

Best Practice Catalog

Station Power System



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Prepared by

MESA ASSOCIATES, INC.
Chattanooga, TN 37402

and

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6283
managed by
UT-BATTELLE, LLC
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1.0 Scope and Purpose

This best practice for the Station Power System (SPS) discusses design components, condition assessment, operations, and maintenance best practices with the objective to maximize overall plant performance and reliability.

The primary purpose of the SPS in a hydroelectric plant is to provide power for plant operation. Power may be sourced locally by generator(s) or via offsite power.

1.1 Hydropower Taxonomy Position

Hydro Power Facility → Powerhouse → Power Train Equipment →
Balance of Plant/Auxiliary Components

1.1.1 Station Power System (SPS) Components

The components of the Station Power System (SPS) which relate to performance and reliability consist of station auxiliary transformers, main or station service boards, chargers, UPS, and inverters.

Station Auxiliary Transformers: Station Auxiliary Transformers (SAT) generally provide power to the generator and plant essential loads via unit and common boards. SATs can be sourced either from the generator or from the utility grid. SATs can step-down voltage directly to the plant's low voltage level (480V level) or medium voltage level (2300V or 4160V). Figure 1 shows a typical configuration for a SAT sourced by a generator.

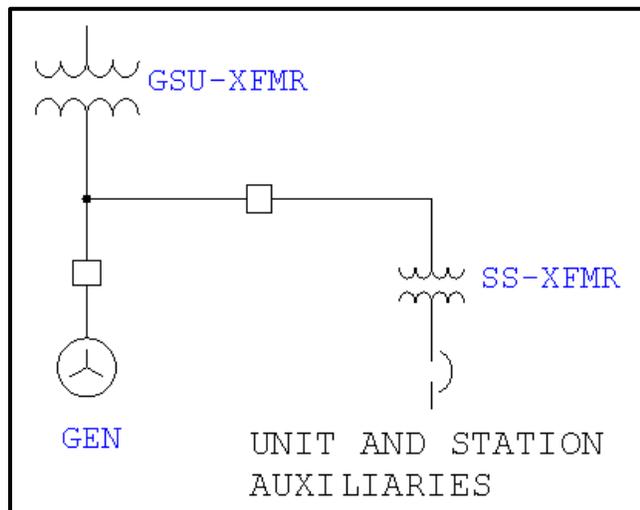


Figure 1: Typical Configuration for Station Power Transformer

SAT insulation may either be liquid-immersed or dry type. The liquid-immersed type can be further defined by the types of liquid used: mineral oil, nonflammable, or low flammable liquids. The dry type includes ventilated, cast coil, totally enclosed non-ventilated, sealed gas-filled, and vacuum pressure impregnated (VPI) types. The selection of the insulation medium is dictated mainly by the installation site and cost. For outdoor installations, the mineral-oil insulated transformer is often used due to its low cost and inherent weatherproof construction. Where mineral-oil immersed transformers are installed, it may be necessary to provide means to prevent any escaped oil, including drips, from migrating into the environment.

The ventilated dry-type transformer has application in industrial plants for indoor installation where floor space, weight, liquid maintenance, and safeguards are key factors. Although more expensive than ventilated dry-type or mineral-oil-immersed units, the totally enclosed non-ventilated dry-type transformer, the cast coil (where both the high and low-voltage coils are cast), and the sealed or gas-filled dry-type transformer are especially suitable for adverse environments. They require little maintenance, need no fire-proof vaults, and generally have lower losses than compared to ventilated or mineral-oil immersed units

Hydro plants in recent times have transitioned their SATs from liquid-filled to dry-type due to advances in dry-type transformer design. These advances have eliminated the need for liquid-immersed station auxiliary transformers. Transformers used for plant electrical auxiliaries today are usually dry-type transformers and may be located indoors or outdoors depending upon plant configuration.

Dry-type transformers are air-cooled as opposed to liquid-cooled. They have voltage ratings up to 72 kV and 63 MVA, which is well beyond the usual requirements for hydroelectric plants. Because air cooled transformers present less of a fire hazard than liquid-immersed types and no containment provisions are needed for liquids, they are preferred for indoor applications at hydroelectric plants. For more details about classifications and types of station power transformers, refer to Section 5.0 Information Sources.

Main or Station Service Boards: The main or station service board is another critical component of the SPS. These boards are generally switchgear and will feed unit critical loads and/or plant common loads. Switchgear is a general term that describes switching and interrupting devices, either alone or in combination with other associated control, metering, protective, and regulating equipment which are assembled in one or more sections. Typically, these boards should be provided with two sources if the plant configuration allows and automatic transfer to maximize uptime of the plant auxiliary loads especially if the hydro plant has multiple units.

There are three major types of switchgear: open, enclosed, and metal-enclosed. For the purpose of this document, we will only consider metal-enclosed of two types: metal-clad and low-voltage.

