumulation of liquids can seriously jeopardize the proper operation of the generator. Leaking liquids can quickly fill the generator terminal box, causing phase or ground faults, or block the flow of cooling gas.

Generators are provided with several drain lines located at low spots in the generator frame and stator core center region. These drain lines may be fitted with liquid level detectors with alarms, and with sight glasses for visual observations. Drain lines must be arranged so that the liquid reaches the detector.

The level of the unit's gas-borne moisture content may be monitored by electronic dew-point or humidity monitors, or by periodic sampling. The dew point of the inlet and outlet gas of the gas dryer may be monitored in order to determine dryer efficiency.

3.1.2 Frame Vibration. Frame vibration may be evidence of poor rotor balance, rotor misalignment, unequal rotor heating, material loss or fracture of rotating parts, improper bearing loading or displacement, poor grouting, or uneven frame foot loading.

Frame vibration may also be the result of excessive core vibration (see 3.2.7), unequal operation of the coolers, or core vibration transferred to the frame. High frame vibrations are sometimes observed due to frame resonant responses to rotor rotational, or core ovalizing frequencies. Structural damage to frames and cores may occur.

Some manufacturers have pedestal-mounted bearings, so any rotor misalignment may not affect frame vibration.

A change in coupling between core and frame may also affect vibration.

Many stator cores are structurally isolated from the frame and foundation by heavy springs. The adequacy of frame weight distribution on the foundation greatly affects frame vibration. An indication of poor frame foot loading may be derived from seismic transducers incorporated with journal-bearing vibration monitors. A means of monitoring this acoustically is sometimes employed.

The monitoring instrument should be capable of detecting vibration at rated and double frequencies.

3.2 Core

3.2.1 General Overheating. A general increase in the core temperature beyond the normal full-load temperature can be caused by an increase in the cold gas temperature, a load output above the normal full-load point, a reduction in gas pressure, deterioration of hydrogen purity, or an increase in gas cooling water temperature. It may also be caused by a flow restriction, such as damper or cover plate, or a bypass around the gas flow circuit.

General core overheating can be measured by thermocouples (TC) embedded in the core at several locations. Monitoring of the hot gas temperature and gas pressure also provides good information about the core temperature condition.

3.2.2 Local Overheating. If the generator is being operated in the underexcited, leading power factor region of the capability curve, the resulting flux distribution may create higher losses, particularly in the stator iron at the ends of the core. The higher losses in turn create higher temperatures. The load should always be limited to points within the capability curve to ensure that the core temperature limit is not exceeded. Operation in the overexcited, lagging power-factor region is preferred in minimizing stator core end temperatures. As a backup, particularly for larger machines, the stator core temperature may be monitored. Core temperatures should not be utilized as the sole basis for machine operation.

Low local temperatures on the stator core should not be used to permit operation beyond the established limits of the generator capability curve. Core heating may vary with terminal voltage and frequency, and the boundaries of the capability curve are valid only for the voltage and frequency for which the curve is drawn.

The core temperature can be measured by a group of TCs strategically located around the stator core in anticipated hot spot regions, and especially at the core ends. Core TCs are sometimes used for initial factory tests on prototype machines, or they may be installed during manufacture of the stator core by special request. The temperature can then be displayed and recorded. If the core temperature exceeds a preset limit, an alarm may be activated.

Severe localized overheating may be detected by a particulate detector. Pyrolysate collectors, with tagging compounds, may provide a means of pinpointing the source of insulation overheating.

3.2.3 Circulating Currents. Local overheating of the core could be a result of a short circuit between adjacent core laminations allowing axial (longitudinal) flow of current between core laminations. Usually the insulation breaks down, creating an electrical short circuit due to mechanical damage. Core circulating currents are difficult to detect. Techniques for detecting hot spots in the stator core include electromagnetic sensors, particulate detectors, scanning thermographic, or physical inspection.

3.2.4 End-Tooth Heating. Core end iron can overheat when the magnetic flux enters the ends of the stator core during underexcited (leading power-factor) operation of the generator. The problem is worse when a unit is also operating at rated MW while underexcited. A particulate detector may be used to detect overheating. Core-end teeth TCs may be used if they were installed during manufacture of the generator.

3.2.5 Flux-Trap Heating. The flux trap, which acts as a flux shunt or barrier lessening the magnetic loading of the core end laminations, and structural elements of the core ends, can also overheat during underexcited operation. Flux-trap TCs can be used if installed during manufacture of the unit.

3.2.6 Core Vibration. The core vibration of the turbine generators results from the unequal magnetic pull in the air gap. The force is greater in the direct axis than in the quadrature axis. The rotating magnetic pull tends to deform the core, creating a double frequency component of core vibration. Loose cores may respond dramatically to the 120 (100) Hz driving force from the rotor. Keeping the core tight by torquing the axial and circumferential bolts (when incorporated) minimizes core vibration. A loose core can result in higher unit noise or, in extreme cases, the breakage of laminations near the bore surface. A loose core also can force vibration of the end turns and cause winding failure. The detection of a loose core may be performed by a noise analyzer test and also by periodically measuring frame vibration, particularly when the core is not spring-mounted.

4. Stator Winding

The stator winding is an important item to be monitored in gauging the health of the generator. Operating load conditions can normally be correlated to temperature, vibration, and other parameters being monitored to judge the condition of the machine. The winding may be monitored for temperature rise of the copper strands and of the cooling medium. The bar ends may be monitored for radial, axial, or tangential vibration at twice operating frequencies, and phase connection rings and terminal bushings may be instrumented for both temperature and vibration.

