Thought leadership
White paper

Modernization strategies for improved generation and power system performance and safety

Jess Yenter
Project Manager, Eaton, U.S.

Abstract

By 2050, it is estimated that about half of the entire fleet of existing hydropower assets will need to be modernized. The upgrades required present an opportunity to do more than keep the proverbial lights on. Today, updates to the electrical infrastructure essential to hydropower plant operations can enhance safety and improve asset management and performance. Innovations in control systems, cybersecurity, plant and fleet modernization, outage management, condition monitoring equipment and more are providing data that can be used to yield actionable insights to increase the value of hydropower assets.[1]

Further, the aging hydroelectric infrastructure is increasingly relied upon to provide regional power and system support. Increasing renewable generation and transmission system constraints are driving changes in regulatory and market conditions. These changes are occurring in an environment where evolving standards are trending towards stricter environmental regulations and treating all grid-connected generation assets the same regardless of machine size or capacity.

Compounding these issues, hydroelectric facilities across North America are typically older and operate with a mismatched and often obsolete assortment of hardware and controls that are not optimized to work as a unified system. These plants have undergone various updates, additions and modifications over the years. The electric power grid has also evolved, frequently leading to conditions such as increased utility contribution to fault current that can impact the safety and reliability of hydro generating stations.

In order to help hydroelectric owners and operators address these challenges, this paper will provide best practices for strategically upgrading aging electrical systems. The strategies, methods and techniques proposed in this paper are intended to support optimum generation and power system performance and safety. For the purposes of this paper, useful life expectancy of electrical equipment is defined as the point in time at which equipment no longer performs its intended function reliably.

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Determining project scope

"Where do I start?" Many factors need to be considered when upgrading a facility, including regulatory compliance, safety, reliability, capacity, cost, and operational constraints. When considering electrical and control equipment, it is important to define system goals and objectives first. Both new and existing system components in a generation facility need to be evaluated to ensure overall system requirements are being met; assessing existing equipment is a key aspect to upgrading facilities.

Categorizing equipment and evaluating each system is helpful and ensures that future operation requirements will be met.

System specifications

The system specification process should take into consideration the specific requirements of the project in conjunction with overall preferences based on past experience and local support. To serve as guides in the system design process, several road maps should be consulted.

The one-line diagram for electrical equipment needs to be analyzed. This document helps visualize the entire scope of the electrical upgrade including equipment sizes, relaying and logic schemes, metering points and data requirements. Simple operating one-line diagrams may not provide enough detail to adequately define the project.

1. International Hydropower Association, 2017 Key Trends in Hydropower, available: www.hydropower.org/sites/default/files/publications-docs/2017%20Key%20Trends%20in%20Hydropower_0.pdf

Control system network architecture requirements should be defined early in the specification process before equipment is purchased. This will guide control and data requirements of the project and determine the communication methods to be used. Modern control and protection systems are capable of gathering and storing tremendous amounts of information that can be critical to the control of the system and aid in tuning, trouble¬shooting and commissioning the plant.

If available, a process and instrumentation diagram (P&ID) is a useful tool in defining process-related systems for the facility. Water convey¬ance diagrams should have all gates and valves clearly identified and labeled such that all stakeholders are calling equipment by the same name. Other P&IDs should include cooling systems, hydraulic systems, temperature monitoring and other auxiliary systems that require instrumentation. The P&ID serves as a roadmap for all work on subsystems so that system requirements are clearly defined and communicated and all parties (owner, engineer, suppliers, contractors and so on) are working toward the same goal.

Once review of these diagrams is complete, detailed design and equipment specification can begin. All of the effort put into the scoping phase should aid in the development of complete and well documented upgrade plans.

Checklist of major system components to consider

Many of these systems include mechanical and/or hydraulic systems that must be controlled:

✔ Switchgear and associated breakers

- Generator breakers
- Station service equipment

✔ Protection systems

- Generator protection
- Bus protection

✔ Control systems

- Plant control system
- Unit control systems
- SCADA/RTU systems
- Governors
- Exciters
- Machine condition monitoring systems
- Metering
- Auxiliary system controls
- Waterway management

✔ Plant auxiliary systems

- AC and DC distribution
- MCCs
- Field instrumentation
- Lighting
- Cable systems
- Security—both physical and network/cybersecurity

Prioritizing plant upgrades

Targeting specific subsystems for upgrades should be based on factors that affect the safety, production, regulatory and economic/market performance of the plant. For example, outage and maintenance records can lead to prioritization for upgrading particular subsystems that have caused failed starts or forced outages. The age and availability of spare parts for existing systems should be considered as repair time affects outage duration. Equipment that is no longer supported by the OEM or a qualified aftermarket service should have a high priority for replacement.

