Generator Auxiliary Systems, The Rest Of The Story

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Abstract

It is not unusual for well maintained and operated generators to be in use long after the OEM's designed life expectancy. In fact, most large utilities in the United States have generators in their fleets that have been in operation for well over 30 years. With a growing dependence on electric power and the prohibitive cost of outage extensions, there have been increased efforts to obtain higher operating voltages while increasing reliability. To accomplish this, it may require the replacement of major components such as armature windings, field windings or a complete rotor. Upgrading generator components can be a complicated process that requires a considerable amount of pre-planning, extended outage time and a significant financial investment.

Not all generator service issues are solved with a rewind. Often ignored during generator upgrades are the auxiliary systems; seal & lube oil, hydrogen cooling, gas supply & controls, stator cooling water and monitoring systems. The auxiliary system equipment is critical to ensure efficient, reliable and safe operation of the generator. Time and wear of auxiliary system components have a direct impact on the generator availability and could potentially lead to a generator problem that could lead to a catastrophic failure. A proactive approach to upgrading these critical auxiliary systems will help secure your return on investment involved in rewinding a generator. This paper identifies the benefits for evaluating and upgrading generator auxiliary systems.

Background

The first hydrogen-cooled electrical generators installed in the U.S. were put into operation in the late 1930's and early 1940's. Modern high capacity turbine generators still use hydrogen gas as well as water as a cooling medium. Most of these generators are rapidly approaching, or have already exceeded, their original design life. Owners of these generators are looking for alternatives, besides replacement, to not only keep these units on line but also upgrade and up-rate their output. Generator stator and rotor rewinds are one method used to up-grade and up-rate generators.

Not all generator service issues are solved however with a with stator and rotor rewind. Often ignored during generator upgrades are the less maintained, obsolete and outdated auxiliary systems; e.g., seal & lube oil, hydrogen cooling, gas supply & controls, stator cooling water (in applicable liquid cooled generators) and generator monitoring systems.

Auxiliary system equipment is critical to ensure efficient, reliable and safe operation of the generator. Time and wear of auxiliary system components have direct impact on generator availability. An unreliable auxiliary system could potentially lead to a generator problem that could lead, if not detected, to a catastrophic generator failure. A proactive approach to upgrading critical auxiliary systems at the time of a stator rewind will help secure the return on investment involved in rewinding a generator.

Generator owners and operators often base the decision for generator stator, field rewinds and refurbishments based on a problem rather then on equipment time in life curve (age). Many times the focus on "fixing it" involves just a stator rewind or refurbishment. Not included or planned for are the auxiliary systems.

Monitoring systems are not typically considered a generator auxiliary. However, with the extended times between maintenance outages, proper generator monitoring has become increasingly important. In the past, typical generator monitoring device(s) were protective relays and OEM-installed RTD's & TC's, mainly looking for hot spots in the stator bars or through the cooling medium, e.g. hydrogen or water. Multiple monitoring systems, looking at a broader range of machine conditions, can provide an operator with the additional information needed to ensure safe and reliable operation of the generator.

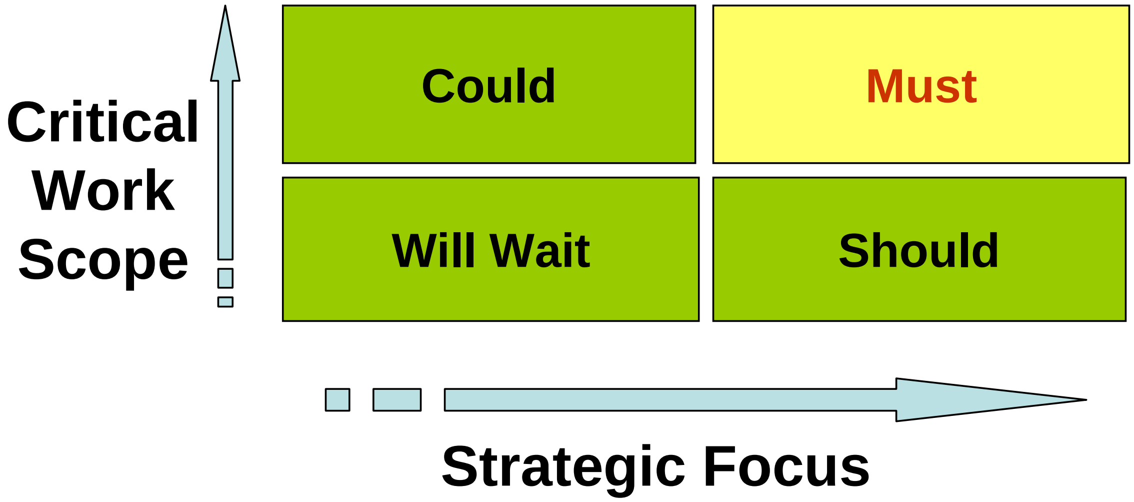
This paper will discuss generator auxiliary systems, including monitoring systems and recent improvements. The paper will also discuss a "flexible philosophy" for prioritizing auxiliary system up-grades and refurbishments.