Correlations normally are made of identical quantities at fixed operating conditions, held constant for an adequate time period to establish steady-state conditions. However, some occurrences relate to changing conditions. In these cases, an exact record and methodical variation of conditions may be required for a proper diagnosis.

4.1 Electrical Quantities. The electrical parameters that may be monitored include voltage, current, frequency, power, reactive power, voltage balance, and negative sequence current.

4.1.1 Stator Voltage. The stator voltage may be monitored by potential transformers. Different classes of potential transformers may be employed for metering and relaying requirements. The stator voltage may be displayed and or recorded on the main control panel.

4.1.2 Stator Current. Phase current may be monitored and alarmed.

The stator current may be monitored by current transformers. Different classes of current transformers may be employed for metering and relaying requirements for each phase. They are located close to the generator winding at the terminal bushings. The analog output from the current transformers, approximately 5 A at rated generator output current, may be displayed and/or recorded on the main control panel.

4.1.3 Frequency. The frequency of the generator output voltage may be monitored from the same potential transformers that measure the generator output voltage. The frequency is usually displayed and recorded on the main control panel. A low-frequency alarm may be provided. Alarms are often set for a period of time in a certain frequency range. The restriction is based on turbine blade damage. Operation of the generator at less than rated frequency, but at rated voltage is also risky (see 4.1.6).

Prolonged or continuous operation at other than rated speed should be avoided. Operation during subsynchronous resonance that stimulates shaft torsional resonant frequencies can be detected by use of a shaft torsional vibration monitor. Operation below rated speed can lead to hydrogen seal damage or wiped bearings due to higher vibrations. Turbine blade damage may result from prolonged operation at off-rated frequency (see 4.1.6).

4.1.4 Power Output. The power output, both reactive power (megavars) and active power (megawatts), may be monitored. The voltage and current signals may be taken from the same potential and current transformers described above (see 4.1.1 and 4.1.2). This information may also be displayed and recorded in the main control room.

4.1.5 Negative Sequence Current. Negative sequence current is usually a result of unbalanced load on the generator. Induced current will flow on the rotor surface, on the pole face region, and in the coil slot wedges and teeth, causing overheating of the rotor body. This may produce rotor vibration and damage if the condition is not cleared.

The negative sequence current is normally monitored to limit possible damage to the machine due to unbalanced line currents. Whenever a generator is connected to an unbalanced fault, or even an unbalanced load, a negative sequence current creates a flux field in the generator that rotates in the opposite direction from the main flux field. This causes the rotor iron and slot wedges to heat at gaps and at high resistance points due to induced double frequency current.

Negative sequence current may be displayed in the control room. Typically, an alarm may be activated from negative sequence current. For specific acceptable values, refer to ANSI C50.13-1977 [1][3] or latest revision thereof. In some units, the mechanical torsional response (particularly on turbine blades) imposes a greater restriction than to the electrical capability. This should be checked with the manufacturer.

4.1.6 Volts per Hertz. Magnetic saturation and resulting overheating of the stator core may be possible if an increase occurs in the volts-per-hertz ratio due to overvoltage or under-

---

[3] The numbers in brackets correspond to those of the references in 1.2.

frequency operation. Limiters and relays are available to minimize exposure to this condition. This monitoring may be particularly important when the machine is off line.

4.2 Stator Winding Condition

4.2.1 Stator Winding Temperature. Damage caused by overheating of the copper conductors in the stator winding can be extensive. For example, the magnetic forces on the strands in a coil are such that if there is deterioration in the bonds between any two or more strands such that a strand can vibrate with the magnetic forces, then rapid mechanical wear and fatigue occurs. Thus it is important to maintain the proper temperatures to maintain the bond strength. Overheating of the copper may be the result of one of the following:

(1) Higher than normal current densities due to overload
(2) Current redistribution due to broken strands in the conductor
(3) Loss of cooling

The overcurrent could be caused by a number of different problems. If abnormally high conductor temperature is allowed to persist, the winding insulation may be damaged. It is important to note that these currents may not cause an alarm or trip, but they could still cause damage to the windings.

The temperature of the stator winding is normally monitored by resistance temperature detectors (RTDs). The RTDs are located in the slots in the stator, between the top and bottom bars. They are distributed circumferentially, often with one RTD in each slot. Sometimes only six RTDs are installed, distributed uniformly around the circumference, in the separate winding groups. RTDs are typically located in an area of expected higher temperatures.

All stator-winding RTDs may be constantly monitored. Should the temperature increase beyond the normal maximum an alarm may be activated, and an immediate investigation to determine the cause is necessary. This may result in the need to reduce generator load.

A word of caution is in order, since large turbine generators are “conductor-cooled.” This means that a cooling medium (oil, water, or hydrogen) is passed through the interior of the stator winding bar, not over the exterior. Therefore the heat flow is inward from the conductor to the coolant. An RTD embedded on the outside of the insulation, while useful, cannot give the complete picture, and it may be necessary to monitor the coolant temperature as well. RTDs do not sense hot-spot temperatures. This is especially true for directly cooled machines. The main function of RTDs is to detect high stator bar temperatures due to overload conditions, or loss of cooling capability caused by flow restriction or gas-pressure drop.