Metal-clad switchgear, as categorized by IEEE Std. 141-1993 [14], is metal-enclosed power switchgear characterized by the following features:

- The main circuit switching and interrupting device is of the removable type arranged with a mechanism for moving it physically between connected and disconnected positions, and is equipped with self-aligning and self-coupling primary and secondary disconnecting devices
- Major parts of the primary circuit, such as the circuit switching or interrupting devices, buses, potential transformers, and control power transformers, are enclosed by grounded metal barriers. Specifically included is an inner barrier in front or part of the circuit interrupting device to ensure that no energized primary circuit components are exposed when the unit door is opened.
- All live parts are enclosed within grounded metal compartments. Automatic shutters prevent exposure of primary circuit elements when the removable element is in the test, disconnected, or fully withdrawn position.
- Primary bus conductors and connections are covered with insulating material throughout. For special configurations, insulated barriers between phases and between phase and ground may be specified.
- Mechanical or electrical interlocks are provided to ensure a proper and safe operating sequence.
- Instruments, meters, relays, secondary control devices, and their wiring are isolated by grounded metal barriers from all primary circuit elements, with the exception of short lengths of wire associated with instrument transformer terminals.
- The door through which the circuit-interrupting device is inserted into the housing may serve as an instrument or relay panel and provide access to a secondary or control compartment within the housing.

If the plant has a need to source motors and pumps greater than 200 hp, then generally this board will be rated at the medium voltage level (2300V or 4160V). Figure 2 shows a typical low voltage switchgear line up for a main or station service board.



Figure 2: Typical Switchgear lineup for Station Service Power System

Metal-enclosed power circuit breaker switchgear of 1000V and below, as categorized by IEEE Std. 141-1993 [14], is metal-enclosed power switchgear with the following required equipment:

- Power circuit breakers of 1000V and below (fused or unfused).
- Non-insulated bus and connections (insulated and isolated bus is available).
- Instrument and control power transformers.
- Instrument, meters and relays.
- Control wiring and accessory devices.
- Cable and busway termination facilities.

Low voltage (LV) metal-enclosed switchgear is typically used to distribute station service power within hydroelectric power plants that have substantial auxiliary loads. In such applications, the switchgear can provide an effective, safe, and economic means for ensuring continued station service.

The switchgear falls under the American National Standards Institute (ANSI) standards for metal-enclosed switchgear and includes power circuit breakers capable of handling voltages from 240V to 600V and consisting of removable circuit breakers with a bare primary bus. Plants with a limited number of auxiliary loads typically use power distribution panelboards with molded case circuit breakers (MCCBs) or motor control centers (MCCs) to feed auxiliary loads. For

more details about classifications and types of switchgear, refer to Section 5.0 Information Sources.

Batteries: Battery systems (large or small) are installed in every hydroelectric powerhouse to provide continuous power. Station battery systems are one of the most crucial electrical systems in a hydro plant because the battery system provides power to critical controls, protective relays, and interruptible power systems associated with computers that control plant operations.

In addition, the station battery system will have to be capable of “black starting” the plant in the event of a system-wide outage which includes field-flashing a generator. Figure 3 shows an arrangement of lead-acid batteries which form a battery bank.



Figure 3: Lead Acid Batteries in a Bank

While there are many types of batteries, the two major categories are flooded liquid electrolyte (such as lead acid antimony, nickel cadmium) and sealed or low maintenance (lead acid calcium and lead acid/special alloy and sealed nickel cadmium) batteries.

Some differences between nickel cadmium (Ni-Cd) and lead acid batteries are that Ni-Cd has higher energy density and better low temperature performance. On the

other hand, lead acid batteries are less expensive and require simpler charging schemes.

Sealed batteries have reduced maintenance requirements, require less space for equivalent capacity, and may eliminate ventilation requirements. However, flooded designs are more robust, have lower total costs, and more predictable performance.

Many hydro plants have retained flooded cells due to their proven track record of reliability. However, required capacity increases and limited space in existing facilities may make the sealed technologies preferable.

Chargers, UPS, and Inverters: Battery chargers supply continuous charge to the plant's battery system. To assure reliability of the DC power system, many facilities utilize redundant charges in either a load sharing or a main/backup configuration. The primary methods used today for battery charging are constant-potential or constant-current.

The battery charger should be large enough to supply the plant constant loads (when AC power is available) and to fully charge the batteries within 8 to 24 hours depending upon plant design criteria.

The constant-potential method monitors the voltage of the battery and automatically tapers off the amount of charging current as the cell approaches the fully charged condition. This method is preferred when voltage needs to be maintained. The charger should be capable of supplying a float or equalizing charge with no more than a plus or minus 1 percent voltage variation with a plus or minus 10 percent supply voltage variation and over a plus or minus 5 percent supply frequency variation. Precise voltage regulation is required because minor voltage variations on the charger output will drastically change the amount of charging current sent to the batteries, resulting in either battery overcharging or undercharging. This method is the one most often used at hydroelectric plants.

The constant-current method feeds a constant charging current into station batteries for a certain period of time regardless of the cell voltage. This method is prevalent in industrial applications where batteries are continuously discharged and is generally not as suitable for hydroelectric plants.

Uninterruptible power supplies (UPS) and inverters are systems that supply continuous uninterrupted AC power to critical or plant essential loads such as computers used for plant controls, communication networks, security systems, emergency lights, board controls, and fire protection equipment. In general, these are divided into static and rotary systems. Rotary systems typically include an alternating current (AC) motor generator set with a flywheel, rectifier, inverter, storage batteries, static transfer switch, a manual transfer bypass switch, and solid state control circuitry. Static systems consist of a rectifier, inverter, storage batteries, static transfer switch, bypass input transformer, manual transfer bypass switch, and solid-state control circuitry. Figure 4 shows a typical one-line diagram for a UPS system.