Flexible Philosophy

Senior executives' at most major utilities are putting more emphasis on profitability and reliability and encouraging senior management to more effectively manage capital projects, e.g. generator rewinds. In this respect, corporate management is working toward decreasing project duration (time) and increasing returns on investment (dollars). Currently, management philosophies employ a traditional waterfall project development methodology that seems limited in its ability to deliver projects on time and within budget, while at the same time focusing a need for not only a stator rewind but also the upgrade and refurbishment of the generator auxiliary systems. A more agile/adaptive development and planning approach for combining the upgrades of the auxiliary equipment into the stator rewind needs to be utilized (2).

MoSCoW

It is important when planning a stator rewind to list all the other work scope issues that need to be conducted and prioritize them according to: it **Must** be done, it **Should** be done, it **Could** be done, it will **Wait**. An example of the above is shown by utilizing a business model for Strategic Focus and Critical Work Scope (3).



The next step is to develop a work scope matrix, showing prioritization (MoSCoW), risk, estimated cost, actual cost.

Scope of Work	Base / MoSCoW	Risk	Estimated Cost	Actual Cost	Total ($)
AFUDC/Surcharge/etc	**Base**				
Escalation if applicable(deferred/other)	Base				
Rewind(complete)gentag& fluxprobe	Base				
Open/Close	Base				
HV Bushings & Standoff Bushings (material only).	Must	High			
Possible strip HVbshings&SO to check (magic dust /flex connection	Must	Med.			
Acid Flush (if applicable)	Must	Med.			
RTD's (2ea)	Must	Med.			
Field Testing &Inspection w/mechanized UT	Must	Med.			
Logistics (30days before support)	Must	High			
EL-CID Testing	Must	Med.			
internal labor+additional matrl	Must	High			
Corp. Eng Time	Must				
Disposal Costs	**Must**	**Low**			
Tax	**Base**				
Exciter Line-up if applicable	**Should**	**High**			
$ Labor for install of HV & Standoff Bushings	**Should**	**High**			
Constant Flow Stator Cooling - H2O if applicable	**Should**	**Med.**			
Duplex Strainer Assembly-Material/Install if applicable	**Should**	**Med.**			
Commercial	**Must**	**High**			
Spare Bars	**Could**	**Low**			
SLMS Material & Installed if applicable	**Should**	**Med.**			

Possible Machine Gaskets, Seals, Bearings	Should	Low			
Hydrogen Aux System – Turn Key (Material, Installed, Checkout, Start-up Support/Training	Should	Low			
Additional Modifications w/Transportation	Should	Med.			
Generator Monitoring System	Should	Low			
Field Borsonic / Collector Ring Maching / other	Could	Med.			
Consultant Services	Should	High			
Connection Rings	Will Wait	Med			
Core End Mods (installed)	Will Wait	Low			
Field Rewind/Refurbishment	Will Wait	High			
Increase Capability	Will Wait	Low			

Even with thorough planning, adaptive flexibility and prioritizing, senior management may still be reluctant to spend the necessary dollars to conduct what these authors feel is a full and complete stator rewind. In other words, the overall goal is to accomplish all of the Musts, Shoulds and Coulds, within a defined time and at or below budget. One or two of the large OEM's today can accomplish the entire matrix work scopes of Musts, Shoulds, Coulds in 30 days or less with proper planning.

What may be left to convince senior management is the importance of "the rest of the story." (Items other than the basic stator rewind that need to be accomplished during the outage window and within the 30 days.)

Generator Auxiliaries

All large generators require auxiliary systems to handle such things as lubricating oil for the rotor bearings, hydrogen cooling apparatus, sealing oil, demineralized water for stator winding cooling and excitation systems for field-current application. Not all generators require all these systems and the requirement depends on the size and nature of the machine (1). The following is a brief description of each auxiliary system and some advancement. The descriptions are general and do not cover every major component that should be evaluated.

Seal & Lube Oil System

A typical lube oil system provides oil for both the turbine and generator bearings while also serving as a source of seal oil to the generator seals. Lube oil systems are generally considered under the turbine auxiliary systems and thus not typically included in generator maintenance. However, there are some lube & seal oil systems that are dedicated to the generator (1).

In order to safely and effectively employ hydrogen for generator cooling, it is necessary to contain the pressurized gas within the generator casing. It is therefore necessary to seal against hydrogen leakage at various locations within the generator. One of the most difficult areas to seal is the location between the generator case and rotor shaft. There are several types of generator seals, but all use a high pressure oil film. The function of the seal oil control unit is to supply and maintain oil to the generator seals to contain hydrogen within the casing.