4.2.2 Temperature Differential—Hottest to Coldest Bar. Bar-coolant temperature differential on conductor-cooled machines may be indicative of problems, and should be minimized among both top bars and bottom bars, and between top and bottom bars. Refer to the manufacturer’s instruction book for guidelines on bar-coolant temperature differential that should not be exceeded. On most hydrogen- and air-cooled generators, only bar group temperatures and embedded temperature detectors are used.

As a general rule with water-cooled machines, stator-slot temperature are not more than 10 °C above the average of all slot temperatures. Water discharge TCs are usually within ± 5 °C for each group; i.e., bottom bars, top bars, and bars that include phase ring or lead connections. Refer to the manufacturer’s recommendations for actual guidelines.

4.2.3 Electrical Discharges. Internal corona discharges can occur at voids around strands or voids within the insulation.

External discharge activity in the form of corona, partial discharges, or slot discharges are sometimes present. These can be damaging to the voltage gradient systems used to equalize voltage stress on each stator bar. If not corrected, insulation damage may result. Radio frequency (RF) monitoring may warn of an increase in discharge activity. Typical sensors include air-core current transformers on the neutral or capacitance probes on the windings.

4.3 Bar End Section

4.3.1 Hydrogen Leakage into the Coolant. On water-cooled units, leaks at the joints, i.e., nipples, hoses, water box, and manifold can permit the entry of hydrogen into the stator-cooling water and increase the hydrogen content that must be vented from the water tank. Hydrogen may enter the coolant circuit through cracked strands that conduct the coolant through the bars. The fatigue strand cracking, or cavitation damage, can occur due to excessive bar vibrations, either in the slot or in the end winding. Excessive hydrogen leakage into the stator-cooling water system can partially or fully block bar water flow, and can adversely affect water conductivity. Hydrogen in-leakage can be detected using either a gas flowmeter or by measuring differential pressure on the stator bar water tank to measure the volume of hydrogen vented from the tank (see 8.1.7). Hydrogen pressure is normally kept above stator-cooling water pressure.

Leaks at the gas tubes diverting gas to RTD on gas-cooled machines can result in artificially low gas temperature readings; otherwise, leaks in the gas-conductor-cooled machines are not normally a problem.

4.3.2 Coolant Overtemperature—General. General increases in the bar outlet gas temperature or water temperature indicate an abnormal condition such as a high load condition, increasing cold gas or cold water temperature, or a loss of cooling capability due to interrupted, or restricted flow, or drop in gas pressure.

It is customary to monitor bar gas temperature by using RTDs reading bar discharge temperature. RTDs reading the inlet hot gas temperature before the coolers may be monitored.

For water-cooled bars, the discharge water TCs mounted on the water hose connections to the outlet water manifold and the TCs on the inlet water manifold may be monitored.

4.3.3 Coolant Overtemperature—Local. A local indication of coolant over temperature from a TC mounted at the nipple on the outlet manifold, or RTD at the end of the hose from the coil, measuring the discharge coolant temperature, could be a result of an overheated bar due to cracking of strands or shorting due to insulation breakdown or due to coolant flow blockage in the bar.

4.3.4 Overtemperature—General. High temperatures should always have the cause identified. Some possibilities include a high load condition, reduced coolant flow, or excessive coolant temperature.

4.3.5 Overtemperature—Local. While it may be virtually impossible to monitor all local conditions, they can be reasonably monitored by temperature sensors and a particulate (burnt insulation) detection instrument.

4.3.6 Plugged Bars (Coils) or Strands. One plugged cooling passage in a strand may have a minimal effect on the bar performance and on its discharge temperature. A partly plugged bar, possibly due to corrosion from incorrect water chemistry, could result in a partial loss of coolant flow, which may result in a large rise in the local discharge temperature reading of a water-cooled unit. Total blockage of a water-cooled bar could result in a normal (or lower) temperature reading at the discharge end. This is because the TC would be reading the outlet manifold bulk water temperature, since there would be no water from the bar itself.

A foreign object or substance in the gas tubes of a gas-cooled unit could result in a high or low RTD reading, depending on the degree of blockage. This is because gas-cooled units have RTDs that normally measure discharge gas diverted from the tube ends of the winding.

4.3.7 Strand Fracture. Strand fracture can be a problem due to hydrogen embrittlement or looseness of the bar structure, often resulting in resonance or excessive vibration. Extreme load swings or load cycling may compound the problem, increasing the rate of failure and decreasing the time to failure. Strand fracture for gas-cooled bars can be monitored indirectly by using hot and cold coolant discharge temperature sensors. An algorithm may be employed to correlate these readings with RF monitor data and particulate detection data.

4.3.8 Vibration. Vibration of end windings has become a gauge of stator winding health. If high winding vibration is allowed to persist, the insulation system may be damaged by abrasion. By charting the magnitude and responsiveness of vibration to load excursions, the prediction of imminent problems is made evident. End-turn vibration can be monitored using fiber-optic vibration sensors or accelerometers, or by periodic visual inspections.

4.4 Phase Connections

4.4.1 Coolant Leakage. Coolant leakage from the phase connections (parallel rings) could result in inadequate cooling of the ring assembly. This is usually determined from TC (or RTD) readings on the rings measuring coolant temperature on the ring, by liquid level detectors, or by gas flow into the stator-cooling water system.

4.4.2 Coolant Low Flow. Low flow of gas or water in the phase connections could result in a general elevation in the temperatures on the phase-connection temperature detectors for a given coolant inlet temperature. Where a separate coolant path is used, a low flow sensor may be used.