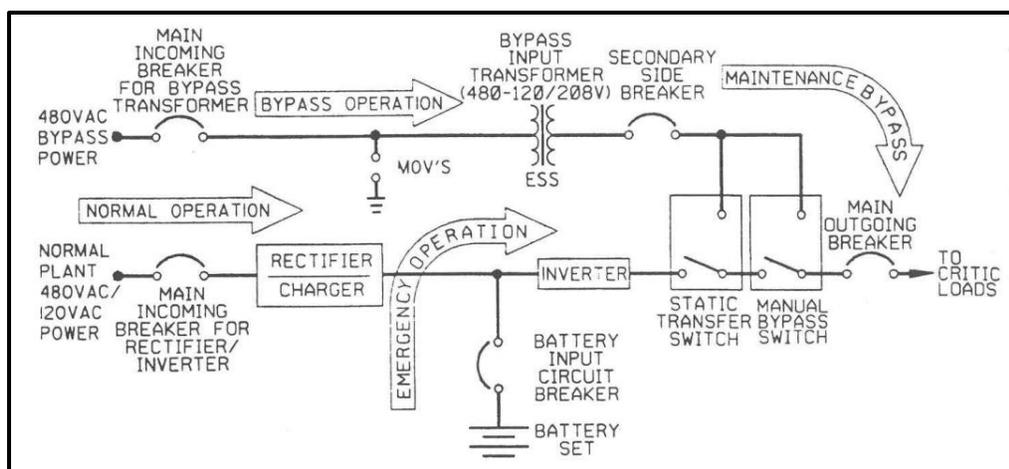


Figure 4: Typical Uninterruptible Power Supply (UPS) System

Because of the installed station battery capacity, many hydro plants choose to incorporate these elements into the preferred power system and utilize only an inverter and transfer switches in lieu of a complete static UPS system.

In addition to chargers, UPS and inverters, distribution panels are used to feed critical loads from the plant's battery board or preferred power system. Typically, the plant battery panelboard (DC board) and preferred power panelboard can be of varying configurations base on the plant layout. The preferred AC panels utilize circuit breakers while the DC boards may use either circuit breakers or fused disconnect switches. Figures 5 and 6 show typical examples of these systems.



Figure 5: DC Battery Panelboard



Figure 6: I-Line Type Power Panelboard

The plant battery board can range from 48VDC to 250VDC and generally powers critical DC loads such as generator excitation, protective relaying, and other critical loads. The 120V preferred power system is usually fed from either the plant batteries through an inverter or from an UPS and generally powers critical AC loads.

Reliability related components of a SPS include protection relays, plant relaying, control systems, 120V non-preferred power boards, and other low voltage DC systems of less than 48V.

1.2 Summary of Best Practices

1.2.1 Performance/Efficiency & Capability – Oriented Best Practices

Station Auxiliary Transformers:

- Maintain transformer loading to less than 100% of the full load OA/FA temperature rating. This will reduce the overheating of transformer windings and other components which can result in degradation of the manufacturer rated life expectancy and lower overall performance and efficiency.

Main or Station Service Boards:

- Maintain switchgear bus loading to less than 100% of the full-load amp rating.
- Perform short-circuit analysis to assure switchgear bus and breaker interrupting ratings exceed available fault currents anytime there are system or generator upgrades.

Batteries:

- Maintain battery room temperature to 25°C (77°F). Higher temperatures increase the rate of chemical reactions while lower temperatures reduce the rated output of the battery.
- Ensure that specific gravity considerations are met. Specific gravity affects overall battery performance and capability. See Section 3.2 for battery maintenance.
- If plant DC loads have been increased, perform a battery load study to assure battery sizing is adequate for the required length of time.

Chargers, UPS, and Inverters:

- Periodically inspect UPS and associated system components to ensure functionality and capability during a total loss of power.

1.2.2 Reliability/Operations & Maintenance – Oriented Best Practices

Station Auxiliary Transformers:

- For both liquid-immersed and dry-type transformers, refer to manufacturer recommendations and IEEE Standards C57.93 and C57.94 [15 and 16] for further operations and maintenance best practices.

Main or Station Service Boards

- Perform yearly infrared (IR) scans for thermal imaging of all associated bus bars, welds, and bus connections in order to determine excessive heating due to component separation and/or arcing between bus components.
- All power circuit breakers (PCB) and molded-case circuit breakers (MCCB) should be tested in accordance with manufacturer's recommendations – typically every 1-3 years depending upon service conditions (environment, frequency of operation, high fault current interruptions).

Batteries

- Perform inspection, testing and maintenance of battery systems in accordance with the manufacturer's recommendations and IEEE 450 for vented lead acid [17], IEEE 1106 for Ni-Cd [18], or IEEE 1188 for value-regulated lead acid [19] recommended practices.

- Utilize online battery systems which provide continuous measurements of critical parameters such as voltage, current, impedance, and temperature in order to monitor and reduce maintenance requirements.
- Ensure that all cabling is clean, free from acidic deposits, and that proper connections are made.

Chargers, UPS and Inverters

- Perform periodic full load test of UPS systems to ensure reliability.