Advancements: Improved instrumentation and sensors, such as pressure switches, gauges/transmitters, pressure regulating valve and controls.

Hydrogen Cooling System & Gas Supply/Controls

For the purpose of this paper the hydrogen cooling system covers storage, delivery, monitoring and conditioning.

Supply of hydrogen is generally provided by banks of bottled gas, refillable pressurized containers or on-site manufacturing plant. The gas is delivered to the generator through a system of piping, valves and regulators commonly referred to as a control valve assembly or gas manifold system. In addition to hydrogen, a separate CO2 supply is required to purge the generator of air before charging with hydrogen and/or purge the hydrogen during degassing following shutdown. The manifold assembly is capable of performing these tasks and allowing the purge of CO2 with air prior to maintenance outages.

Generators operate with hydrogen rather than air as the internal medium because hydrogen has less drag for a given thermal convection capability. The generator internal gas is pressurized (typically at 15, 30, 45, 60, or 75 psig as defined by the ordering drawing) to increase thermal convection cooling inside the generator. Because hydrogen readily oxidizes, air in the generator is purged with an inert gas prior to the admission of hydrogen during setup for normal operation.

The gas control valve manifold assembly provides the operator with an efficient and safe means of handling hydrogen and is the operator's control station during the purge process. The hydrogen gas control system's function is to help maintain safe hydrogen purity levels and generator efficiency through continuous supply of high purity hydrogen to the generator casing.

Advancements: Devices such as isolation valves, pressure switches, gages/transmitters pressure regulators and controls have been improved over the years to increase reliability and performance. Transmitters are now available that can provide local indications, adjustable alarm points and electrical outputs that can be feed into the distributed control and information system DCIS). New systems now incorporate a mass flow meter to monitor gas usage. Instruments used on the gas control valve assembly should be third-party approved for use in a hazardous.

Stator Winding Cooling Water System

The stator cooling water system is used to remove heat from generator armature bars. It consists of a tank, piping, flow and pressure regulating valves, heat exchangers and a filtration/de-ionizing subsystem. Pumps and heat exchangers are typically redundant on this skid to ensure reliability of this critical cooling assembly. The de-ionizing subsystem is necessary to maintain low conductivity of the stator cooling water. High conductivity of the demineralized cooling water can result in electrical flashover to ground in the stator winding.

Stator water chemistry must be maintained to ensure availability and avoid costly failures. Water conductivity is monitored and controlled through make up supply and the de-ionizing subsystem. As a related matter the copper/iron content must be kept below 20 ppb typically, thus reducing conductivity problems. Hydrogen content in the water can be monitored for indications of stator leaks. The dissolved oxygen content is also monitored and controlled to prevent corrosion of the hollow copper strands that make up the stator bars. Both high-oxygen and low-oxygen systems are used to avoid corrosion product buildup and subsequent blocking of cooling water flow. The cooling water pH is also monitored and matched to optimum conditions of a high or low oxygen system. Numerous stator cooling water parameters such as flow, pressure, temperature, conductivity, pH and oxygen content are monitored throughout the system.

Advancements: Improved instrumentation and sensors, such as pressure switches, gauges/transmitters, flow regulating valve, analyzers and controls. The use of a stator leak monitoring system (SLMS) is recommended. The system is designed to detect stator water leaks by monitoring the amount of hydrogen gas venting from the stator cooling water tank.

Exciter Systems

A number of different types of excitation systems are used on large synchronous machines. Within the three main categories, rotating, static and brushless, there are many different designs (1). It would be quite difficult to detail all issues that should be addressed during an outage. Users should refer to the OEMs recommendations.

Monitoring/Sensor Systems

Generator monitoring and sensor systems cover a wide range of approaches. They can be as simple as a single point sensor or as sophisticated as an expert system.   For the purpose of this paper, the devices include the following: gages/transmitters, vibrations monitoring systems, generator condition monitoring, dew point analyzers, gas purity analyzers, temperature monitoring systems and gas dryers.

It should be noted that although the number of devices discussed in this paper are limited, all monitors and sensors should be evaluated and considered for upgrade or replacement during a generator rewind:

- **Generator Case Pressure Gages and Transmitters** monitor the hydrogen pressure in the generator. Generator case pressure has a direct effect on performance capability of the generator.

- **Generator Fan Differential Pressure Gages and Transmitters** are used to determine the integrity of the hydrogen blower and ventilation system. A change in fan differential pressure can be a result of missing fan blades, ventilation blockage or change in hydrogen purity.

- **Vibration Monitoring Systems** consist of individual sensors that are used to monitor frame vibration, stator end winding vibration, rotor vibration and torsional vibration. High vibrations can be an indicator of cracking in frame welds, loose end winding support structures, mechanical or thermal unbalance, shorted rotor turns, severe system disturbances or power system resonant frequencies.

