ISBN: 978-3-95450-238-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2023-TUPDP105

THE SLS 2.0 BEAMLINE CONTROL SYSTEM UPGRADE STRATEGY

T. Celcer†, E. Zimoch, X. Yao, Paul Scherrer Institut, Villigen PSI, Switzerland

Abstract

With over two decades of successful operation, the SLS facility is now undergoing a major upgrade that includes the complete replacement of the storage ring, yielding substantial improvements in beam emittance and brilliance and setting the stage for a new era of scientific exploration. As a critical component of the SLS 2.0 project, beamline upgrades are integral to harnessing the full potential of these enhanced beam characteristics.

To ensure that our users enjoy an optimal beamtime experience and maximize the scientific output, it is imperative to elevate the capabilities of our beamline control and data acquisition tools. Therefore, a thorough modernization and upgrade of our current control system stack is not just desirable but essential.

This article provides a comprehensive overview of the planned beamline control system upgrade, examining it from both technical and project management perspectives. We investigate the key sub-areas encompassed within a beamline control system upgrade and explore the strategies for efficiently integrating them together.

INTRODUCTION

The Swiss Light Source (SLS) is a third-generation light source which has seen the first light in 2001 and has been one of the leading accelerator facilities in the last two decades. Nevertheless, with the latest innovations in storage ring designs, it is time for the SLS facility to undergo a major upgrade yielding the improved beam performance of the fourth-generation light sources.

The SLS dark time started on October 2nd this year, and is planned to last until the end of 2024, giving a very tight time window for such a major upgrade. The SLS 2.0 project is focused on the upgrade of the storage ring, and it does not cover the linac and the booster part [1]. Only a smaller part of the total project budget is allocated for the beamline upgrades, therefore only selected beamlines are included in the upgrade under the scope of the SLS 2.0 project. Nevertheless, all beamlines will go through larger or smaller upgrades and for this purpose, a parallel project, ESup (End Station upgrade), was started, in which the upgrades of beamlines outside of the SLS 2.0 project scope are planned. From control system point of view, we do not differentiate between these two projects.

Currently, the SLS hosts 18 user operation beamlines. During the SLS 2.0 project, two additional beamlines will be built (Debye and I-TOMCAT), two beamlines will be merged (PEARL and SIS), and one beamline will move to a different sector (microXAS), hence 19 beamlines will be available for user operation after the SLS 2.0 upgrade. While the SLS 2.0 project officially finishes end of 2024, the beamline upgrades will continue to take place until the last planned milestone in mid 2026 and further.

To guarantee the availability of limited resources, the beamlines will be upgraded in three phases. During Phase 0, which concluded with the start of the dark time, one new beamline (Debye) was (partially) commissioned while one crystallography beamline (PX III) and few systems on other selected beamlines were upgraded. This phase was important not only for the time distribution of allocated resources, but also for testing and confirming the feasibility of the chosen SLS 2.0 control system solutions. During Phase 1 another seven beamlines in user program will be upgraded and 1 new beamline will be commissioned (I-Tomcat) and they are planned to restart the user operation in mid 2025, while the remaining beamlines will be upgraded during Phase 2, mainly during the additional 6-months shutdown in 2026.

SLS Legacy and Challenges Ahead

The upgrade of the SLS and the project's timeline will pose many challenges, but also offer important opportunities. During the two decades of SLS operation the technical debt was growing, along with user demands. For instance, the chosen HW portfolio, mainly based on the VME platform, as well as existing SW capabilities could over the time not keep up with rising demands of the end user community. Meanwhile, e.g., fly scanning, which brings together complex motion control, device synchronisation, detector integration and data acquisition and handling, became a highly complex and critical task.

Furthermore, there was no centralised approach in providing a higher layer tool above the standardized EPICS layer, which would be responsible for beamline experiment control (BEC) and orchestration. Consequently, different solutions were adopted at different beamlines, but none of those solution were properly supported by a central organisation at PSI. Several years ago, controls section attempted to bridge this gap and developed pShell [2], however it was not adopted by all beamlines and could not resolve the lack of standardisation and lack of proper centralised strategy when it comes to the higher-level beamline experiment orchestration tools.