1.3 Best Practice Cross-references

- Electrical– Main Power Transformer
- I&C– Automation

2.0 Technology Design Summary

2.1 Material and Design Technology Evolution

The station power system has evolved as the individual components that make up the system have evolved. In many cases, vacuum tubes have been replaced with transistors, flywheels for UPS systems with static systems, liquid-immersed transformers with dry-type transformers, and switchgear with stronger and more durable components have replaced vintage equipment. The result of this evolution is equipment with higher capacities, greater efficiencies, and improved reliability with reduced maintenance requirements.

2.2 State of the Art Technology

State of the art technologies for station auxiliary transformers, main and auxiliary boards, batteries and UPS systems are discussed below and will focus on new advances in modern engineering and design.

Station Auxiliary Transformers (SAT)

Since most SATs fed from GSUs are located indoors, hydro plants normally opt to use dry-type transformers in order to reduce the potential for fire hazards. Three types of dry-type transformers used for SATs are listed as follows:

- Vacuum Pressure Impregnated (VPI)
- Vacuum Pressure Encapsulated (VPE)
- Cast Coil Epoxy Resin (Cast Coil)

Cast coil transformers are the most robust of the three and generally the most expensive. Cast coils are simply windings which have been placed in molds and vacuum cast with an epoxy resin compound. The clearest advantage of cast coils over ventilated dry and liquid filled coils is mechanical strength. The epoxy casting is extremely inert and renders the windings impervious to moisture, dirt, and most corrosive elements. For future transformers, designers seek to reduce losses from both hysteresis and eddy currents by utilizing evolving transformer technologies such as amorphous metal cores.

Main/Station Service Boards

As safety from arc flash hazard becomes more of a concern, the demand for arc resistant switchgear will increase. New technologies are being developed to prevent internal components, doors, and glass from opening and being projected away from the switchgear due to extreme pressure build-up during a fault.

Low voltage switchgear design trends are expected to continue with greater interrupting capacities, reduced space, and increased embedded intelligence and communication capabilities.

For medium voltage switchgear, partial discharge testing and circuit breaker monitoring may be implemented. SF₆ indoor switchgear, which is inherently arc resistant, is now available. Over time, this standard may become more of an economic solution for medium voltage switchgear replacement.

In addition, light sensing methods using fiber optic detection systems are being integrated into new switchgear designs to isolate energy feeds during the commission of a fault. Arc detection systems are protection systems that use sensors to detect the presence of an internal arc and then isolate the faulted section by opening the incoming feeder circuit breaker. In general two types of systems exist:

- Pressure relief systems
- Light detection systems

Figure 7 shows a typical design of a venting chamber used to direct the buildup of pressure due to arc flash. Note that care must be taken to duct the arc energy to a location that does not jeopardize personnel or plant equipment.

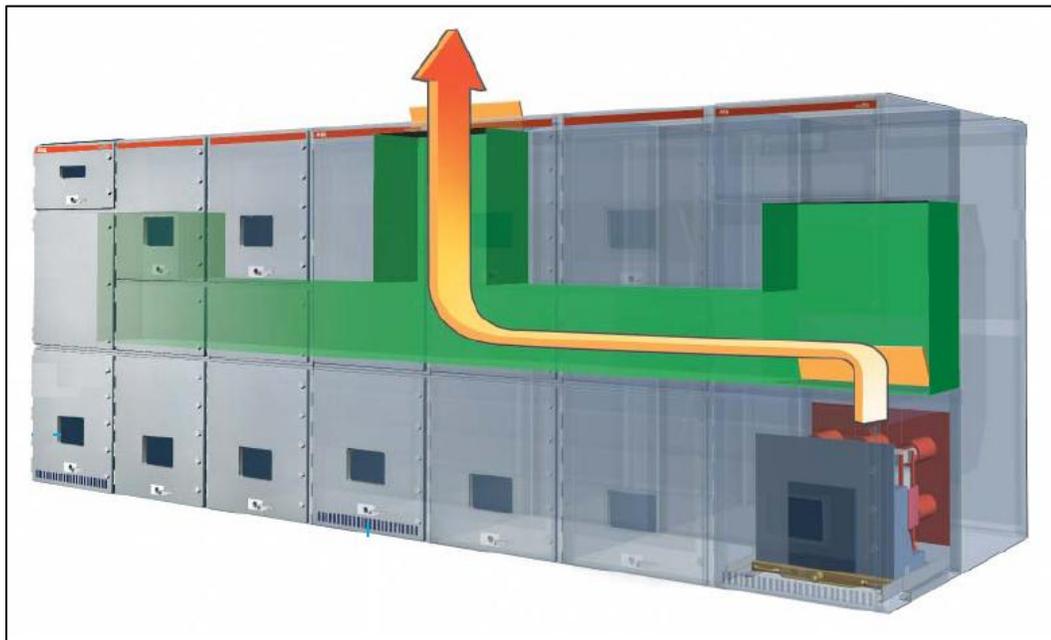


Figure 7: Venting Chamber Design for State-of-the-Art Switchgear

Figure 8 shows a typical optical sensor used to detect light due to arc flash. Because this optical system detects light, the clearing time is usually about 0.1 seconds (6 cycles) or less.



