# DEVELOPMENT STATUS OF THE TPS CONTROL SYSTEM

Y. S. Cheng, Jenny Chen, C. H. Kuo, C. Y. Wu, P. C. Chiu, C. Y. Liao, K. H. Hu,
Y. T. Chang, Demi Lee, C. H. Huang, S. Y. Hsu, C.-J. Wang, K. T. Hsu
National Synchrotron Radiation Research Center, Hsinchu 30076, Taiwan

*Abstract*

The EPICS was chosen as control system framework for the new project of 3 GeV synchrotron light source (Taiwan Photon Source, TPS). The standard hardware and software components had been defined, and the various IOCs (Input Output Controller) are gradually implemented as various subsystems control platforms. The subsystems control interfaces include event based timing system, Ethernet based power supply control, corrector power supply control, PLC based pulse magnet power supply control and machine protection system, insertion devices motion control system, various diagnostics, and etc. Development of the infrastructure of high level and low level software are on-going. Installation and integration test are in proceeding. Progress will be summarized in the paper.

## INTRODUCTION

The TPS [1] is a latest generation of high brightness synchrotron light source which is being in construction at the National Synchrotron Radiation Research Center (NSRRC) in Taiwan. It consists of a 150 MeV electron linac, a booster synchrotron, a 3 GeV storage ring, and experimental beam lines. Civil construction has started from February 2010. The construction works are approximately finished in half of 2013. Accelerator system installation and system integration will be proceeding in later 2013. The control system environment should be ready in early 2014 to support subsystem integration test and hardware commissioning without beam. Commissioning with beam is scheduled in later 2014.

Control system for the TPS is based on the EPICS framework [2]. The EPICS toolkit provides standard tools for display creation, archiving, alarm handling and etc. If users have found these tools inadequate, development of in-house alternatives is feasible and compatible. The big success of EPICS is based on the definition of a standard IOC structure together with an extensive library of driver software for a wide range of I/O cards. Many users of the system report a steep learning curve and the need for significant development resources, but this is balanced by the large installation base and proven ability of this approach. The EPICS toolkits which have various functionalities will be employed to monitor and to control accelerator system.

The control system consists of more than a hundred of EPICS IOCs. The CompactPCI (cPCI) IOC will be equipped with input/output modules to control subsystems as standard IOC or the TPS control system. The power supply and fan module of the cPCI crate will be hot-swapped. Adopting cPCI platform for EPICS IOCs provides us a chance to take advantages of local IT industry products with better supports and low cost. The other kinds of IOCs are also supported by the TPS control system, such as BPM IOC, PLC IOC, various soft-IOC and etc. Consoles and servers are PCs or blades PC running Linux.

To achieve high availability of the control system, emphasis has been put on software engineering and relational database for system configurations. Data channels in the order of $10^5$ will be serviced by the control system. Accessibility of all machine parameters through control system in a consistent and easy manner contributes to the fast and successful commissioning of the machine. High reliability and availability of TPS control system with reasonable cost and performance are expected.

## CURRENT STATUS

Major procurement is scheduled in 2011 to 2013. The design for the control system environment is already frozen in the hardware part. The software environment will be completed in 2013. Control related applications are started and expected to a preliminary form before subsystem ready in early 2014. The definition of TPS control system standard has been processed during the last couple of years. The development status of the control system is summarized in following paragraphs. The progress on various issues is summarized in following paragraphs.

### Networking

Mixed of 1/10 Gbps switched Ethernet will be deployed for the TPS control system [3]. The Gigabit Ethernet connection will be delivered at edge switches installed at control and instruments area (CIA). One CIA corresponding to one cell of the storage ring, there are 24 CIAs in total. The control network backbone will be 10 Gigabit link to the control system computer room and redundancy network installation site in the specific CIA #24. Private Ethernet is used for Ethernet based devices access which will support fast Ethernet and GbE. Adequate isolation and routing topology will balance between network security and needed flexibility. The file and database servers are connected to the control and intranet network, allowing the exchange of data among them. Availability, reliability and cyber security, and network management are focus in the design phase.

### Equipment Interface Layer

There are several different kinds of IOC at equipment layer to satisfy various functionality requirements,

convenience, and cost consideration. Most of the devices and equipments will be connected to cPCI IOCs with EPICS running directly. The 6U cPCI platform was chosen for the EPICS IOC. Local company manufactured crates and CPU modules are chosen for a low cost consideration. To simplify various developments at construction phase, only 6U modules are supported for the machine control system. The cPCI EPICS IOC equipped with the latest generation CPU board will be standardized as ADLINK cPCI-6510 CPU module [4]. The CPU module equipped with Intel Core i7 CPU running Linux provides high performance to meet various applications. The latest releases version of Fedora core Linux distribution is adopted at IOC level.