4.4.3 Coolant Passage Blockage. A blockage would prevent the coolant from reaching the rings, quickly overheating them if operating at or near full-load conditions. This can be monitored by temperature sensors and a particulate (burnt insulation) detection instrument.

4.5 Terminal Bushings

4.5.1 Coolant Overtemperature (Water). Loss of cooling water to the terminal bushings on machines with water-cooled bushings may cause overheating of the bushings. Generator bushing cooling water discharge temperatures may be monitored using TCs. Where a separate coolant path is used, a low flow sensor may be used.

4.5.2 Coolant Overtemperature (Gas). Loss of cooling gas to the terminal bushings on machines with gas-cooled bushings may cause overheating of the bushings. Accumulation of liquids (water, seal oil, etc.) may flood the ventilation passages in the bushings. This may be monitored using temperature sensors. Where a separate coolant path is used, a low flow sensor may be used.

4.5.3 CT Temperatures. Current transformers and their cases can overheat but are usually not monitored for temperature. Thermovision or infrared scanners can be used to determine case temperatures.

4.6 Flexible Leads. Breakage of the flexible leads used to isolate vibration and thermal expansion may be detected by visual inspection, particulate (burnt insulation) detector, or by RF monitors.

5. Rotor

The rotor usually has minimal instrumentation due to the rugged environment that the sensor would have to endure to maintain acceptable integrity and also due to the difficulty in obtaining data because of the rotation of the shaft. Rotor shaft unbalance, loose rotor parts, and loose retaining rings may show up as increased rotor vibration, amplitude, or orbit changes. Degraded blower blade performance may be detected as loss of acceptable differential fan pressure. Parameters that may be monitored include vibration, field current, field voltage, and vibration for both the exciter and main fields.

5.1 Shaft and Forging

5.1.1 Torsional Vibration. Torsional vibration of the rotor shaft results in loss of life related to the severity and duration of each incident incurred that is cumulative in nature over the life of the unit (unless repaired). This is not usually monitored, but may be minimized through torsional modeling with appropriate changes in construction, or equipment modifications in the case of existing units. Several types of torsional monitors, to evaluate and display transient events, are available.

Shaft torsional vibration may be most severe during electrical faults. It may also be caused by any rapid shift in the transmission network power flow that, simply stated, creates a twisting effect on the turbine generator shaft. The twisting will oscillate back and forth for a time, and should eventually decay to zero. The torsional effects can be amplified by unsuccessful reclosure and are affected by power system stabilizers where fitted.

5.1.2 Shaft Voltage. The presence of voltage on the shaft relative to ground can lead to problems. See 7.2.4 for more details.

6. Rotor Winding

The rotor winding parameters may be monitored indirectly through the measurement of field voltage and current. Brushless exciters lack slip rings, and the rotor winding may be indirectly monitored through measurement of the exciter parameters. Estimates of generator field rotor quantities may be made using generator “V” curves and exciter constant resistance load saturation curves, permanent magnet generator (PMG) voltages, and exciter field voltage and current.

6.1 Electrical

6.1.1 Excitation Current (Brushless). Main generator excitation current (field current) may be monitored indirectly by supervising the main generator exciter field current, and applying the proper correction curve to detect any degradation in the generator rotor winding. For instance, generator rotor shorted turns usually causes higher excitation current requirements for a given load output. Sometimes instrument slip rings may be used with a brushless excitation system to give a positive method of monitoring excitation volts and rotor winding integrity.

6.1.2 Excitation Voltage and Current (Slip Rings). Field voltage and current may be monitored at the slip rings, displayed, and/or recorded on the generator control panel. These quantities may be used directly to detect increased generator excitation current, thus shorted turns.

6.1.3 Rotor Winding Ground Fault. Rotor ground faults may be detected by a device that continuously or periodically determines the insulation resistance of the rotor winding to ground. The danger inherent in a ground is the possibility of developing a second ground. This could create a magnetic unbalance, and could result in large ground loop currents that could damage the rotor winding and forging extensively. Depending on the insulation resistance, an alarm may be initiated. Although it may be possible to detect the second ground, usually the damage has already been done.

6.1.4 Rotor Winding Shorted Turns. Problems created by interturn short circuits are rarely catastrophic in nature. The rotor may exhibit symptoms of thermal imbalance resulting in vibration due to the uneven thermal expansion caused by the uneven distribution of losses in the field circuit. Generator capacity could be affected if there were a large number of shorted turns requiring a significant increase in the excitation current at a particular load point to compensate. A change in the rotor heating pattern could also develop shaft bowing and high vibration. A more serious problem occurs if the interturn short develops into a ground fault. Shorted turns are caused by failure or bridging of the insulation between turns of the rotor winding. They may be caused or aggravated by centrifugal forces at full speed.

Since the current-carrying rotor conductors are rotating, they create a rotating magnetic flux wave in the machine air gap. The flux density in the machine air gap is proportional to the magnitude of the current and to the actual number of conductor turns in each slot in the rotor. Therefore, measurement of the air-gap flux density using a transducer such as a Hall effect probe, or search coil, may indicate possible shorted turns.

6.1.5 Rotor Resistance. Rotor resistance is a function of field winding temperature. The thermal time constant creates a delay in the change of resistance. This is evident in non-base-loaded generators, particularly during transient conditions.

6.2 Mechanical

6.2.1 Overheating. Rotor overheating may, in some cases, be detected indirectly by an increase in the warm gas temperature.