Figure 8: Optical Sensor for Arc Flash Detection

Batteries

Currently the most widely used battery types for hydroelectric plants are wet cell lead acid batteries. These batteries require maintenance and take up a large footprint in a plant. Some hydro plants have begun to implement sealed wet cell batteries in order to reduce the maintenance requirements of the batteries. Even newer technology that is in the process of being tested for hydro plants is that of lithium-ion (Li-ion) batteries.

A major advantage for Li-ion battery technology compared to the lead acid battery system is the reduced amount of floor space required. The batteries are fully sealed and reduce maintenance giving a number of advantages for plant maintenance crews. Problems associated with the build-up of hydrogen gas and handling of acid are reduced or eliminated. On-site maintenance is also reduced due to the ability to view charge status and other parameters remotely. These advantages are reasons for continued research in this field. Currently, the highest obstacle against the Li-ion batteries today is cost. However, developments in the electrical vehicle industry are expected to decrease the cost level.

Other battery types, such as lithium polymer, are being developed and will likely have a wider deployment due to lower production costs. Long term, battery testing and technologies are developing a Li-ion battery that has a 20 year lifetime making it very robust and attractive to hydroelectric plant maintenance departments due to reduced maintenance efforts. No additional cooling has to be provided for Li-ion batteries as they are designed to work without aging in temperatures up to 60°C. The only recommended maintenance requirement is that plant personnel perform a 5 hour discharge test annually. This process can be used to detect the aging of the battery.

Due to environmental advantages, space savings, and reduced maintenance operation, the Li-ion battery will be an appealing alternative for lead acid batteries once the price level becomes more competitive.

Chargers, UPS, and Inverters

Advances in UPS technologies have caused a transition almost exclusively from rotary flywheel-type systems to solid state (static) systems which include advanced control systems.

Generally, there are two major types of static UPS systems for capacities typically required at hydro plants: 1) double-conversion and 2) delta-conversion. The double-conversion UPS represents greater than 90% of the UPS systems installed and supports a wide load range (10kW - 1.6MW).

A slightly newer technology for UPS systems is the delta-conversion type which is smaller, requires less maintenance, and has the highest efficiency (lower cost).

Future UPS evolution is in designing higher efficiency systems which can support all types of load demand from real to highly reactive.

3.0 Operation & Maintenance Practices

3.1 Operations

A typical life span for the following station power components is as follows:

- Station/Unit Auxiliary Transformers – 20-30 years
- Main Auxiliary Boards (Switchgear) – 30-40 years
- Wet Cell Batteries – 15-20 years
- Chargers, UPS and Inverters – 20-30 years

While breakers in switchgear boards and distribution panels are required to operate during a fault condition or in order to isolate a power source, no further operation is required. All other components of station power are meant to operate for the life of the device.

3.2 Maintenance

Maintenance is essential to proper operation. The installation should have been designed so that maintenance can be performed with onsite or contract personnel. During times of maintenance, redundant or backup systems may be utilized so that maintenance can be performed without impact difficulty or excessive cost to the utility. Where the continuity of service is essential, suitable transfer equipment and alternate sources should be provided. Such equipment is needed to maintain minimum lighting requirements for passageways, stairways, and critical areas as well as to supply power for critical loads. These systems usually include automatic or manual equipment for transferring loads during loss of normal supply power. Annual or other periodic shutdown of electrical equipment may be necessary to perform electrical maintenance.

Station Auxiliary Transformers

To avoid failures and problems, it is essential to conduct a program of careful supervision and maintenance. The life of a transformer is highly dependent upon the heat prevailing in the windings and core of the unit and the quality of the liquid in circulation, if applicable. Therefore, it is important that the temperature be monitored and integrity of the dielectric liquid (if liquid-filled) be maintained at a high quality.

For the first few days after a purchase and recent energization of a new transformer, daily inspections are recommended, before the warranty period ends. If applicable, oil samples should be taken at 24 and 72 hours after carrying normal load to check for abnormal gas generation.

Per IEEE Std. C57.93 [14], the following recommended maintenance practices for liquid-immersed type transformers are to be followed monthly, yearly, one to three years, and three to seven years:

Note: Before performing any maintenance on energized equipment, ensure that the plant's Lockout/Tag-out procedure has been followed and that equipment has been de-energized.

Monthly maintenance practices for liquid-immersed transformers.

- Check all liquid level gauges including main tank, oil expansion tank, and bushings
- Record winding hot spot and top liquid temperatures (both instantaneous and maximum values); reset all maximum indicator hands on temperature gauges.
- For gas-blanketed transformers, the transformer gas pressure should be recorded. The cylinder pressure of transformers equipped with nitrogen systems should also be checked.
- For transformers with an oil expansion tank, inspect dehydrating breather.
- Check the pressure relief device for operation or a target indication.
- Check the bushings for chipped or broken sheds.
- Check the arresters for broken or damaged sheds.
- Check the general condition of the unit, including ground connections, paint condition, possible liquid leaks, etc.
- If applicable, test transformer alarm annunciator and any other monitoring or alarm device.
- Check transformer loading, voltage, and neutral current values.
- Transformers equipped with auxiliary cooling equipment such as fans and pumps should have their fans and pumps tested to ensure operation.
- Unusual or abnormal conditions may require further investigation or tests.