BEAMLINE CONTROL SYSTEM UPGRADE STRATEGY

Learning from these experiences, creating a clear strategy for the SLS 2.0 control system upgrade, together with higher level SW solutions is critical for the success of the SLS 2.0 project, as its impact on the end user experience will be comparable to the impact of the improved beam characteristics obtained with the storage ring upgrade. This fact was also recognised by the SLS 2.0 project management, making Controls systems and Scientific IT area one

† tine.celcer@psi.ch

ISBN: 978-3-95450-238-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2023-TUPDP105

of the four SLS 2.0 sub projects (Controls & Science IT - CaSIT). In this subproject, three PSI departments, namely AWI (department for Scientific IT), AIT (Department for IT), and AEK (department for Electronics and Control Systems), are closely collaborating (along with PSD, Photon Science Division) and bearing responsibility for provision of modern IT and control system solution, capable of meeting modern user demands [3].

Figure 1 depicts a big picture view of the control system upgrade strategy and splits it into smaller sub-areas that need special attention. Clearly, there are different ways one could define these individual areas, and, they are also not completely independent, as there is always a certain overlap between them. However, here we differentiate between four main sub-areas, namely, the control system HW portfolio, control system SW portfolio (predominantly EPICS related), Beamline control system's infrastructure, and Data acquisition, data processing, and IT infrastructure (including network, storage, computing). Special attention must be placed on how these four pieces of the puzzle will be placed together and be integrated into different applications and the higher-level experiment orchestration workflow. Lastly, the project management aspect plays an important role in such a complex system upgrade strategy and its implementation, especially when faced with a relatively short upgrade time window, limited resources, large number of stakeholders, and diverse nature of individual beamlines.

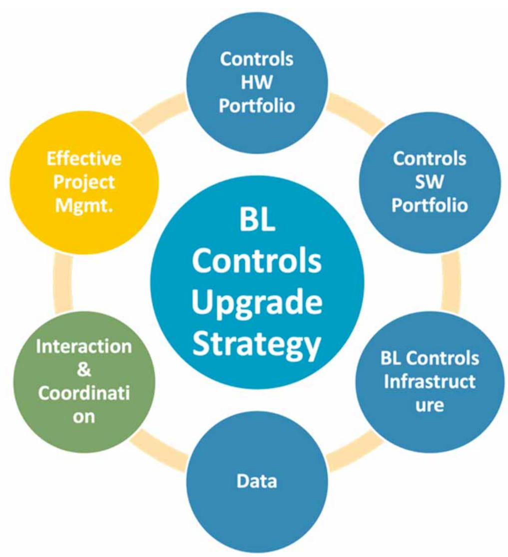

Figure 1: Different sub-areas of the beamline control system upgrade.

The HW portfolio and specifically the strategy of migration from the current VME (Versa Module Eurocard) platform towards modern HW solutions will be discussed in more detail. Other areas will be addressed in lesser detail and on a higher level. Furthermore, relevant contributions from other PSI colleagues, presented at this conference, which go into more detail on selected topics of the SLS 2.0 control system upgrade will be referenced.

Diversify Control System HW Portfolio

When building SLS, the control system hardware strategy was to use one solution for all problems, which led to the choice of a uniform control system based on the VME bus. The portfolio of various VME form-factor cards provided solutions for the timing and event system, digital/analog I/O, scalers, high voltage power supplies, and motion control.

The continuous use of the VME platform has been disregarded for SLS 2.0 due to increasing problems with speed and performance of the VME bus, VME HW availablity and its limitation to meet modern needs for motion or high-end ADCs, as well as increasing difficulty to keep supporting this system in combination with newer EPICS versions. Different options were evaluated, and finally it was decided that the portfolio will be diversified, thus enabling us to find optimal solutions for individual challenges.

The VME solution will be partially replaced by the Compact PCI - Serial (CPCI-S) bus-standard [4]. CPCI-S was chosen because it is based on modern and widespread technologies (PCIe, Ethernet), HW components are easily available and there is existing PSI internal know-how. CPCI-S Toolbox will cover timing and event system needs, fast ADC/DAC or DIO signals, and importantly provide an option for user tailored customized applications (using FPGA development), based on the Zync-UltraScale chip. It is currently discussed if CPCI-S could also provide the existing scaler functionality. The complete set of requirements is still being collected and a prototype solution is being worked on.

