

## CHALLENGES AND BENEFITS OF INTEGRATING MODERN AUTOMATION TECHNOLOGY INTO LEGACY HYDROELECTRIC CONTROL SYSTEMS

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Technological advancements in process control systems, along with changing hydroelectric business models, have created a need for automated unit control and plant control systems. Unit control and plant control systems have evolved from hardwired relays, switches and meters mounted on bench boards to digital Programmable Logic Controller (PLC) platforms with computer-based Human Machine Interfaces (HMIs). Retrofitting an existing hydro unit or hydro station with modern automation equipment presents many challenging design questions to the owners, engineers, operators, and maintenance staff. This paper explores several of these design considerations, how best to implement them, and the associated cost implications as they relate to four main topics: control system design concepts, implementation strategies, security issues, and training considerations.

### CONTROL SYSTEM DESIGN

#### BASIC DESIGN CONCEPTS

There are many ways to approach an existing hydro unit or hydro station automation project. One such way is to eliminate, or minimize, the hardwired bench board controls and replace them with microprocessor based control systems, typically PLCs and HMIs. This approach is often less expensive than other alternatives as it can save on field work, engineering, and construction costs. Field work can be somewhat limited to the identification and nameplate data gathering of the various Input & Output (I/O) devices, which may include some of the existing bench board switches and meters.



Engineering becomes a little less complicated due to the design being all new, except for the I/O devices; that is to say, the engineer does not need to try to integrate the new system into the old control strategy. For example, with an all PLC & HMI based system, the engineer can assign the I/O devices for a cooling water system to specific PLC I/O points and implement the entire control functions with software logic. Whereas, with a hybrid system of PLC & HMI controls with legacy hardwired controls, the engineer would need to integrate the I/O in parallel, or in series, with the existing hardwired controls and account for any actions from either system in the software. For example, if an operator changed the state of an existing On-Off-Jog switch in the field, the new PLC system would likely need to know and react accordingly.

Construction will likely be less for a PLC & HMI (only) based system as PLC I/O racks can be strategically located where the I/O cables currently enter the control system and then the I/O racks can be networked to the process rack via a single (or redundant) network cable(s). This approach makes use of existing cabling, which helps keep costs down.

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Another common control system design concept, as alluded to above, is a mix between hardwired controls and PLC & HMI controls. This hybrid system has many advantages over utilizing the traditional hardwired controls concept or PLC & HMI controls concept alone. This approach allows for the continued manual operation of the units, via existing hardwired components, if the PLC based system is malfunctioning. Additionally, this approach facilitates all the advantages of the modern control systems, such as efficient unit/plant scheduling, monitoring, alarming, trending, and full remote (off-site) operation, when in service.



The biggest disadvantage of the hybrid system is the upfront capital cost during the field work, engineering, and construction phases. More time and effort will be required for the field work because existing systems, devices, and hardware will require detailed documentation (or verification of existing documentation). Existing cable tray and conduit routings will also need to be identified for any additional cables needed. The existing bench board devices will also require investigation for spare contacts and signal I/O.

Existing protective relays do not necessarily require replacement; however, investigation and documentation of their I/O and settings may be necessary. The stakeholders may wish to consider upgrading the protective relays to modern digital relays, as they can be easily networked into the new PLC based control system for monitoring and data gathering. Many modern relays can provide additional protections, metering information, and oscillography data for little added cost.

If the main objective of the project is achieve remote (off-site) monitoring and controls, a more economical option may be to interface a Remote Terminal Unit (RTU) directly with the unit(s). An RTU is a digital electronic system, like the PLC, but is limited in its capabilities for localized control. Typically, an RTU will automate certain basic functions, such as a stop command or trouble alarm, for a central command center (off-site). RTUs are more suitable for networking and communicating with various sites across a wide geographic area than for localized controls. A PLC based control system can be networked to the central command center so the local control limitations of the RTU may not be worth the trade off.

The various concepts are summarized in Table 1 below.