Yearly maintenance practices for liquid-immersed transformers

- Inspect coolers for leaks.
- Check cooler fans and fins for damage and proper operation.
- Clean coolers.
- Infrared (IR) thermography may be appropriate; record ambient temperature, winding and top oil temperatures, and loading. Hot spots may be located in the main tank, bushings, tap changer compartments, control

cabinets, coolers/radiators, fans and pumps, overhead connections and ancillary equipment.

One to three year maintenance practices for liquid-immersed transformers.

- Test transformer insulating liquid for dielectric strength and note color of oil.
- Conduct a total combustible gas (TCG) analysis test of the gas space on all gas-blanketed transformers.
- Conduct a dissolved gas analysis. Use IEEE Std. C57.104-1991 for testing guidelines.

Three to seven year maintenance practices for liquid-immersed transformers.

- Inspect the bushings for any chipped spots; clean the surface to remove any foreign material.
- Check all external connections, including ground connections, to assure a solid mechanical and electrical connection.
- Conduct power-factor or dissipation factor tests of the transformer and bushing insulation systems.
- Verify the integrity of thermal and alarm sensors and circuitry
- A transformer-turns-ratio test should be conducted
- Winding resistance measurements should be made and compared with factory measurements.
- Verify the condition of all oil pumps by checking running current.
- Inspect cooling system and electrical supply to pumps and fans.
- Core ground should be tested if accessible, and leakage reactance, as well as core excitation tests should be performed.

Per IEEE Std. C57.94 [16], the following recommended maintenance practices for ventilated and non-ventilated dry-type transformers are to be followed:

Yearly maintenance practices for dry-type transformers.

- Check that windings and insulators are free from accumulations of dirt and grime to permit free circulation of air and to guard against possibility of insulation breakdowns.
- Lead supports, tap changers and terminal boards, bushings, and other major insulating surfaces should be brushed or wiped with a lint free cloth. The

use of liquid cleaners is undesirable because some of them have a solvent or deteriorating effect on most insulating materials.

- For sealed dry types, the gas pressure must be maintained and periodically checked. Inspection items should include bushings, tank and accessories.

Main Auxiliary Boards

To avoid failures and problems, it is essential to conduct a program of careful supervision and maintenance. Switchgears are designed to be virtually maintenance free with very few exceptions. Common practices of preventive maintenance are usually conducted around every 5 years, or per manufacturer recommendation for both medium-voltage and low-voltage switchgear. These practices will vary between the different manufacturers, but for the most part are common between all:

Note: Before performing any maintenance on energized equipment, ensure that the plant's Lockout/Tag-out procedure has been followed and that equipment has been de-energized.

Five to ten year maintenance practices for medium-voltage switchgear.

- Inspect the condition of the cubicle for soot, smoke, stained areas or other unusual deposits including oil or other liquids. In addition, check for metal shavings, nuts, bolts or anything that may have shaken loose during operation.
- Check to ensure that wiring and terminations are securely fastened. Check that insulation is intact – not brittle failing or discolored.
- Ensure that terminal blocks and lugs are not damaged and that there are no visible or loose connections.
- Ensure that there is no loose, broken or missing hardware. Ensure the integrity of secondary disconnects, shutter assemblies, male disconnects, instrument and control switches, space heaters, contacts, mechanical interlocks, etc.
- Ensure the integrity of the cell/breaker grounding contact.
- Ensure the integrity of all fuse holders, i.e. trip and close fuses, DC fuses, etc.
- Inspect the lift mechanism (if applicable) and all associated components to ensure integrity.
- Inspect current transformers (CT) for cracking, signs of overheating and discoloration. Check tightness of CT connections and all shorting blocks (if used) for continuity.

- Inspect potential transformers (PT) for cracking, signs of overheating and discoloration. Inspect and clean drawer slides and rollers, insulators, primary and secondary wiring, transformers and connections. Check tightness of connections; verify primary and secondary finger contact and wipes.
- Check, tighten and torque (as needed) all bus connections per manufacturer recommendations.
- Manufacturers recommend that breakers and trip modules associated with switchgear be drawn-out into test mode periodically and cycled in order to confirm functionality. The use of a breaker test kit may also be used to perform this test.

Five to ten year maintenance practices for low-voltage switchgear.

- Inspect the condition of the cubicle for soot, smoke, stained areas or other unusual deposits including oil or other liquids.
- Check to ensure that wiring and terminations are securely fastened. Check that insulation is intact – not brittle failing or discolored.
- Ensure that terminal blocks and lugs are not damaged and that there are no visible or loose connections.
- Ensure that there is no loose, broken or missing hardware. Ensure the integrity of secondary disconnects, shutter assemblies (if applicable), male disconnects, instrument and control switches, contacts, etc.
- Check, tighten and torque (as needed) all bus connections per manufacturer recommendations.
- Manufacturers recommend that where applicable, breakers and trip modules associated with switchgear be drawn-out into test mode periodically and cycled in order to confirm functionality. The use of a breaker test kit may also be used to perform this test.

Batteries

To avoid failures and problems, it is essential to conduct a program of careful supervision and maintenance. Proper maintenance will prolong the life of a battery and will help enable the battery to satisfy its design requirements. A good battery maintenance program will serve as a valuable aid in maximizing battery life, preventing avoidable failures, and reducing premature replacement. Common maintenance recommendations, based on IEEE standards, will be listed for Vented Lead-Acid (VLA), Nickel-Cadmium (Ni-CD), and Valve-Regulated Lead-Acid (VRLA) batteries.