Safety

Safety, in particular arc flash safety, should be a prime consideration. Arc flash hazard analysis is required, as the National Electrical Code (NEC) requires that personnel are to be protected from arc flash hazards associated with electrical systems. This analysis should be performed in the planning stages of a project to guide systems engineers in the selection of the appropriate protection and power equipment.

Figure 1: Recent innovations in arc quenching technology can significantly enhance safety and enable low-voltage switchgear to withstand an arc flash event with minimal or no damage, substantially reducing downtime resulting from arc flash events.

Integration of system protection studies (short circuit, load flow, protection coordination) into the review process will also identify capacity-related problems with existing infrastructure. The entire protection system needs to be evaluated against today's standards, as practices have evolved. Existing protection may need to be updated. Often owners, interconnected utilities and/or insurance companies require that protection systems meet current Institute of Electrical and Electronics Engineers (IEEE) and American National Standards Institute (ANSI) standards.

System protection and control

Modern digital protection and control systems have advanced control and diagnostic capabilities not available in previous generations. Digital speed, accuracy, memory and repeatability have been leveraged to improve performance of and increase information available from these systems. Multi-function devices have reduced the amount of wire and cable required for these systems and new operator interface systems provide far more information than older hardwired systems. Advanced communication systems allow wider, secure sharing of the data available.

The addition of expanded communication networks and integration of multiple digital devices results in the need for increased emphasis on cybersecurity. Along with the physical security of the plant including perimeter and station security, the design and access capabilities of new networked devices need to be understood and accounted for in the design of any upgrade.

Plants that have already been through an upgrade to newer analog and/or digital technology will typically be easier and less expensive to upgrade to newer versions of these systems. It is often possible to replace and upgrade just the "brains" (ex. processors and memory) of these systems with little disruption to field structures, cables and wiring. While it is true that new digital controls systems will not have the same expected life as the original mechanical/hardwired protection and control systems, the lower cost, reduced complexity and easier upgrade path of the updated systems make them the better choice.

Machine condition monitoring

Along with the protection and control systems, field instrumentation and sensors should be evaluated for performance, reliability and maintainability. These devices are typically inexpensive relative to a failed start or forced outage, and technology has improved to provide increased reliability and more information.

In many cases switches or relays related to variables such as temperature, pressure, level, flow, position, etc. can be replaced with analog devices that provide improved monitoring, diagnostic and condition monitoring capability. Integrating these new, smart sensors into an updated protection and control scheme can improve reliability, troubleshooting and maintenance planning.

A relatively quick tour of a hydro power plant can be used to identify other areas that need to be prioritized. For example:

- **Alarms that are routinely disabled** can indicate a potential hazard or impending failure and should be addressed
- **Calibration stickers on protection,** metering or measuring devices that are out of date may indicate other events or conditions have overtaken these routine tasks or that specific expertise to perform these duties has been lost
- **Devices that are commonly locked out,** bypassed or require regular special attention to operate should be considered for updates
- **Identification of hazardous material** such as mercury switches and asbestos wire insulation or cable trays may indicate an opportunity to reduce long-term risk of exposure within the plant

Finally, a review of the existing drawings/documentation at the plant will indicate the quality of these documents relative to operating and maintaining the facility. Many plants have undergone updates and repairs that are not recorded on the documentation, which makes troubleshooting, repair and upgrade work more difficult and time consuming.

Evaluating two approaches to plant modernization

Two methods are regularly employed to upgrade hydro plant electrical infrastructure. In this paper they will be referred to as subsystem replacement and comprehensive update. As implied by the names, the subsystem replacement upgrades are undertaken on a limited scope of supply while a comprehensive update refers to an integrated solution intended to improve reliability and performance at a unit, plant or system level.

Figure 2: A highly skilled and experienced project team can help reduce project risk based on demonstrated, successful completion of similar hydroelectric projects – whether they involve the replacement of a subsystem or a comprehensive update. Further, a vendor able to provide resources and experience needed allows facility staff to stay focused on broader initiatives.

Subsystem replacement

There are various features, benefits and drawbacks associated with each of these two approaches that will factor into the decision-making process. In the subsystem replacement process, planning time and effort are minimized and, in some cases, it may be possible to pay for the upgrades using O&M budget money. This type of upgrade often indicates a particular subsystem has reached the end of its useful life and the upgrade may be compelled by a failure leading to an unplanned outage. This type of project will often address an immediate need and will require a relatively limited budget.

