ePIC Slow Controls Plan

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Revision History

Rev	Author	Description	Release Date
1.0	L. Flader	Initial release	2024-07-19

List of Acronyms

BNL	Brookhaven National Laboratory
DAQ	Data Acquisition System
EIC	Electron Ion Collider
ePIC	electron-Proton and Ion Collider experiment
EPICS	Experimental Physics and Industrial Controls System
MPS	Machine Protection System
PL	Performance Level
PLC	Programmable Logic Controller
SIL	Safety Integrity Level
UPS	Uninterruptable Power Supply

1.0 Document Summary

The following will describe a high-level proposal for the implementation of slow controls in the electron-Proton and Ion Collider experiment (ePIC). For this document and the experiment at large, slow controls are defined as: the collection of equipment and software that samples, aggregates, interprets, and responds to data changing at a rate multiple orders of magnitude slower than is sampled by the experiment's Data Acquisition System (DAQ).

2.0 Slow Controls Network

The slow controls network will consist of multiple serial interfaces within the experiment facility through which all slow controls equipment will communicate. Detailed in this section are a plan for equipment integration, a suggested network topology, and a projected data load the network may witness.

2.1 Protocol Support

The slow controls system for ePIC will be run using the open-source Experimental Physics and Industrial Controls System (EPICS). All equipment managed by EPICS will need to communicate over an ethernet connections. For any devices not equipped with a means to communicate over TCP/IP directly a protocol gateway will be required. It will be the responsibility of detectors to provide any gateways needed to interface with their equipment.

2.2 Topology

The slow controls subnet will assume a star topology with redundant ring networks branching from a central trunk for use by programmable logic controllers (PLCs) managing the machine protection system (MPS) and detector subsystems (see Figure 1). All equipment that communicates over ethernet will connect to the trunk directly. Any equipment that does not use an ethernet supported protocol (MODBUS, CANBus, ASCII, etc.) will connect to the network through either a dedicated PLC IO module or a network enabled gateway. Sensors and actuators for interlocks will be integrated into the network via the subdetector and infrastructure PLCs. This topology will ensure robustness in communication while leaving room for expansion as ePIC grows and incorporates new hardware. This also creates a physical reflection of the host/client structure of EPICS.

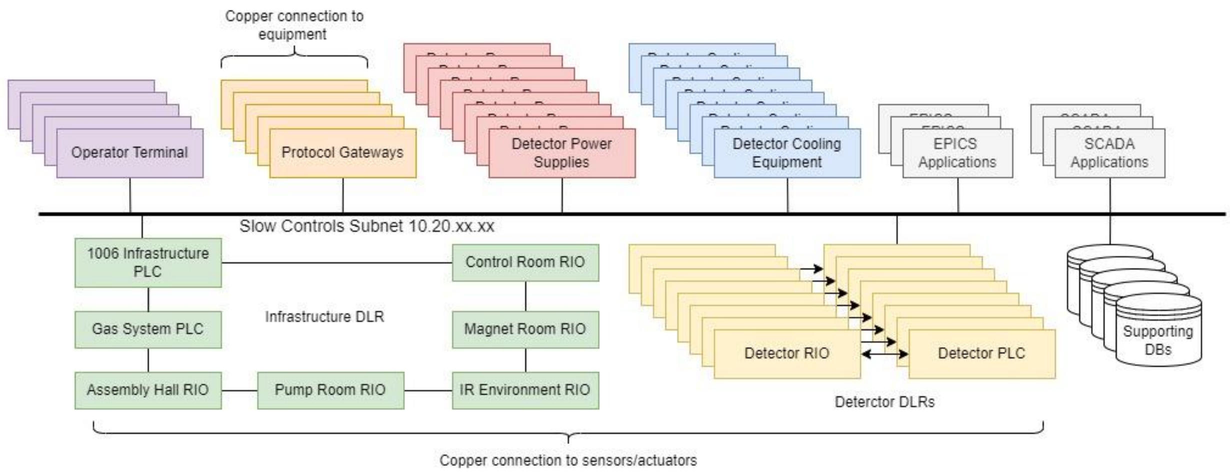

Figure 1 – Proposed ePIC Slow Controls network topology

2.3 Network Load

In January of 2024 a survey was submitted to the ePIC subdetectors to estimate the slow control demands of each subsystem. The survey responses are mostly qualitative but collected information about the type and rough number of parameters to be polled, as well as the polling rate of these parameters. Responses were used to estimate data load with the following method:

1) Each producer of data (i.e. a piece of equipment or subsystem) is considered a data channel
2) Each data channel produces at least 1 data point
    a. For the case of specified cooling and gas parameters, a minimum of 2 data points is assumed for supply and return measurements
    b. For unspecified cooling and gas parameters, a minimum of 6 data points is assumed for supply and return measurements corresponding to the three most common measurements: temperature, flow, and pressure
3) All data points are generalized as 32-bit floating point numbers
4) All data is transmitted at a frequency less than or equal to 1Hz (unless otherwise specified by the detector)

Using the above rules, a yearly data estimate in GB and data traffic estimate in Mbps was made for each detector. To account for any detectors that did not submit a response, three cases were considered. The first case, a worst-case scenario, assumed that all unreported detectors would produce similar data loads as the heaviest data load among reported detectors. The second case assumed unreported detectors produced the median data load of reported detectors. The third case assumed an additional 20% load from unreported detectors. An additional 20% load was added to all cases as system overhead. Based on the method explained, the following results were found:

Scenario	Yearly Database Storage (TB)	Network Traffic (Mbps)
Reported Detectors	52.4	22.2
Unreported worst case	173.5	73.4
Unreported median case	53.9	22.8
Unreported 20% case	61.1	29.7

Table 1 – Estimated data required for slow controls

3.0 Slow Controls Equipment

It is the role of the Slow Control System to interface with equipment that both comprises the ePIC subdetector and its supporting infrastructure. The integration of this diverse ecosystem of hardware will require computers, controllers, power supplies, uninterruptable power supplies (UPS), networking equipment, gateways, sensors, actuators, and software. Described in this section is some of the hardware that may comprise the Slow Controls System.

These descriptions are only suggestions to be used as guidance when selecting products for use within ePIC. This section is neither prescriptive, nor is it exhaustive.

3.1 Machine Protection System (MPS)

In addition to the monitoring and modification of detector parameters, the Slow Controls System will contain a machine protection system. The MPS will interlock or isolate any hazards to the detector equipment as they arise.

In the event of an interlock, some level of personnel interaction with the detector's supporting infrastructure and subsystems is inevitable. For cases in which the hazard provided to the equipment could also present a hazard to personnel, such as high voltage or gas under pressure, Safety Integrity Level (SIL) and Performance Level (PL) requirements should be considered in the design of the MPS. This topic is especially relevant given BNL's recent pressure for increased safety considerations in designs.

3.1.1 SIL and PL Overview

SIL and PL are rating systems used to classify equipment, systems, and processes for hazard reduction. For in-depth information on the safety integrity levels and performance levels, standards IEC-61508 and IEC-61511 must be consulted. This section will present a high-level discussion of SIL and PL ratings.

SIL ratings range from SIL1 to SIL4 and reflect the severity of hazards present. The possibility of a scratch or bruise from interaction with a piece of equipment might be considered for a rating of SIL1, while risk of fatality or serious permanent injury would be associated with SIL4.

When a SIL rating has been determined, the frequency of the exposure and potential to avoid the hazard will determine a risk level, or safety category. A safety category informs the architecture of the circuit monitoring a system (table 2).

Safety Category	Architectural Requirements
B (basic)	None
1	Safety rated devices required
2	1 and testing, monitoring, and diagnostics required
3	2 and a redundancy system with its own testing capabilities
4	Enhanced implementations of 3

Table 2 – Safety Categories and architectural requirements

With the safety category known, performance level is determined based on the average time to dangerous failure (determined by the equipment selected) and the diagnostic coverage percentage (i.e. the number of failures that need to be detected). Performance level ratings range from PLa to PLe. PLe is the highest degree of performance, typically associated with systems and equipment in which failure would present a great deal of danger to personnel.

Again, for the vast majority of the MPS and Slow Controls System at large, these topics need not be considered. But it is highly advised that any interaction point between personnel and equipment (e.g., in an experiment rack or at equipment banks on the IR floor) be assessed for hazard exposure as soon as reasonably possible as it will not only be of interest to BNL Safety but may also inform equipment needs.

3.2 Programmable Logic Controllers (PLC)

The following sections will suggest PLC equipment for use with the MPS, building infrastructure system, and potential schemes to approach equipment expansion. It has been decided that Allen Bradley PLCs will be used exclusively in ePIC.

Programmable logic controllers will play an integral role in the management of the Slow Controls System. A PLC program consists of several tasks that can either run continuously, be scheduled, or be triggered on event or interrupt. Each task is further broken down into a series of subroutine. Since PLCs will run the breadth of their programs continuously, are built for harsh industrial environments, and have modules designed to fail safe, they are ideally suited to implementing the ePIC MPS and interfacing with the sensors, actuators, and equipment throughout the experiment complex.

A revision to the PLC driven MPS used at sPHENIX is recommended for use by ePIC. In sPHENIX, a single PLC was used to monitor the entirety of the 1008 building complex. This solution came with some advantages, but having a single controller responsible for the while facility resulted in issues with maintenance planning and contingencies for system failure.