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TABLE 1 CONCEPTS OF AUTOMATION

SYSTEM	INITIAL COST	OPERATING & MAINTENANCE COST	UNIT & PLANT CONTROLLABILITY
Legacy Hardwired	N/A	High	Low
PLC & HMI (only)	Medium	Low	Medium
Hybrid System	High	Medium	High
RTU	Low	High	Low

**DESIGN APPROACHES**

When using PLCs to automate any process there are generally two distinct design approaches: distributive and centralized. A distributive control system installs several I/O racks throughout the process that are physically located close to I/O devices. Some control systems, such as the Allen-Bradley Point I/O equipment, allow for the automation to be distributed such that the I/O racks can be taken out to individual or small groups of I/O points. More commonly, however, an I/O rack will be placed statically in area where many field devices are located within one hundred (100) feet or so of the I/O rack and each point will be wired back to that particular I/O rack. The number of I/O racks and their locations are dependent on I/O device densities and geographic proximity, which will be the engineer's responsibility to analyze. Once the I/O devices have been wired to the I/O Racks, then a communication cable (e.g., Ethernet) is installed from the I/O racks back to the processor rack. This approach saves money on installation costs by minimizing conduit, cable, and cable tray, as each I/O device is wired into the system locally.

A centralized system typically has one location, which is often a control room, where the processor rack and all I/O racks are located. Each I/O device is wired back to that location for a connection to the system. This approach allows for tighter security, as all of the "intelligent" hardware can be located in a physically controlled area. In some cases, maintenance may be easier, as most of the equipment and connections are concentrated in one area. Troubleshooting may be a little harder, however, as the field devices are not located locally to their connection the points into the system. Another typical disadvantage is the installation costs due to the longer cable runs and wire ways.



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**TABLE 2      DISTRIBUTIVE VS. CENTRALIZED APPROACHES**

<b>SYSTEM</b>	<b>INSTALLATION COST</b>	<b>SECURITY</b>	<b>MAINTENANCE</b>	<b>TROUBLESHOOTING</b>
Distributive	Medium	Low	Harder (Distributed over large area)	Easier (connection are local to devices)
Centralized	High	High	Easier (Local connections and controls equipment)	Harder (connections are not local to devices)

**GOVERNOR CONTROLS**

Governor control is often the most challenging portion of a hydro automation project. Many legacy governing systems have hydraulic wicket gate servomotors controlled by fly ball governors. One approach is to replace the fly ball governor portion of the system with a digital governor controller (e.g., Woodward 505) and leave the remaining governor and hydraulic components in service. This approach will allow for excellent governor response times. The digital governor can be interfaced with a PLC for integration into the overall process control system. This approach will typically allow for isochronous (A.K.A. Islanded) control, although there may be limitations dependant on the size of the unit and load demands.

Another approach is to implement the governor control functions in the PLC programming. This approach simplifies the control system design and lowers cost somewhat because the purchase, installation, and interface with a digital governor are not required. The existing hydraulic components can often be modified and reused, as compared to installing all new hydraulics, which can also save money. The hydraulic power unit (HPU) system will require a servo valve, if it does not already have one, which can be interfaced with the PLC control system. The servomotor and PLC based governing controls, in this approach, are usually acting only as a gate positioner (e.g., power setpoint), and are somewhat more limited in terms of governor response times. Isochronous controls are still possible, but are impacted more significantly by larger fluctuation in load demand than if using a digital governor.

**TABLE 3      GOVERNOR CONTROLS**

<b>SYSTEM</b>	<b>INSTALLATION COST</b>	<b>RESPONSE TIME</b>	<b>ISOCHRONOUS CONTROL</b>
Fly Ball	N/A	Medium	Medium
Digital Governor	High	High	High
Gate Positioner	Medium	Medium	Medium

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## **REDUNDANCY**

Modern PLC based controls systems are typically very reliable; however, they are subject to malfunctions like any other system. For this reason, redundancy can be designed into the control system to minimize down time. There are many levels of redundancy that can be implemented and each stakeholder must have a voice in the decision. A few of the redundant options are listed below:

- Power Supply Redundancy: Redundant power supplies.
- PLC Redundancy (option A): Redundant I/O cards (in a single rack), processors (in a single rack), and power supplies.
- PLC Redundancy (option B): Redundant I/O racks, processor racks, and power supplies.
- PLC Redundancy (option C): Redundant I/O racks, processor racks, networking equipment, networking cables, and power supplies.
- Full Redundancy: Redundant I/O devices and wiring (for critical devices), I/O racks, processor racks, networking equipment, networking cables, and power supplies.

There are many variations to the different levels of redundancy and each has an impact on the stakeholders. Full Redundancy, for example, will be costly, as the owners will nearly be purchasing two systems for a single process. In addition, the design, programming, and maintenance of these systems tend to be more involved, which will increase the costs of engineering, installation, and overall ownership. The reliability and uptime of the system will be very high, however, and thus may be well worth the investment.