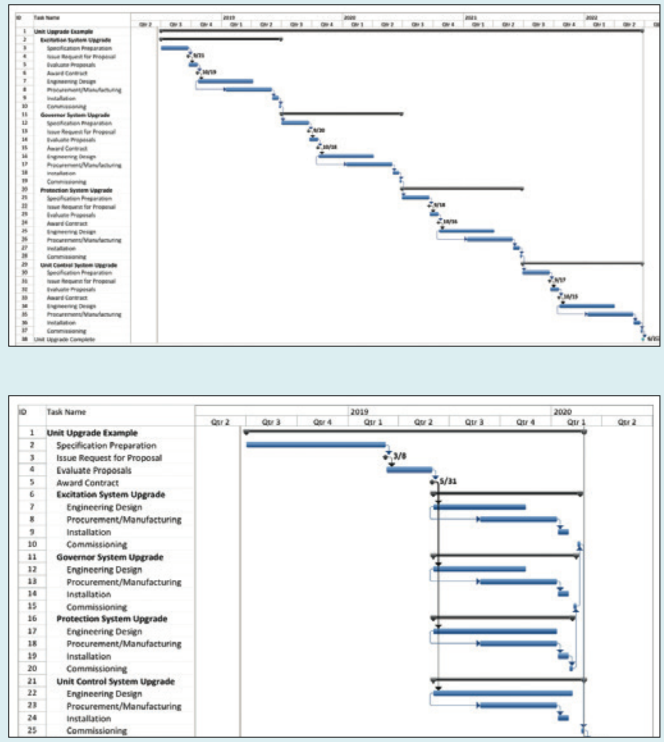

Figure 3: These charts show sample project management schedules for a subsystem replacement (top) and comprehensive upgrade (below). It is noteworthy that these figures represent an equivalent amount of work, however the subsystem approach will likely require a much longer timeline (and corresponding increase in cost) than an comprehensive update.

Comprehensive update

A comprehensive update can leverage the capabilities of new devices and platforms into a more capable system with a reduced footprint and less complex wiring. The new systems can add further value by utilizing remote communication, control and monitoring capabilities. An additional benefit is that final plant documentation can be produced with high confidence since a comprehensive update will, by its nature and definition affect the entire electrical infrastructure of the plant. Since the errors/omissions in current documentation were primarily due to changes made since the plant was constructed, replacing these systems as completely as possible will ensure what is left of the original drawings/documentation is limited to field devices and cabling that are well known.

Before undertaking a comprehensive update, it should be understood that the planning and specification process might be complex and lengthy. The capital budget required to perform the upgrade will be significant and justification will have to be well documented.

Installation and commissioning considerations

A significant challenge in any upgrade project is scheduling the work to minimize downtime and to yet allow sufficient time for planned work to be executed. Multiple factors impact the schedule, including:

- **Seasonal variations**—peak demand periods, spring runoff, winter flows, planned releases, and so on
- **Concurrent work at the plant**
- **Resources**—contractors, plant staff, owner's representatives, and the like

If possible, build flexibility into the schedule to accommodate seasonal variations. Scheduling too much work during an outage is also a concern, especially at smaller facilities where space and access are limited. One project manager should be responsible for coordinating all activity onsite to ensure that each group (mechanical, electrical, civil) has the time and access required to efficiently perform their scope of work.

Final considerations and conclusion

While our collective demand for power continues to increase, hydroelectric utilities and plant operators are challenged not only with an aging infrastructure but are also tasked with doing more with less. Additionally, many experienced personnel are eligible for retirement; for example, according to a 2015 workforce survey by the American Public Power Association (APPA), 55 percent of electric utilities reported that within five years at least 20 percent of their workforce will be eligible for retirement. In other words, approaching plant modernization projects to reduce maintenance requirements and improve performance is essential.

Hydroelectric power generation is a significant resource that can be used to balance the intermittent nature of other renewable energy and provide a reliable and predictable power source—all while offering recreational opportunities. By strategically approaching plant upgrades and automation projects, operators can extend the serviceable life of their equipment while improving the efficiency, reliability, and safety of their systems.

Whether a subsystem replacement or comprehensive update approach is taken, it is always vital to first clearly identify the project requirements, goals and risks. To enhance project success, establish priorities and set a budget and schedule that take into consideration factors such as market, control area, regulatory requirements and business goals. Leverage internal resources that have engineering, operations and maintenance experience with the facility and understand plant, unit and waterway characteristics. Once these steps have been completed research available technologies, solutions, integrators and equipment suppliers to best meet the specific needs of the upgrade

Figure 4: The hallmark of a successful project is the relationship between the project manager and its supplier. It is not simply a matter of selecting equipment that meets a specification but finding a supplier that will be a partner to actively listen to evolving system requirements and ease integration of new technologies into existing systems and facilities.

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Author

Jess Yenter has over thirty years of experience in managing and working on automation and control systems for hydrogeneration facilities. He's currently a project manager at Eaton and leads turnkey projects for generator station protection and control solutions. He has extensive experience in system design, field service, sales and marketing management.

Eaton
1000 Eaton Boulevard
Cleveland, OH 44122
United States
Eaton.com

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