What is recommended instead is a system of multiple controllers that implement two levels of machine protection. The first level MPS will be driven by one or more controllers for interfacing with building infrastructure. This level would provide upstream protection for all equipment in the IR, forward, and backward tunnels. The second level MPS would, ideally, consist of dedicated controllers for each ePIC subdetector and run smaller, targeted machine protection systems. This two-tiered system will prevent undue influence of any one controller on the detector. The MPS is not complete without EPICS, which will act as an alarm manager for all subdetectors.

3.2.1 Controller Options

Allen-Bradley has several families of programmable logic controller, most of which are appropriate for use within ePIC. Three families of note are the ControlLogix, CompactLogix, and Micro800 series controllers. These three series can remotely exchange data through a network enabled messaging system. ControlLogix and CompactLogix devices support the use of remote IO modules. The Point IO series of remote IO was considered when making cost estimations for ePIC.

ControlLogix controllers are AB's most robust models. They have the greatest amount of program memory per unit and are the only Allen-Bradley controllers that support redundancy. These devices are recommended for large applications. The redundancy feature of ControlLogix requires two ControlLogix PLCs and chasses that have the exact same configuration. In addition, the use of the redundant PLC cuts down on the number of network nodes the PLC may communicate with. ControlLogix all has safety rated modules and PLCs that have improved performance levels and when used with similarly rated equipment can improve SIL ratings. There is currently EPICs support for ControlLogix series controllers.

CompactLogix controllers are a flexible series of controllers meant for medium to large size applications. While they do not support redundancy, CompactLogix also offers safety rated modules for improving SIL ratings. There is currently EPICs support for CompactLogix series controllers.

Micro800 series controllers are technically meant for small, single machine systems. The controllers have a surprising amount of flexibility and can support nearly 200 mixed IO when expanded. The small form factor of the Micro800 makes them easy to install and could provide a means of installing a controller in each equipment rack, if it is desired. EPICS support for Micro800 controllers does not yet exist.

3.2.2 Cost Estimates

Using Integrated Architecture Builder (IAB), a free system architecture design tool from Allen-Bradley, three controller system architectures were created to estimate controller hardware budgeting needs. The three architectures assumed different levels of influence between controllers. Hardware estimations assumed a standard distribution of IO for each subdetector or subsystem.

The first architectural design gave the least amount of influence to any individual controller. In this design, a ControlLogix unit with redundancy controlled the first level MPS, while the second level MPS was managed by a collection of Micro800 controllers distributed in each experiment rack in the IR. This design was the most expensive but has the highest degree of flexibility and severely limits the impact of a single level 2 controller.

The second design used a ControlLogix unit with redundancy to control the first level MPS, and a series of CompactLogix devices to control the second level MPS. The second architecture is not a reflection of the ideal however, as it was made assuming one controller per category of subdetector (i.e., grouping all calorimeters into a single controller, etc.). This design also presents a high degree of flexibility and low level of influence and showed a significant cost reduction from the first architecture from reduced volume.

The third architecture used a ControlLogix unit with redundancy to control the first level MPS, and a second ControlLogix unit with redundancy to control the second level MPS. This design is not recommended as its cost reduction compared to the second design was marginal while detector influence greatly increased.

Architecture	Description	Estimated Cost
1	ControlLogix and Micro800 hybrid	$197.0k
2	ControlLogix and CompactLogix hybrid	$159.9k
3	ControlLogix only	$153.0k

3.2.3 Expansion Considerations

When adding modules to a PLC, the controller's memory must be remapped and the PLC reset. This is necessary for local and remote IO configurations. This presents a problem when an enclosure becomes increasingly full, when a remote module has reached its maximum number of supported IO, or when a new piece of equipment must be quickly integrated with limited IO availability. While such an update does not require much time, the interruption will require intense planning depending on the influence of the controller in question. In these scenarios a smaller controller, such as the Micro800 series or ADAM controller, can be used for a quick work around while more permanent solutions are planned.

sPHENIX has ran into all three of the previously mentioned problems. As the experiment matured and equipment and sensors were added in the IR and surrounding areas, any first level machine protection equipment was connected to the facility's PLC. When it came time to add hardware beyond the PLC configuration's capacity, the solution was to install an ADAM controller and use a program to pass data between the ADAM and the AB controller.

This solution can be simplified further. Allen-Bradley PLCs have a messaging function that allows controllers to pass data over a TCP/IP connection. Keeping several Micro800 PLCs available during ePIC runs would ease integration efforts of new hardware mid-run and provide adequate time to schedule larger PLC reconfigurations.