The cPCI-7452 128 bits DI/DO module is used for BI, BO solution, this high density version in 6U form-factor satisfy most of applications. Industry pack (IP) carrier board in 6U cPCI form-factor can equip up to 4 IP modules. Various IP modules are adopted for required applications. ADC and DAC modules in IP module form factor will be used for smaller channel count application, such as insertion devices control. Event system modules are in 6U cPCI form-factor. Private Ethernet will be heavily used as field-bus to connect many devices. Power supplies of all magnets except for correctors are equipped with Ethernet to the EPICS IOC. Multi-axis motion controller with Ethernet interface will be the standard for the control system.

Ethernet attached devices will connect to the EPICS IOC via private Ethernet. Some network attached devices might not work properly if the network traffic is high due to the simple TCP/IP stack implementation. Private network with lower traffic is to ensure the reliability and performance of the links. Devices support VXI-11, LXI, Raw ASCII and Modbus/TCP protocol are supported to connect to EPICS IOC directly via TCP/IP interface. Devices of this category include power supply, temperature acquisition (RTD or thermocouple), digital multi-meters, oscilloscopes, signal generator, and other instruments.

High resolution ADC module embedded with EPICS IOC from D-tAcq [5] will be used for the analogue signal reading, it provides 10Hz reading and the transient capture rate is up to 100K sample/sec.

All corrector power supply will be driven by the corrector power supply controller (CPSC) module. The CPSC equip with 20 bits DAC and 24 bits ADC. Two SFP ports supported by the on board FPGA (Spatan 6), these SFP ports will receive correction setting (Autora and Gigabit Ethernet by using UDP/IP protocol) from fast orbit feedback FPGAs to slow orbit feedback PC, feed-forward correction computer and IOC. Setting command sent to these SFP ports will be added with the slow setting from EPICS CA client.

## Power Supply System Control

TPS power supplies control interface are divided into three categories rather than a unified solution [6]. All of the power supplies will be provided by three different vendors. The reason of this choice is to meet the practical situation from budget and available vendors and manpower.

The small power supplies for corrector magnets, skew quadrupoles are in the range of ±10 Amp categories. This category power supply will be in module form factor. Each power supply sub-rack can accommodate up to 8 power supply modules. A custom design CPSC module will be installed at control slot of the sub-rack. The CPSC will be embedded with EPICS IOC and provide fast setting SFP ports to support orbit feedback functionality. Power supply modules installed at the same sub-rack will interface to this CPSC module. The CPSC installed 20 bit DAC and 24 bit ADC to ensure necessary performance for the orbit control especially in vertical plane of the storage ring. To simplify the type of power supply, this category power supply will be used for the corrector of LTB/BTS/Booster Synchrotron, and storage ring as well as skew quadrupole magnet power supply. The CPSC modules support waveform capability which can support corrector ramping for the booster synchrotron if necessary.

The intermediate power supply with current rating 250 Amp will be equipped with Ethernet interface [7]. Power-supplies are expected to have internal data buffer with post-mortem capability. Output current of the power supply will output at rear plane BNC connector, which can connect to the cPCI ADC module also. There are two versions of power supply in this category, sextupole power supply with 16 bits resolution and quadrupole power supply with 18 bits resolution DAC. Both kinds of power supply can meet the 50 ppm and 10 ppm performance specifications for long-term drift. Both kinds of power supply noise level are in the 10 ppm range of the full scale

The storage ring dipole DC power supply and power supplies for the dipole and quadrupole power supply of the booster synchrotron had already contracted to the IE Power (Acquired by Eaton in 2011). The control interface will be a serial interface. It is expected that a serial and Ethernet adapter enable directly Ethernet connection. Control resolution of these power supplies will be 18 effective number of bits, noise and drift will be better than 10 ppm of these power supplies. The dipole and quadrupole power supply of the booster synchrotron have built in waveform support with external trigger capability. This functionality is essential for energy ramping of the booster synchrotron. All of these power supplies will interface with the EPICS IOCs directly.