Systems that are not critical to unit or plant operations may not warrant the added cost of Full Redundancy or may simply require some lower level, such as redundant power supplies. Many times, at least one of the sources of control power originates from the station battery system which, in itself, contributes to the overall reliability and uptime of the system.



## **IMPLEMENTATION STRATEGIES**

Pre-shutdown installation work is one of the major challenges of implementing a new control system over a legacy system, as it is often desirable to maintain operation of the legacy system during construction. The challenges can vary slightly depending on the controls concepts being deployed and they may include location of HMI equipment in the control room, location of the PLC processor and I/O racks, tie-ins into existing wiring or power panels, reuse of existing conduit & cable tray.

Legacy systems often utilize bench board controls with hardwired switches and meters and, therefore, often make great locations for the HMI as well. It is sometimes difficult, however, to integrate an HMI into an existing bench board without first moving, or removing, some of the existing devices. This is especially true with a hybrid system, because many of the existing

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devices will remain in service. One approach to mitigate this issue is to make use of a desktop computer based HMI for the new automation system. This will allow for the start-up team to complete many of the checkout and start-up task prior to cutover of the field devices. In the meantime, operations can continue to run the plant with the hardwired controls. After cutover the unit can be operated via the desktop HMI while the bench board is being reconfigured for the new HMI. Once this is complete, the bench board can be reintegrated with the system and checkout completed. After the project is complete, the desktop computer based HMI can either be removed or left in service as a redundant HMI.

Location of the PLC processor and I/O racks can become an issue, particularly if a centralized approach is deployed and is making use of existing wiring. Most of the field device wiring terminates behind the bench board, as it was typically hardwired to the bench board devices, making this the ideal location for I/O racks. However, the insides and back sides of bench boards are often overcrowded, leaving little room for additional hardware. One approach is to identify unused cable, terminal blocks, equipment, and devices and remove them or, if they are needed, relocate them, which may free up enough room. A first stage cutover then may then be possible, which will allow for more equipment and cables to be removed or relocated. This can be repeated until the entire system has been cutover.

Another approach is to find a location near the control room, where most of the cables pass by, and install the equipment there. During the cutover, the cables can be determined, hauled back, and reterminated in the new system. It is likely that not all cables will be long enough or take the necessary route to make this possible, so some new cables may be needed in this approach.

An approach used at a facility on the Androscoggin River in Maine, was to identify the major “trunk” runs of cables that were installed from various areas of I/O devices to the control room, and then to install new runs from these areas to various secure rooms where the new I/O racks were installed. The processor rack was installed in the control room and then networked to the various I/O racks. This approach, comprising a mixture of the distributed and centralized concepts, allowed for existing controls and operation to remain undisturbed until the entire new PLC equipment was in place, started-up, and checked out. Cutover went very quickly as most of the debugging was already complete.



### SECURITY ISSUES

The project team members must consider the new security risks that may be introduced when implementing modern control systems in existing hydro stations. Modern control systems are typically microprocessor based, networked together, and networked to the “outside world” (off-site locations), which may make them vulnerable to cyber attacks. However, depending on the system design, automation concept, and equipment selection the security risks can be minimized.

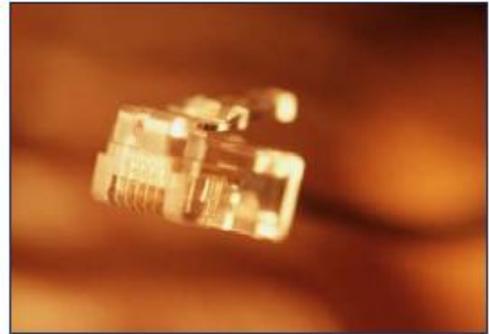
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In addition to the electronic protections of a hydro facility, physical protection of the cyber equipment and networks must also be addressed. The North American Electric Reliability Corporation (NERC) has published a set of Critical Infrastructure Protection (CIP) standards that outline various cyber and physical security requirements based on the classification of particular facilities and assets. For example, if a facility has black start capability and the regional ISO relies on that facility to help recover from an outage event, then that facility is likely in a higher classification of security and may be required to have more robust security protections in place.