The average temperature can be calculated from the winding resistance obtained from field current and voltage, after appropriate compensation for the voltage drop of the brushes and slip rings if applicable. The temperature may be displayed and recorded. A high temperature alarm may be provided.

Depending on the type of rotor cooling, winding hot-spot temperatures can exceed average temperatures by a factor of 1.1–1.5. Alarm points may be set to recognize this as well as the rotor insulation class.

6.2.2 Vibration. Shaft vibration may be a symptom of many different mechanical problems. Rotor imbalance, misalignment, cracks, hydrogen seal rubs, oil whirl, defective bearings, uneven rotor heating, and damaged fans and mechanical stimulation through the turbine are only some of the causes of changes in shaft vibration. Whatever the cause, vibration is the symptom of a problem that should be corrected before further damage occurs. Bearing vibration on the exciter and turbine ends of the generator may be monitored to detect abnormalities in the magnitude, phase, and frequency of the vibration at variable load conditions. A frequency analysis may be required for detailed analysis of the vibration pattern. Seismic and proximity vibration sensors, usually two sets 90 degrees apart at each bearing, are used for monitoring.

The amplitude of the vibration may be monitored by either a shaft riding accelerometer, bearing housing mounted accelerometer, proximity detector, or by velocity detecting sensors.

There are two approaches to vibration monitoring. The first is to simply measure the amplitude of the vibration and to take action when the amplitude reaches some preset maximum. The second approach is to analyze the frequency spectrum of the vibration. The coast-down vibration signature provides very useful information since as the machine runs down it passes through a wide range of mechanical excitation frequencies.

7. Miscellaneous Components

The monitoring of fans, bearings, seals, etc., has not been given high priority in the past. However, the machine availability can be increased if early warning is provided by signals on the fan differential pressure, bearing temperature and vibration, seal leakage, etc.

7.1 Fans

7.1.1 Gas-Differential Pressure. The differential pressure developed across the fan (blower) indicates whether hydrogen purity has changed, an abnormality exists in the ventilation circuit (lost seals, baffle failure, or obstructions), fan blades have been lost, or adequate pressure is being maintained across the fan. Using a reference purity fan to cancel or subtract out purity/temperature changes aids in interpreting the data.

7.2 Bearings

7.2.1 Lubricating Oil Leak. Loss of lubricating oil can cause severe damage to the bearings and journals. One way to monitor oil leaks may be with liquid level detectors (see 3.1.1), and by thorough inspection of the lubrication oil system.

7.2.2 Temperature. An increase in bearing temperature could be caused by one of several factors, such as a reduction or loss of lubricating oil, pitting of the babbitt due to shaft currents, or deterioration of the babbitt material. If any of these conditions continues, the bearing may fail, causing extensive damage.

Each bearing temperature may be measured by TCs or RTDs. One or two sensors are typically located in the bearing lower half, very close to (but not in) the babbitt material. If the bearing is insulated, the sensor must also be insulated from the bearing to prevent shorting the insulation.

The temperature of the generator bearings may be monitored and recorded constantly. If the temperature rises above normal, the cause should be determined and corrected. Excessive bearing temperatures may initiate an alarm. An elevated bearing metal temperature at the bearing indicates a problem with a potential rub condition if the bearing vibration is also higher than normal.

7.2.3 Vibration. Vibration is normally monitored. An alarm may be initiated if limit values are exceeded (see 6.2.2).

7.2.4 Shaft Currents. Shaft currents are a result of the shaft voltage being discharged through the bearings, seals, gears, etc., possibly damaging them. Several conditions within a generator can result in a potential between the rotor shaft and ground. Shaft voltages above 50 V peak to peak can occur from the electrostatic charges developed on low-pressure turbine blades. Generator stator magnetic asymmetries, residual magnetization of the rotor or frame, and high-frequency transients developed from thyristor excitation controls may also cause shaft voltages that can damage bearings.

Bearing current erodes the bearing babbitt, resulting in a dull surface (frosting), and spark tracks or both, higher bearing temperatures, and ultimately bearing failure.

This usually does not happen to a generator main bearing but can occur on one of the high-pressure turbine bearings, the governor mechanism, seals, or other surfaces that operate with a thinner oil film that can break down if sufficient voltage is present. Grounding of the shaft between the turbine and generator through brushes, copper braids, or an active shaft grounding system can be used to neutralize these currents and prevent conditions such as pitted bearings.

Symmetrical electrical filters between the exciter and slip rings are sometimes employed for static excitation systems to reduce shaft voltage created by the solid-state rectifier excitation system.

Continuous shaft voltage monitoring with a dedicated monitor, or frequent measurement with an oscilloscope, may be desirable to verify proper operation of the shaft grounding system.

7.2.5 Lubricating Oil Flow. The bearings must have a continuous flow of oil for lubrication and cooling. A flowmeter can be installed on the main supply, or on each bearing supply line to monitor the flow of lubricating oil. A low-flow alarm may be provided.

7.2.6 Lubricating Oil Pressure. An alternate to monitoring the oil flow to each bearing would be to monitor the oil supply pressure for each generator bearing. A low-pressure alarm may be provided.

7.2.7 Lubricating Oil Temperature. The temperature of the lubricating oil exiting the bearings gives an indication of the condition of the bearing. This temperature is typically monitored and recorded for each bearing, with a high-temperature alarm.