## Timing System

The event system consists of event generator (EVG), event receivers (EVRs) and a timing distribution fiber network [8, 9]. EVG and EVRs can be installed with various universal I/O mezzanine modules to meet different input/output requirements. The mechanical form factor of EVG and EVRs is in 6U cPCI module. The 125 MHz event rate will deliver 8 nsec coarse timing resolution. Fine delay is supported by UNIV Output module on EVRTG which generates gun trigger signal. Its

high resolution and low timing jitter provide accurate synchronization of hardware and software across the TPS control system. This mechanism simplifies the operation of the machine and allows complex sequences of events to be carried out by changing few parameters. Prototype system was delivered in March 2011 and applied to the TPS Linac system commissioning at the temporary site successfully. The procedure of the injection sequence is in development.

### Insertion Devices Control Interface

Insertion devices (ID) control for the phase I project include one set of EPU46, two sets of EPU48 and seven sets of in-vacuum insertion devices (two sets of 2 meter long IU22, three set of 3 meter long IU22, and one set of 3 meter long IU 22 with taper functionality) [10]. The motion mechanism of EPU46 and EPU48 are driven by servo motors. All IU22 are driven by stepping motors. The motion controller is Galil DMC-404x motion controller. Preliminary version of EPICS devices supports for this motion controller is in use. Improvement is underway. A cPCI EPICS IOC equips with AI/AO/BI/BO I/O modules will serve an ID. The SSI optical encoder is selected for all ID. The encoders are connected to the motion controller directly. All parameters of motion controller will be created as EPICS PV. Update rate may be up to 200 Hz. This would be useful for feed-forward compensation process.

### Diagnostic System Interface

New generation digital BPM electronics [11] is equipped with Ethernet interface for configuration and served as EPICS CA server with 10 Hz data rate. Another multi-gigabit interface will deliver beam position for fast orbit feedback purpose at rate up to 10 kHz. The BPM electronics will also provide post-mortem buffer for orbit analysis during specific event happened like beam loss. Post-mortem analysis can help to find the weakest point and provide information to improve system reliability.

High precision beam current reading and lifetime calculation will be done at a dedicated IOC. This IOC will install EVR to received booster cycle timing signals and high resolution IP ADC modules to digitize the DCCT signal and perform beam lifetime calculation.

The GigE Vision digital cameras will capture images for diagnostic purposes and other applications.

Counting type and integrating type beam loss monitors will be connected to the control system by counter or ADC modules installed at IOCs.

### Feedbacks and Feed-forward Plans

Since the TPS adopt aluminium chamber with 4 mm in thickness. Eddy current effects prevent the standard corrector from fast corrector. Four fast correctors will be installed at bellows site for each cell. So, the global orbit feedback system needs to deal with fast and slow correctors in the same feedback loop. A counter rotate multi-gigabit links will circulate 10 kHz rate orbit data among all BPM platforms. The FPGA module embedded

in the BPM platforms will be configured as distributed fast orbit feedback engines. All of these platforms will be installed with EPICS interface for various feedback supports such as PID parameters, and matrix download. The correction command from FPGAs will be sent to the CPSC module located at the power supply sub-rack via Aurora links. The data buffer in the FPGA module can be used to capture fast orbit data up to 100 sec at 10 kHz rate for feedback system diagnostic and performance study. The capture can be triggered either software or hardware with post-mortem capability.

To avoid saturate of the fast correctors, a DC remover algorithm to remove DC offset of the fast corrector to slow correctors are in study. This scheme can meet the stability requirement for TPS. The fast corrector DC remover loop will read the DC value of the fast corrector regularly every few seconds, multiply the inverse of the fast response matrix to get the orbit distortion which cause due to the DC setting of fast correctors. The same orbit distortion will transfer to the setting value by the slow correctors via slow transfer matrix. This scheme can ensure the setting of the fast corrector always around zero. This will keep the maximum dynamic range of the fast corrector to suppress fast perturbation.

Slow orbit feedback can also deploy based on EPICS CA. The slow orbit feedback will used the slow transfer matrix to calculate the correction values. The corrector setting for the slow orbit feedback loop is via EPICS CA channel. All CPSC can be to do synchronized setting up to 10 Hz rate by the aid of event system.

The bunch-by-bunch feedback system will adopt signal processor based on the latest generation FPGA processor with embedded EPICS IOC and build-in diagnostic functionality.

### Turnkey System Solution

Turnkey systems such as linear accelerator and RF transmitters were delivered by industry as turnkey EPICS or PLC control environment. Work on EPICS support for the turnkey system with proprietary control environment is also not a problem. The turnkey systems delivered no matter with or without EPICS control system can integrate with the TPS control system.