For slow I/O, currently provided with the use of Hytec VME cards, an alternative solution will be the WAGO system [5], which is already in use at PSI in different facilities.

High voltage Power Supplies (HVPS) are planned to be controlled with ISEG HVPS controllers, already used at the SwissFEL facility, and integrated into EPICS control system using the Simple Network Management Protocol (SNMP) protocol.

Evaluations were also made for the next motion system controller. The goal was to move to a modern standard which will be supported for a long time also in a wider community, and where standard, industry widespread HW components as well as cabling and connector standards could replace customized in-house developed components. The decision was to go ahead with the EtherCAT bus system and use Beckhoff HW modules. The master bus controller will be EtherCAT Motion Controller (ECMC), initially developed by the European Spallation Source (ESS), and now further developed in a close collaboration between the two institutes [6]. ECMC is based on the open source EtherCAT master and is running on a Debian 10 Operating System (at PSI). ECMC can also be used for

ISBN: 978-3-95450-238-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2023-TUPDP105

digital/analog I/O signals, of course being limited to EtherCAT bus capabilities. The system schematic is depicted in Fig. 2 while its implementation at PSI is described in more detail in [7].

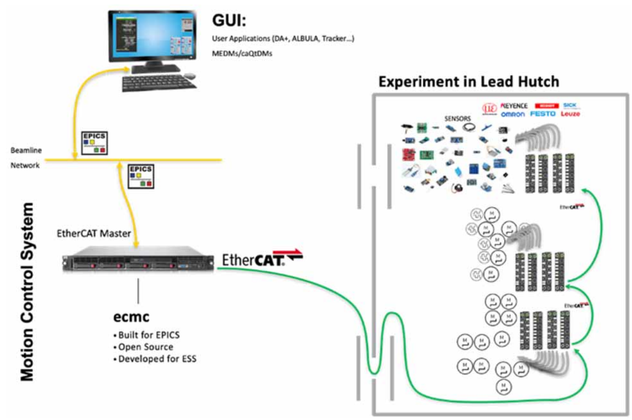

Figure 2: Schematical view of the ECMC system.

In SLS many different types of motor actuators were used, which resulted in a wide portfolio of in-house developed motor driver modules, compatible with the VME based controllers (e.g., for 2-phase, 3-phase, 5-phase, SmarAct, Pico-motors, etc.). Along with the migration to ECMC, we are focusing on keeping a leaner portfolio and hence prescribe the use of 2-phase bipolar stepper or servo motors and ideally only specific absolute encoders for all newly designed motion devices. Until now, we did not work on a migration solution for 3-phase, 5-phase and pico motors (other than replacing the HW and conform to SLS 2.0 guidelines, or alternatively keeping it as legacy for the time being). We are also investigating the option of supporting SmarAct motors with EtherCAT interface using ECMC, but the provider's SW is not yet at a desired level, and until then, the integration of SmarAct MCS2 controllers will be done using the existing community motor driver. In addition to ECMC and SmarACT controllers, other specialized controllers serving specific beamline needs, that cannot be met by the above prescribed standard portfolio, could be adopted. The HW portfolio replacing existing VME based solutions is presented in Table 1.

Of course, due to different reasons (budget, time, available resources, as well as beamline needs), many beamline devices will not be upgraded according to new SLS 2.0 guidelines and replaced with the SLS 2.0 HW portfolio. This will mostly be the case for the end station equipment, and partially for some beamline optics devices, while all front ends will be fully refurbished. Consequently, after the official project end, we will be faced with the coexistence of the systems conforming to SLS 2.0 guidelines as well as significant amount of legacy SLS systems.

Modernize Control System SW Portfolio

For SLS 2.0 our control system will continue to be based on the EPICS toolkit, and the decision is that at SLS 2.0 only EPICS 7 will be supported. Recently, significant effort was put into the migration from EPICS base 3.14.12. to EPICS 7 and we managed to upgrade all existing systems few months before the Dark Time started. Due to lack of resources as well as lack of critical use-cases, we do not foresee the use of pvAccess immediately after the SLS restart, thus only channel access protocol will remain to be supported on day one.