7.3 Hydrogen Seals

7.3.1 Shaft Seal Oil Leak. There is a minimum required flow of seal oil past the seal oil rings. An overpressure of the seal oil relative to the gas pressure, excessive seal ring clearance, or excessive seal oil temperature can cause excessive flow past the seal oil rings. Excessive flow past the seal oil rings on the generator shaft permits oil to enter the generator frame and may deposit oil on the windings or other live parts, creating a potential for surface-tracking discharge (also increases the potential for additional stator-winding vibration). This condition can be detected by the liquid-level detectors.

7.3.2 Seal Oil Flow. Very low oil flow to the seal rings can result in loss of sealing, thus allowing gas to escape from the generator. Excessively high oil flow can result in oil entering the machine—possibly as a result of excess clearance in the seal gap. Both low and high flow conditions can be detected by monitoring the seal oil pressure, and alarming when it deviates from an acceptable range.

7.3.3 Seal Oil Pressure. Low oil pressure can result in overheating, increased vibration, and/or possible rub condition. Hydrogen may escape past the oil barrier if the pressure is too low.

NOTE: Required seal oil pressure changes with hydrogen pressure.

The seal oil pressure at each bearing is typically monitored, with an alarm if the pressure is too low (see 7.3.2). If the machine is equipped with a differential pressure regulator to maintain the oil to gas-differential pressure, the differential pressure at the regulator may be monitored.

7.3.4 Seal Metal Temperature. By monitoring the temperature of the metal components of the hydrogen seals, it may be possible to detect seal rubs or misalignment.

7.3.5 Seal Oil Temperature. Oil temperature should be maintained between the normal operating limits as defined by the manufacturer. Unbalanced temperature can result in increased vibration levels. Excessively high oil temperatures can result in increased oil flow and can cause some oil to enter the generator. Excessively low oil temperatures can cause reduced oil flow, a loss of clearance, and a possible rub with the rotor. The seal oil temperature at each hydrogen seal may be monitored with an alarm if the temperature deviates beyond acceptable limits.

7.4 Permanent Magnet Generator (PMG)

7.4.1 PMG Voltage. Permanent magnet generator voltage may be monitored for voltage variation as one possible indication that a magnet in the PMG may have become demagnetized.

7.5 Collector Rings

7.5.1 Air In/Out Temperature. Collector ring temperatures cannot be monitored directly; however, the difference in cooling medium temperature flowing through the rings and brush rigging, and the actual discharge temperature, may be monitored. Typical limits are: maximum discharge temperature = 65 °C, maximum temperature rise = 25 °C.

7.5.2 Plugged Air Filters (where applicable). Monitor the pressure drop across the filters to detect pluggage.

7.5.3 Hydrogen Leaks. A device to measure the presence of hydrogen in the air may be located in the vicinity of the slip rings. This detects hydrogen escaping from the radial pins connecting the upshaft lead to the slip rings.

7.6 Hydrogen Cooler

7.6.1 Hydrogen Cooler Leaks. If the hydrogen cooler leaks water from the cooler's own cooling circuit, then moisture may be added to the gas, or standing water may collect under the cooler frame. Liquid level detectors under the generator are useful for monitoring this problem. In machines which operate under higher hydrogen pressure (60 or 75 psig), the hydrogen gas may enter into the cooling circuit (depending on cooling water pressure), resulting in higher gas consumption.

A cooler gas-baffling leak, where hydrogen is bypassing the cooling circuit inside the hydrogen cooler, results in the warm gas being insufficiently cooled before being returned to the generator, causing reduced cooling system efficiency. This results in a warmer exchange gas for the generator to transfer its losses.

7.6.2 Air-Bound Coolers. Should the cooler vents become inoperative, air may collect in the cooler, impeding its performance. The cooler vent lines may be monitored to ensure that there is a continuous flow of water. The water and hydrogen TCs or RTDs may also identify this problem.

CAUTION

If cooler leaks do occur, hydrogen can accumulate in the cooler vent lines.

8. Auxiliary External Systems

The external systems should be given special attention. These systems are critical to proper operation of the generator and may be monitored to prevent misoperation and ensure optimal performance.

8.1 Hydrogen System. Hydrogen gas is circulated under pressure through some machines for cooling of the rotor and stator. Continuous monitoring of the hydrogen can yield much useful information. Those parameters that may be monitored include hydrogen dryness, purity, pressure, temperature, consumption, loss, and presence of particulates.

8.1.1 Generator Humidity. A dryer may be used to maintain the required gas dew point by removing moisture from the gas when the generator is both on and off line. Prolonged operation with high dew point can result in electrical tracking. It can also lead to stress corrosion cracking of various components, such as the rotor retaining rings in the generator.

If the temperature of the various metal or insulated parts inside the machine falls below the dew point of the gas, there may be a possibility of forming a film of surface moisture due to condensation.

Gas-coolant humidity may be monitored continuously by a dew-point indicator and maintained at a value much lower than the expected cooling water temperature. A gas-coolant dew point of below 0 °C is typically acceptable. An alarm may be provided if the dew point rises above the set point.

To minimize condensation, some manufacturers recommend that the generator metal and insulated surfaces should be maintained at a higher temperature than the coolant gas. On these machines, therefore, the stator-cooling water is typically maintained at least 5 °C warmer than the cold coolant gas. If this temperature difference falls below 3 °C, an alarm may be activated. Refer to the manufacturer for actual temperature differential limits (if applicable).