Per IEEE Std. 450-2010 [17], the following recommended maintenance practices for VLA batteries are to be followed monthly, quarterly, and yearly:

Monthly maintenance practices for VLA batteries.

- Check float voltage measured at the battery terminals.
- Check the general appearance and cleanliness of the battery, rack or cabinet area.
- Check charger output current and voltage.
- Check electrolyte levels.
- Check for cracks in cells or evidence of electrolyte leakage.
- Check for evidence of corrosion at terminals, connectors, racks or cabinets.
- Check ambient temperature and ventilation.
- Check pilot cells (if used) voltage and electrolyte temperature.
- Check battery float charging current or pilot cell specific gravity.
- Check for unintentional battery grounds.
- Check (if applicable) that all battery monitoring systems are operational.

Quarterly maintenance practices for VLA batteries.

- Check the voltage of each cell.
- For lead-antimony battery, check the specific gravity of 10% of the cells of the battery and float charging current. For technologies other than lead-antimony, if battery float charging current is not used to monitor state of charge, check the specific gravity of 10% of the cells of the battery.
- Check the temperature of a representative sample of 10% of the battery cells.

Yearly maintenance practices for VLA batteries.

- Check the voltage of each cell.
- For lead-antimony battery, check the specific gravity of all of the cells of the battery and float charging current. For technologies other than lead-antimony, if battery float charging current is not used to monitor state of charge, check the specific gravity of all of the cells of the battery.
- Check cell condition. See IEEE Std. 450-2010 Annex E for guidelines.
- Check cell-to-cell and terminal connection resistance. See IEEE Std. 450-2010 Annex F for guidelines.

- Check the structural integrity of the battery rack and/or cabinet. See IEEE Std. 450-2010 Annex E for guidelines.

Per IEEE Std. 1106-2005 [18], the following recommended maintenance practices for Ni-CD batteries are to be followed quarterly, semiannually, and yearly:

Quarterly maintenance practices for Ni-CD batteries.

- Check float voltage measured at the battery terminals.
- Check the general appearance and cleanliness of the battery, rack or cabinet area.
- Check charger output current and voltage.
- Check electrolyte levels.
- Check for cracks in cells or evidence of electrolyte leakage.
- Check for evidence of corrosion at terminals, connectors, racks or cabinets.
- Check the adequacy of ventilation.
- Check pilot-cell electrolyte temperature.

Semiannual maintenance practices for Ni-CD batteries.

- Check and record the voltage of each individual cell.

Yearly maintenance practices for Ni-CD batteries.

- Check the integrity of the battery rack
- Check the intercell connection torque
- Check the resistance or cable connections.

Per IEEE Std. 1188-2005 [19], the following recommended maintenance practices for VRLA batteries are to be followed monthly, quarterly, and yearly:

Monthly maintenance practices for VRLA batteries.

- Check float voltage measured at the battery terminals.
- Check the general appearance and cleanliness of the battery, rack or cabinet area.
- Check charger output current and voltage.
- Check electrolyte levels.
- Check for cracks in cells or evidence of electrolyte leakage.

- Check for evidence of corrosion at terminals, connectors, racks or cabinets.
- Check ambient temperature and ventilation.
- Check for excessive jar/cover distortion.
- Check the DC float current (per string). This should be measured using equipment that is accurate at low (less than 1 A) currents.

Quarterly maintenance practices for VRLA batteries.

- Check cell/unit internal ohmic values per IEEE Std. 1188-2005 Annex C4.
- Check the temperature of the negative terminal of each cell/unit of battery per IEEE Std. 1188-2005 Annex B3.
- Check the voltage of each cell/unit per IEEE Std. 1188-2005 Annex B2.

Yearly maintenance practices for VRLA batteries.

- Check cell-to-cell and terminal connection detail resistance pf entire battery per IEEE Std. 1188-2005 C1 and Annex D.
- Check AC ripple current and/or voltage imposed on the battery per IEEE Std. 1188-2005 C5 and manufacturer.

Chargers, UPS and Inverters

To avoid failures and problems, it is essential to conduct a program of careful supervision and maintenance. IEEE Std. 944-1986 – *IEEE Recommended Practice for the Application and Testing for Uninterruptible Power Supplies for Power Generating Stations* was withdrawn based on the spectrum being too broad for UPS testing and maintenance. For this reason, the type and frequency of maintenance testing will be based on manufacturer's standards and recommendations.

4.0 Metrics, Monitoring and Analysis

4.1 Measures of Performance, Condition, and Reliability

Measures of performance, condition, and reliability for the station power system should be in accordance with IEEE standards and manufacturer recommendations and practices. General recommended practices for replacement of station power components such as transformers, switchgear, batteries and station battery backup components will be based on but are not limited to the following criteria:

- Transformers are to be replaced once insulation and/or other crucial components have significant wear or damage.
- Switchgear is to be replaced once the integrity of the components is no longer acceptable according to IEEE and manufacturer standards.
- Batteries are to be replaced once the capacity has fallen below 80% of its initial capacity.
- Station battery backup components are to be replaced once functionality has ceased beyond required expectations.

The graph in Figure 9 compares the full published life of a VLA battery discharge versus an end-of-life condition.