A centralized control system is preferred from a security point of view since the cyber equipment is located in physical enclosures (e.g., a control room), is more concentrated, and easier to control access. There are typically little or no communication lines routed outside the physically secure area, which makes the cyber security measures easier to implement. For those communication lines that do cross the physical security perimeter, a fire wall, unified threat manager, and/or other similar equipment and software, must be installed at the first point of entry.



A distributive control system is more difficult to secure due to the large communications network. Each network switch, hub, and router, as well as PLC processor and I/O rack, may be required to be secured in a “six-walled” enclosure with controlled access, making maintenance and troubleshooting more cumbersome.

Selection of communication network hardware, media, and protocols can be chosen to help mitigate cyber attacks. For example, in one facility we have chosen to use Ethernet networks in physically secure locations only. Networks that extend outside the physical perimeter must go through the backplane of a PLC rack, through a network scanner card, and must be a different protocol, such as ControlNet or Modbus. While this does not protect the system by itself, it does provide another layer or two for a potential hacker to work through.

There seems to be a general agreement among the community members that the NERC-CIP standards require “routable protocols” be secured and not “non-routable protocols.” However, there seems to be some disagreement on which protocols fall into either category. Some argue that Ethernet is the only routable protocol, while others argue that all protocols are routable. Regardless of which side individuals seem to fall on, most agree that in the future, NERC-CIP standards will likely require that all protocols be secured; therefore, it good design practice for all new networks should consider including the proper security measures.

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## TRAINING CONSIDERATIONS

To insure a smooth turnover of the automation upgrade, the operations and maintenance staff will need adequate training on the new system and equipment components prior to start-up and turnover. Engineers and designers often go to great lengths to make the transition as easy as possible, but the legacy system and modern system are fundamentally different, and the modern equipment requires a different set of comprehensive skills.

Operations staff will be most interested in the HMI function of the new systems and how they relate to the existing controls. Through the design process, the engineer should be conscious of the existing controls functions, process, and layout to minimize the impact on operations staff. For example, in a hybrid system, the PLC & HMI start-up sequence (in either manual or auto mode) should follow the existing process to the extent possible, even if small modifications are possible.



Advanced unit and plant monitoring, alarming, and trending functions are typically features of the modern control system. This may be all new to the operations and maintenance staff and should be a major focus of the training program. The training for operations should concentrate more on the various responses to the new information while the training for maintenance should focus on viewing these as troubleshooting and preventive maintenance tools.

Maintenance staff will require training beyond the functions of the HMI and into details of the PLC hardware, network hardware, software programming and troubleshooting functions for the PLC processor, HMI, and network equipment. Design engineers should be aware of the hydro station's existing hardware and software, if any, so as to minimize the training required for maintenance staff.

## SUMMARY

Each stakeholder—owners, engineers, operators, and maintenance staff—should be fully engaged during all stages of the design, construction, and start-up process of a hydro unit or hydro station automation upgrade. The controls concept should be one of the first things considered, with each stakeholder weighing in on the challenges and benefits to the existing, PLC & HMI (only), hybrid, and RTU control options. The hybrid option provides the most flexibility, but is typically the most expensive to implement.

If a PLC & HMI (only) or hybrid option is chosen, the stakeholders should then weigh the challenges and benefits to the design approach—distributed vs. centralized—while being sure to address governing and redundancy options. A distributed system with a gate positioning

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governor and no redundancy will likely be the least costly approach, but will also likely provide the least amount of security, isochronous flexibility, and up-time.

Implementation strategies are important to discuss early on and should not be left until the construction phase draws near, as early design decisions can have an impact on the execution of the project. The focus of the implementation strategy is typically around the physical layout of control rooms and bench boards, and what equipment or hardware is to be added during construction, while minimizing the impact to operations.

Security concerns should be discussed prior to the beginning of design to identify the facility and asset classification and level of security required, as it may be a governing factor for the controls concept and design approach. For example, the security concerns may warrant a centralized design approach when a distributive design would otherwise be desirable.

Finally, training needs for the operations and maintenance staff may be high, particularly if they are unfamiliar with the new equipment and software, and may require several weeks or months of training. Early design decisions can minimize the need for training if similar existing systems are in service elsewhere in the facility. Training is often one of the last items to be addressed, but waiting until the end of a project is typically not prudent. At a minimum, training must be completed prior to start-up.

Navigating the challenges and weighing the benefits of upgrading legacy hydro electric control system with modern digital equipment is as much an art as it is a science. Discussions on control concepts, design approaches, and system maintainability, by all stakeholders throughout the project, will greatly increase the chances of project success.