8.1.2 Hydrogen Purity. A gas analyzer may be provided to monitor the concentration of hydrogen gas in the generator. Hydrogen from the generator may be continuously passed through the analyzer. The output from the analyzer may be displayed as hydrogen purity in the control room. If the purity (concentration) should fall below the manufacturer's recommendation, an alarm may be activated; the operator should investigate and initiate corrective action.

The purity of the hydrogen gas is normally maintained above 92% purity. For effective thermal performance, a purity above 98% is typically preferred. Low hydrogen purity results in increased windage losses and lower efficiency, and may also raise the stresses on the ventilation system (blower).

Pure hydrogen will not support combustion. However, when mixed with air, hydrogen is explosive. At atmospheric pressure, hydrogen concentrations from 4% to 74% are dangerous. For this reason the concentration of hydrogen in the generator must be maintained at a high level.

Additional monitoring for safety purposes may be required during purging operations.

8.1.3 Hydrogen Pressure. The heat removal capability of hydrogen is determined by its pressure inside the generator. The capability curve limits are related to the hydrogen pressure of the generator. At full load, the hydrogen pressure should be maintained at rated design pressure. At reduced load, the generator is more efficient if the pressure is just slightly higher than needed as determined by the capability curves.

Pressure regulators are used to reduce the supply pressure of the hydrogen gas to the required operating pressure of the generator. Proper generator cooling depends on maintaining proper hydrogen pressure. If adequate pressure cannot be maintained, the load capability of the generator will be affected.

The hydrogen pressure inside the generator may be monitored and displayed in the control room. In addition, a low-pressure alarm may be provided and set below the normal operating pressure. The existence of a low-pressure alarm indicates that a hydrogen leak exists.

A differential-pressure indicator and alarm may also be provided to monitor the pressure across the rotor fan blades (blowers). This would provide an indication of restricted flow, changes in purity, or changes in moisture. This can also be monitored periodically.

A third point to monitor is the pressure difference between the hydrogen and the stator-cooling water system (if applicable). The hydrogen pressure is normally higher than the stator-cooling water pressure to prevent ingress of water into the stator in the event of a leak in the stator-cooling water system.

8.1.4 Temperature—Cold Gas. Cold gas temperature may be monitored and maintained between upper and lower design limits. In general, the temperature of the cold gas supplied by each gas cooler is typically balanced to within 2 °C in general with only short excursions to an unbalance of up to 5 °C. Normal recommended cold gas temperature can be obtained from the manufacturer's instruction book.

The cold gas temperature may be measured by RTDs or TCs located in the gas flow path at the discharge of the gas coolers. Usually a sensor is provided for each cooler. A temperature indication and high alarm may be provided.

8.1.5 Temperature—Hot Gas. The temperature of the hot gas returning to the coolers reflects the heat absorbed by the gas. The gas temperature rise may be monitored and is typically maintained at less than maximum recommended by the manufacturer. Excessive temperature rise can indicate abnormalities such as low purity, or pressure in case of hydrogen-cooled machines.

The gas temperature may be measured by RTDs or TCs located in the gas flow path at the inlet to the gas coolers. Usually a sensor is provided for each cooler. A temperature indication and high alarm may be provided.

For those machines that have direct hydrogen-cooled windings, the temperature of the hydrogen leaving selected coils may be measured by individual RTDs or TCs.

8.1.6 Hydrogen Consumption. Hydrogen consumption may be monitored to ensure that the consumption rate is not increasing, and that hydrogen leakage rates are at acceptable levels. Excessive levels of leakage are both dangerous and expensive. Purge and fill (vent and add) operations may be closely watched and recorded. A gas-totalizing flow meter on the inlet (makeup) line may provide indication of the total machine hydrogen consumption.

8.1.7 Hydrogen Loss to Stator-Cooling Water. Hydrogen gas leakage into the stator water system through the stator bar hollow strands or water hoses at the water manifold can lead to blockage of the cooling path, becoming hydrogen bound due to a gas bubble. This may result in overheating of the bars. For water-cooled stators, a gas flow measurement system may be installed on the vent line of the stator water tank to monitor excessive gas leakage.

8.1.8 Hydrogen Loss to Hydrogen Coolers. A hydrogen cooler leak may also result in hydrogen entering the cooler water system. This condition, while difficult to monitor, may eventually be detected by high hydrogen consumption.

8.1.9 Hydrogen Loss to Oil. Hydrogen gas leakage into the seal oil system is possible where hydrogen and oil come into contact. For systems with dual flow, i.e., separated air and hydrogen side supply, the hydrogen side can be considered a closed loop and no appreciable hydrogen losses are incurred. For single-flow systems, which typically have a vacuum chamber and pump, constant hydrogen losses occur. They are included in total consumption.

8.1.10 Particulates. An indication of general or local overheating may be provided by a gas particulate detector commonly called condition monitor or core monitor. This device monitors a continuous sample of generator hydrogen. If any overheating of the generator internal components occurs (stator winding, laminations, etc.), small particles of organic material are released into the gas stream due to thermal decomposition. The gas-particulate detector may sense these particulates and may provide an alarm at a preset level.

In addition, a pyrolysate collector can be incorporated as part of the gas-particulate detector. The collector will automatically collect a sample of the gas whenever a gas-particulate detector alarm is activated. The sample can then be analyzed to determine the actual source of the particulates.

8.2 Seal Oil System. The seal oil system is designed to prevent leakage of hydrogen from the generator to the atmosphere. With some machines, the system is split into two parts—the air side and the hydrogen side. The air-side seal oil is pumped to the shaft seals through coolers and filters. It then flows through the seals via annular gaps between the shaft and the seal rings. Finally, it drains to the air-side seal oil storage tank for recirculation.