- **Generator Condition (Core) Monitors** detect overheating and the breakdown of insulating materials in the generator. A Generator Condition Monitor detects thermal decomposition particulates in the hydrogen stream at the earliest stages of thermal decomposition and before a “hotspot” can lead to a catastrophic failure.

- **Gas Purity Analyzers** monitor the purity of the hydrogen gas inside the generator case during normal operation. Some equipment may also monitor the purity of gas used during generator purging. A loss in hydrogen purity will cause higher windage losses that will cause lower generator efficiency. Monitoring hydrogen is also a safety issue since hydrogen is potentially explosive when its purity falls below 75%.

- **Dew Point Analyzers** monitor the moisture level in the hydrogen gas inside the generator case. High moisture levels in the hydrogen can cause several undesirable conditions such as, electrical tracking of the insulation, stress corrosion cracks, rotor turn-to-turn shorts and reduced generator efficiency. Dew point is an indicator of the effectiveness of hydrogen dryers.

- **Temperature Sensors** are used to monitor various mediums within the generator, such as armature bars, hydrogen cold gas, hydrogen hot gas, stator water inlet, stator water outlet, seal oil and metals.

- **Gas Dryers** are used to remove moisture from the cooling hydrogen. High dew point in the hydrogen can lead to component failure, shorted rotor turns and tracking in the windings.

Advancements: All of the above-listed devices have been improved over the years to increase reliability and performance. They are now available with local indications, adjustable alarm levels/with contact closures and electrical outputs that can be feed into the distributed control and information system (DCIS).
Instruments that are used in a hazardous area should be third-party approved for that area. All wiring to the instruments shall be per the applicable code (NEC/NFPA-70) for the hazardous area. Switches in Div 2 areas should have NEMA 7 enclosures with hermetically sealed contacts, even if in non-incentive circuits.

Redundant Indications: Unnecessary plant load reductions should be avoided with the same emphasis put towards ensuring the load is reduced when necessary. This is the philosophy of the plant operators as well as of the plant designers. Therefore, it is recommended that critical measurements be redundant, so that alarms can be confirmed within the time frame the operator has available to make the critical applicable decision. Mechanical local gauges are required for secondary confirmations, which will often be performed by the operators.

Advanced materials and circuit design have led to instrumentation capable of operating at higher ambient temperatures while providing a stable signal. This point is of particular importance in applications where instrumentation will be installed in high temperature locations.

Other monitors that should be evaluated are partial discharge monitors, shaft-grounding monitoring, radio frequency monitoring and rotor shorted turns detection.

Conclusion

Upgrading generator components can be a complicated process that requires a considerable amount of pre-planning, extended outage times and a significant financial investment. To help secure this significant investment, a proactive approach for evaluating and up-grading critical auxiliary systems should also be considered. Utilizing a "flexible philosophy" for prioritizing auxiliary system up-grades should prove to be a valuable tool in this process.

A Footnote On Safety

Although the use of hydrogen gas as a cooling medium has several performance benefits, it must be monitored carefully to prevent catastrophic oxidation. Colorless, odorless, tasteless and nontoxic, hydrogen exists as a gas at atmospheric temperatures and pressures. Hydrogen is flammable and burns in air with a pale blue, almost invisible flame. In its gaseous form, hydrogen dissipates quickly. These unique properties call for strict safety measures in hydrogen use and storage.

Precautions must be taken to safeguard against a hydrogen explosion. One such precaution is to never permit an explosive mixture to exist. Hydrogen ignites over a wide range of concentrations (from 4 to 74.2 percent by volume). Generators and auxiliary systems are designed with many features to avoid an explosive mixture. In order to ensure the design is operating properly operators should monitor hydrogen gas purity on a continuous basis. The following information is intended to define the basic components of a hydrogen auxiliary system in addition to identifying some areas worth upgrading during planned outages.

In the power industry, millions of cubic feet of hydrogen gas are used every year. The intent is that hydrogen is used under carefully controlled conditions using specified procedures by trained personnel. However, as equipment ages and personnel changes occur with limited training, there becomes a potential for a serious problem.

A safe modern hydrogen auxiliary system is designed to operate in a Class 1, Division 1, Group B hazardous area. These systems will often apply the following protective mechanisms:

- Explosion proof or flameproof enclosures — Electronics are housed in a flameproof enclosure that incorporates a bolted cover or screw cap requiring tooling to remove. The enclosures are in conformance with recognized standards.
- Intrinsic safety — Displays and sensors are designed as an intrinsically safe circuit in which any spark or thermal effect produced under normal operation and specified fault conditions, is not capable of causing ignition of a given explosive gas atmosphere.
- Encapsulation — Devices such as solenoid coils are encapsulated in order to keep any potential flammable gas mixtures out of and away from the coil.

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