Another important development is the migration from S7PLC protocol towards a more modern and universal OPC-UA protocol. This will be predominantly used for the integration of different PLC based systems (safety systems). During beamline upgrade Phase 0, we already commissioned beamline Equipment Protection Systems (EPS) using OPC-UA. Other safety systems such as PSYS (Personal Safety system), MIS (Machine Interlock System) and VCS (Vacuum Control System) will follow.

Table 1: SLS 2.0 HW Portfolio as a Replacement for the Existing VME Platform

Subsystem	SLS	SLS 2.0
Timing/EVR	VME	cPCI-S
Fast I/O	VME (Hytec), other special ADCs	cPCI-S
Slow I/O	VME (Hytec), Wago	Wago, ECMC (EtherCAT)
High Voltage Power Supplies	VME (ISEG)	ISEG - network device (SNMP)
Motion	VME (OMS58, MaxV cards) Encoders (ECM cards)	ECMC (EtherCAT) MCS2 SmarAct controller
Scalers	VME (Struck, Jörger, Hytec)	cPCI-S – decision not fina

ISBN: 978-3-95450-238-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2023-TUPDP105

For the time being we will continue using caQtDM [8] as our display manager tool. At the beamlines it will predominantly be used for expert use and commissioning, while for experiment orchestration, the Graphical User Interfaces (GUIs) developed under the scope of the higher-level BEC system, should be used long-term.

Renew Beamline Controls System's Infrastructure

An important aspect of the control system upgrade is also the decision what kind of controls and IT infrastructure needs to be available at beamlines so they can run their experiments efficiently. In the scientific environment it is unrealistic to expect complete requirements, as its basic purpose is about continuous improvement, trying new things and learning how to push the science to the next level. Therefore, we are trying to anticipate their potential needs in advance and provide the necessary infrastructure to them already from the beginning, as it is always more difficult to add it later.

We aim to equip each beamline with both virtual (for all network devices) and physical (for e.g. USB devices) EPICS IOC hosts, triggering infrastructure, timing and event system distribution, provide the Precision Time Protocol (PTP) for high precision synchronized time stamping, as well as an EtherCAT connection (for beamlines with undulators) between the insertion device (in the machine network) and the Monochromator ECMC server, for potential synchronization of these devices for fly scanning applications.

Improve Coordination Across Data Acquisition, Processing, and IT Systems

Data is a big topic, both in terms of data volume, throughput, variety, and regarding expertise and organization units involved. From a conventional Controls integrator's perspective, large detector integration task distinguishes itself from the rest of device integration because besides the basic device control, this task also involves integration into a beamline's data acquisition and data processing environment according to the specific beamline needs. Usually, different experts in different organisational units are responsible for delivering individual building blocks (e.g. intended detector usage, device control, data acquisition, data processing, network, data storage, and computing solutions), which makes the coordination and communication very costly.

While we will not go into many details in this paper, we will aim to provide a basic overview of current efforts in this area. At PSI the responsibility of the overall data area is split between the Controls section, the Science IT department, the AIT department, and PSD. The Controls section is working towards a unified data ingest, processing and storage solution, which will be adopted by both SLS and SwissFEL. We are currently working on (a) a standardized data acquisition backend layer, providing a unified interface to higher level services, (b) a new archiving system for EPICS channel access and general time series [9] and (c) optimising the framework for online camera image/data processing, currently used at SwissFEL, which could be a potential solution also for the SLS beamlines [10]. The Science IT department provides data storage and computing infrastructure (including dedicated network), data cataloguing and archiving service (along with AIT), as well as data processing services along with beamline staff in PSD. The AIT department provides enterprise network and other critical services.

Pay Special Attention to Sub-systems With Coordination Features

Ultimately, the sub-areas discussed so far must be well coordinated and integrated together to provide the desired impact of the upgraded control system on the quality of user experiments, conducted at the SLS. There are two main sub systems which have the greatest coordination features, namely fly scanning and the BEC SW.