The hydrogen-side seal oil system is a single-flow system and is similar to the air side except that the oil flows into a separate seal oil tank where the entrained hydrogen escapes from the oil. The hydrogen-side seal oil supply pressure is maintained higher than the hydrogen gas pressure, and slightly lower or equal to the air-side seal oil supply, if so equipped.

8.2.1 Differential Pressure—Filters. The seal oil filter differential pressure may be monitored to ensure proper operation of the filter. A high differential pressure may be a result of a clogged filter or excessively high oil flow. A low differential pressure can be an indication of low oil flow.

The differential pressure across the seal oil system filter may be monitored (or periodically checked) with a differential-pressure indication and a high-pressure alarm.

8.2.2 Differential Pressure—Gas to Oil. The differential pressure between the hydrogen gas and the supply oil must be maintained at a safe margin (approximately 10 psig) to prevent the hydrogen from escaping from the generator at the seal rings. Oil pressure must always be higher than hydrogen pressure when there is hydrogen in the generator.

The differential pressure between the seal oil and the hydrogen gas may be monitored with a differential-pressure indication and a low-pressure alarm.

8.2.3 Differential Pressure—Air Side to Gas Side. The differential pressure of the seal oil between the air-side seal oil system and the hydrogen-gas-side seal oil system may be monitored with a differential-pressure indication and a high-pressure alarm.

8.2.4 Air-Side Seal Oil Pressure. The pressure of the seal oil on the air side of the system may be monitored, if applicable, with a low-pressure alarm.

8.2.5 Hydrogen-Side Seal Oil Pressure. The pressure of the seal oil on the hydrogen side of the system may be monitored with a low-pressure alarm.

8.2.6 Seal Oil Pump Discharge Pressure. The discharge pressure of the seal oil pump may be monitored with a low-pressure alarm.

8.2.7 Seal Oil Tank Level. Vacuum detrain tanks with high oil levels could back up into the defoaming tanks and eventually into the generator. Low oil levels indicate an oil leak from the system.

The level of oil in the seal oil tanks may be monitored with high- and low-level alarms.

8.2.8 Seal Oil System Temperature. Measure the temperature in the seal oil system at the following points: seal oil leaving the coolers (high temperature alarm); cooling water leaving the coolers; and cooling water inlet to the cooler.

8.2.9 Seal Oil System Flow. Measure the seal oil flow to each seal (if possible) on both the air side and the hydrogen side of the seal oil system.

8.3 Stator-Cooling Water System. Direct cooling of conductors using deionized water may be the most effective way to achieve high generator capacity. The cooling water is passed through hollow conductors or tubing inside the winding. To achieve reliable operation, continuous monitoring and periodic sampling may be provided to determine the water conductivity, temperature, pressure, and content of oxygen, hydrogen, copper, and pH value. Overheating can cause thermal degradation of the insulation, physical damage to the insulation due to relative movement, and boiling of the water, producing gas pockets and impaired water flow.

8.3.1 Conductivity. The demineralized water may be monitored for acceptable conductivity. High conductivity may be dangerous in the stator bar environment of the water system. Demineralizer beds should be functional and effective during system operation. High conductivity can result in electrical tracking to ground. Typical conductivity levels are between 0.1 µΩ/in and 1.0 µΩ/in. An alarm may be initiated whenever the conductivity is outside acceptable limits as established by the manufacturer.

8.3.2 Differential Pressure—Inlet to Outlet. The differential pressure across the stator winding from inlet water manifold to outlet water manifold may be monitored to ensure adequate cooling water flow, and to maintain the effectiveness of the cooling system. Increased differential pressure at a given flow may be an indication of increased flow resistance due to fouling or plugging.

8.3.3 Inlet Temperature. Inlet stator cooling water temperature may be monitored for stable operation at acceptable levels as described in the manufacturer's instruction book. An alarm may be provided at the maximum permitted temperature, such as 50 °C. Refer to ANSI C50.13-1977 [1].

8.3.4 Outlet Temperature. Outlet stator cooling water temperature may be monitored for stable operation at acceptable levels as described in the manufacturer's instruction book. This may include an alarm at a temperature above that expected with normal operation, such as above 75 °C.

8.3.5 Oxygen Content. The dissolved oxygen content of the water in closed systems is normally controlled to prevent corrosion of hollow copper strands, which could block off the cooling passage through the bars. Normal level is typically less than 50 ppb (parts per billion) for hydrogen-saturated systems. There is essentially no limit for open ventilated systems. See the manufacturer's instruction book for requirements. Oxygen content may be continuously monitored.

8.3.6 Pressure. The water pressure of the stator cooling water system is typically maintained at the proper levels to ensure adequate high-pressure water supply to the inlet water manifold and (if applicable) that the stator-cooling water pressure is always less than the hydrogen gas pressure.

8.3.7 Copper and Iron Content. Copper and iron concentration may also be monitored. Normal levels are typically less than 20 ppb.

8.3.8 Hydrogen Content (see 8.1.7). The hydrogen content of the water system typically is minimal if no leaks into the system are present. Excessive venting from the relief valve on the stator water tank may be an indication that hydrogen is entering the system.

8.3.9 pH Value. The pH value of the water may be determined to ensure stable water chemistry according to the manufacturer's recommendations.

Index