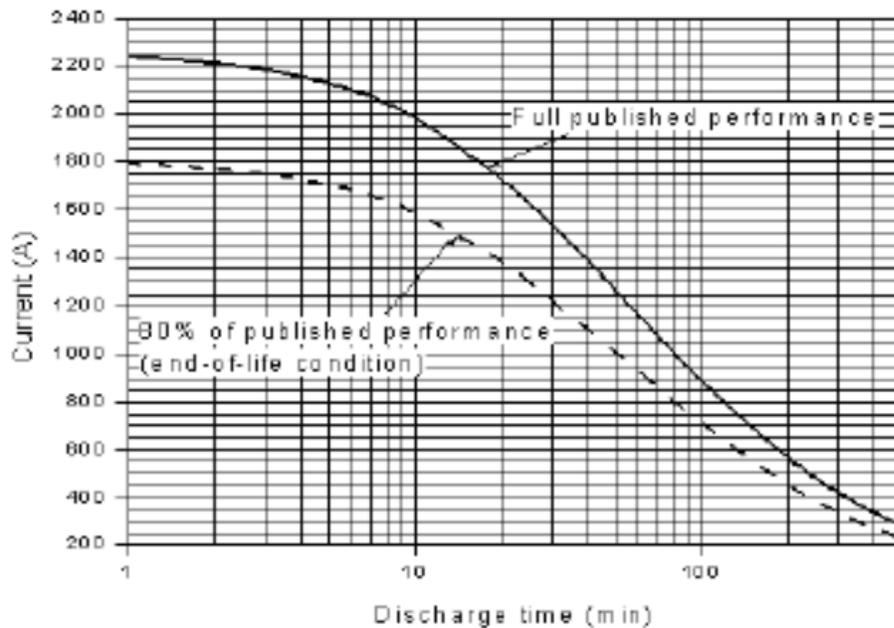


Figure 9: Current vs. Discharge Time – VLA Battery

4.2 Data Analysis

Trend analysis of test data (used for i.e. battery replacement) should be interpreted with the assistance of IEEE standards and manufacturer recommendations and practices. See Section 5.0 Information Sources for references.

4.3 Integrated Improvements

The periodic field test results should be used to update the performance characteristics of the subject components of the SPS. These can be integrated into computer programs to provide on-line analysis results and anomalies to all involved personnel. Parameters can be established to trigger various maintenance or immediate action activities as required. Data trends allow preventative maintenance to be performed in lieu of reactive maintenance.

As the condition of the SPS changes over time, the condition indicator and reliability indexes are trended and analyzed. Using this data, projects can be ranked and justified in the maintenance and capital programs to return the SPS to an acceptable condition and performance level or indicate the need for replacement for long-term reliability and unit performance.

5.0 Information Sources

Baseline Knowledge:

1. US Corps of Engineers, *Hydro Plant Risk Assessment Guide*, September 2006
2. *Transformer Maintenance Guide*, Transformer Maintenance Institute, 2001
3. EPRI, *Increased Efficiency of Hydroelectric Power*, EM 2407, June 1992
4. David M. Clemen, *Hydro Plant Electrical Systems*, HCI Publications, Inc, 1999
5. TVA SMP-1222A, *Medium Voltage Switchgear, Boards and Cubicle Inspection and Maintenance*, January 2007
6. TVA SMP-1203A, *Six Year Inspection and Maintenance Low Voltage Metal-Enclosed Switchgear Board, Revision 0000*

State of the Art:

7. GE Industrial Systems, *Cast Coil Transformers*, EPO-560, September 2009
8. ABB, SafeGear, *The most advanced ANSI arc-resistant switchgear in the world*, 2010
9. RMS Protection and Control, *Optical Arc Fault Sensor*, 2012
10. Peter Kron, Bertil Nygren, Trond Beyer, *Field Experience From the World's Largest Stationary Lithium-Ion Battery*, 2005
11. Schneider Electric, Richard L. Sawyer, *Making Large UPS Systems More Efficient*, White Paper 108, Rev 3
12. Schneider Electric, Carl Cottuli, *Comparison of Static and Rotary UPS*, White Paper 92, Rev 2
13. Pioneer Electric, *Dry Type Power Transformers*

Standards:

14. IEEE Std 141-1993, *IEEE Recommended Practice for Electric Power Distribution for Industrial Plants*
15. IEEE Std C57.93, *IEEE Guide for Installation and Maintenance of Liquid-Immersed Power Transformers*
16. IEEE Std C57.94, *IEEE Recommended Practice for Installation, Application, Operation, and Maintenance of Dry-Type General Purpose Distribution and Power Transformers*
17. IEEE Std 450, *IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications*

18. IEEE Std 1106, *IEEE Recommended Practice for Installation, Maintenance, Testing and Replacement of Nickel-Cadmium Batteries for Stationary Applications*
19. IEEE Std 1188, *IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications*

It should be noted by the user that this document is intended only as a guide. Statements are of a general nature and therefore do not take into account special situations that can differ significantly from those discussed in this document.

For overall questions
please contact:

Brennan T. Smith, Ph.D., P.E.
Water Power Program Manager
Oak Ridge National Laboratory
865-241-5160
smithbt@ornl.gov

or

Qin Fen (Katherine) Zhang, Ph. D., P.E.
Hydropower Engineer
Oak Ridge National Laboratory
865-576-2921
zhangq1@ornl.gov