Fly scanning Fly scanning development is driven by the need to reduce the overhead introduced by the motion settling time in standard step scans. Its main goal is therefore the increase of scanning efficiency through continuous motion and synchronised triggering of other devices and detectors involved in the experiment. An important topic related to fly scanning is also the ability to correlate collected data and metadata, either via indexing or with the help of precise time stamping (e.g. via PTP protocol).

We first approached all beamlines and collected their current status regarding fly scanning and their vision on how they plan to perform experiments in the future. From these discussions we were able to divide fly scanning needs into three complexity tiers [7]. The lowest complexity tier can easily be implemented on a SW level (i.e., high level BEC system). The intermediate complexity use cases, which are most common, will be implemented on a lower level, using our standard HW portfolio, where ECMC will play an important role. The high-complexity use cases will need customised solutions and dedicated motion controllers and will as such be tackled last đ.

BEC The BEC layer will be the heart of the experiment orchestration as it will be the layer users will interact with. It will integrate and interact with a lower-level beamline control system, with the fly scanning applications, as well as with different DAQ services and other services collecting and managing experimental metadata, and potentially also get feedback from live data processing.

For SLS 2.0 an extensive evaluation campaign was done to select the system of choice which would meet the requirements given by the SLS beamlines. In the end we chose to use components of the Bluesky toolbox [11] as a basis and developed a microservice based solution to meet our users' needs, which include both scripting and graphic user interface. Fundamentally, we rely on Bluesky's Ophyd library as an abstraction layer for all integrated devices. The use of an abstraction layer facilitates a consistent interaction with devices, regardless of their underlying implementation details. We are therefore able to provide the unified interface for standard EPICS devices, PSI-specific EPICS devices as well as devices bypassing the EPICS layer. The BEC system is presented in more detail in [12].

ISBN: 978-3-95450-238-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2023-TUPDP105

Effectively Manage the Control System Upgrade

General management aspects In general, standard aspects apply when it comes to planning and managing such an upgrade, where many different stakeholders are involved (beamline staff and different expert groups). Enough time needs to be invested into initial discussions, collection of requirements and overall design phase. Intensive and frequent communication significantly increases the probability that things will move in a good direction. This gives us a chance to align different expectations and plan the architecture from a global perspective. Having Controls and Science IT officially represented in the SLS 2.0 project organisation structure is of high importance to achieve the visibility and the necessary acceptance of the importance and impact of our work on the overall project success.

Staged upgrade approach A key factor for a successful implementation of the migration and upgrade strategy, is obtaining a detailed global overview of beamline upgrade plans and requirements. To plan a staged upgrade of the HW portfolio, we are collecting detailed upgrade information from all 19 beamlines which will help us to define priorities and make decisions which systems to upgrade and which systems to temporarily keep as legacy, considering the availability of resources across involved expert groups.

First priority includes all new systems that will be designed following the SLS 2.0 guidelines. Second priority are (a) the systems which themselves will not be upgraded but the existing cabling will have to be redone anyway due to e.g., beamline moving to a different sector or a different rack location inside the beamline and (b) systems which are planned to be used at different locations or beamlines (e.g., different motorized microscopes). With ECMC, most of the cabling is done locally, close to the device, while only a single EtherCAT cable needs to be pulled between the ECMC master (server) and the Beckhoff slaves. Lastly, with lowest priority we would migrate the remaining systems, which will not move. Most of these systems, if not all, will be left as legacy systems and their migration to SLS 2.0 HW standard will be delayed to a later time (after 2026).

Lessons Learned We also collected valuable experience from the Phase 0 of beamline upgrades. It helped us to identify issues, critical gaps, or misconceptions of the new beamline control system components as well as issues in project coordination and workflows early, so we can now work on improvements and apply them during the following upgrade phases. It is especially worth mentioning two main aspects related to control system commissioning:

- An essential element for the success of each upgrade project is the appointment of a dedicated beamline upgrade coordinator. The coordinator must possess a deep understanding of the project's overarching objectives and be familiar with the contributions expected from various expert groups and their responsibilities. This role carries significant responsibilities and plays a central role in ensuring effective coordination, communication, and prioritization. Controls experts should actively support this coordinator for two primary reasons: (a) The control system interfaces with numerous other critical systems, relying on the collaboration of various expert groups such as hardware support, cabling, PLC, network, etc., and (b) the commissioning of the control system typically occurs at the project's final stages, where there is usually limited or no room for contingency, and thus making it vulnerable to all delays accumulated over the project time.
- Adequate time and attention is needed for unit testing, integration testing and user acceptance testing (UAT). For instance, proper testing of the cabling infrastructure (motor and encoder cables, electrical connections) as well as motion components such as limit switches and encoders before the commissioning phase begins is of utmost importance. This necessitates the availability of appropriate testing equipment and infrastructure. Additionally, all cables must be properly labelled on both ends. Too often, cabling issues were identified only during controls commissioning phase, which led to many stressful moments, introducing additional delays that could easily be prevented.

CONCLUSION

The upgrade of the beamline control system for the SLS 2.0 is a complex task and it will have an impact on the success of the SLS 2.0 on par with the impact of improved beam characteristics resulting from the storage ring upgrade. With a careful focus on different control system areas, the aim is to create an experiment orchestration and device control and data environment that aligns with the evolving needs of users and their scientific aspirations for the foreseeable future.

This upgrade encompasses 19 user beamlines and will be executed in phases, extending beyond the official SLS 2.0 project timeline. The development of a comprehensive global migration plan is imperative, with particular emphasis on facilitating the temporary coexistence of new and legacy systems, as well as plenty of testing time for both commissioning without beam and commissioning with beam.

REFERENCES

[1] H. Braun *et al.*, "SLS 2.0 storage ring: Technical design report", Paul Scherrer Institut, Villigen PSI, Switzerland, Report No. 21-02, 2021.

[2] A. Gobbo, S. G. Ebner, "PShell: from SLS beamlines to the SwissFEL control room", in *Proc. ICALEPCS'17*, Barcelona, Spain, Oct. 2017, paper TUSH102, pp. 979-983. doi:10.18429/JACoW-ICALEPCS2017-TUSH102

[3] A. Ashton *et al.*, "Conceptual design report on controls and science IT for the SLS 2.0 upgrade project", Paul Scherrer Institut, Villigen PSI, Switzerland, Report No. 21-03, 2021.

[4] P. Pollet, B. Kalantari, W. Koprek, D. Maier-Manojlovic, G. Theidel, "Development of a CompactPCI-Serial hardware

ISBN: 978-3-95450-238-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2023-TUPDP105

toolbox for SLS-2.0", presented at TWEPP'22, Bergen, Norway, Sept. 2022, unpublished.

[5] WAGO, `https://www.wago.com/global/`

[6] T. Gahl *et al.*, "ECMC, the open source motion control package for EtherCAT hardware at the ESS.", in *Proc. ICALEPCS'17*, Barcelona, Spain, Oct. 2017, paper MOCPL05, pp. 71-75. doi:10.18429/JACoW-ICALEPCS2017-MOCPL05

[7] A.S. Acerbo, A. Sandström, "Open source EtherCAT motion control rollout for motion applications at SLS-2.0 beamlines", presented at the 19th Biennial Int. Conf. on Accelerator and Large Experimental Physics Control Systems (ICALEPCS'23), Cape Town, South Africa, Oct. 2023, paper TH2BCO02, this conference.

[8] caQtDM, `http://caqtdm.github.io`

[9] D. Werder, T. Humar, "Modular and scalable archiving for EPICS channel access and general time series using ScyllaDB and Rust", presented at the 19th Biennial Int. Conf. On Accelerator and Large Experimental Physics Control Systems (ICALEPCS'23), Cape Town, South Africa, Oct. 2023, paper WE3BCO01, this conference.

[10] A. Gobbo, A. Babic, "CamServer: stream processing at SwissFEL and SLS 2.0", presented at the 19th Biennial Int. Conf. on Accelerator and Large Experimental Physics Control Systems (ICALEPCS'23), Cape Town, South Africa, Oct. 2023, paper THSDSC04, this conference.

[11] Bluesky, `https://blueskyproject.io`

[12] K. Wakonig *et al.*, "A beamline and experiment control system for SLS 2.0", presented at the 19th Biennial Int. Conf. on Accelerator and Large Experimental Physics Control Systems (ICALEPCS'23), Cape Town, South Africa, Oct. 2023, paper MO2AO02, this conference.