### PLC and Interlock Solution

Current TPS control system will support Siemens S7-300 or compatible model from VIPA PLC which are delivered from the turn-key vendors. Yokogawa FM3R PLC will be used for most of control system related interlock system. FM3R with embedded EPICS IOC will be used for some applications also [12, 13]. Each subsystem is responsible to build their own interlock and protection system based on their requirement and preference. The global machine interlock system will collect various interlock signals from local interlock subsystem of orbit, vacuums, front-ends, radiation dosage monitors and etc. The beam disable commands to trip beam or inhibit injection can be distributed to the specific devices or subsystem by the global machine interlock

system or uplink functionality of the event system.

## *Operator Interface*

The operator interface level consists of Linux PCs for consoles and servers for various purposes. Various EPICS OPI tools and MATLAB will be adopted for OPI development [14-16]. All GUIs are implemented by EDM, MATLAB and CSS (Control System Studio). Consoles in the control room have multiple LCD screens as shown in Figure 1. The OPI computer will be installed at the equipment area of control room with optical PCIe extension to remote display unit at control room. This can provide better cooling for the computer, reduce loudness at control room and provide clean control consoles. Large screen format displays hang on the roof at control room will be available for display of important parameters likes beam current, lifetime, vacuum distribution, synchrotron radiation image and etc.



Figure 1: Console in the TPS control room has multiple LCD screens.

## *Control Applications*

Generic applications provided by the EPICS toolkit will be used for all kinds of applications. Standard tools such as the archiver, alarm handler and save/restore tools are supported. Channel Access (CA) is used as an interface for machine process variables (PVs) access. Simple tasks such as monitoring, alarm handling, display and setting of PVs are performed using EDM panels and strip tools. Cold start, warm up and shutdown process will done by MATLAB scripts.

## *Physics Applications Interface*

The accelerator physics tools for TPS include extensively adopted MATLAB Middle Layer (MML) and Accelerator Toolbox (AT) software packages. High level application (HLA) library based upon Python is also considered. It enables various developed applications from different machines to be directly adopted for TPS. To enable early testing of the physics tools with control system, a virtual accelerator has been implemented to support simulation of the accelerators via the EPICS PV access.

## SUMMARY

Implementation of the TPS control system is in on going. Installation will be started in Q4, 2013. The TPS control system will take advantages of the latest hardware and software technology to deliver high performance and functionality, prevent obsolesce and to be economical. There are many issues require further efforts and focus including relational data base, system configuration and management and various application programs. To identify priority and find adequate measurements to deal with various issues are current efforts.

## REFERENCES

[1] TPS Design Book, v16, September 30, 2009.

[2] EPICS, http://www.aps.anl.gov/epics/index.php

[3] Y. T. Chang, et al., "Infrastructure of Taiwan Photon Source Control Network", Proceedings of ICALEPCS2011, Grenoble, France, Oct. 10-14, 2011.

[4] ADLINK, http://www.adlink.com

[5] D-Tacq, http://www.d-tacq.com

[6] C. Y. Wu, et al., "Power Supply Control Interface for the Taiwan Photon Source", Proceedings of ICALEPCS2011, Grenoble, France, Oct. 10-14, 2011.

[7] Y. S. Cheng, et al., "Power Supply Control and Applications Development for the TPS Storage Ring Quadrupole and Sextupole Magnet", Proceedings of IPAC2013, Shanghai, China, May 12-17, 2013.

[8] Micro Research Finland, http://www.mrf.fi

[9] C. Y. Wu, et al., "Status of the TPS Timing System", These Proceedings.

[10] C. Y. Wu, et al., "Status of the TPS Insertion Devices Controls", THPPC063, ICALEPCS 2013, to be published

[11] C. H. Kuo, et al., "BPM System and Orbit Feedback System Design for the Taiwan Photon Source", Proceedings of ICALEPCS2011, Grenoble, France, Oct. 10-14, 2011.

[12] C. Y. Wu, et al., "Control of the Pulse Magnet Power Supply by EPICS IOC Embedded PLC", Proceedings of IPAC2010, Kyoto, Japan, May 23-28, 2010.

[13] C. Y. Liao, et al., "Design of Machine Protection System for the Taiwan Photon Source", Proceedings of IPAC2012, New Orleans, Louisiana, USA, May 20-25, 2012.

[14] Y. S. Cheng, et al., "Progress of TPS Control Applications Development", TUPPC122, ICALEPCS 2013, to be published

[15] C. Y. Liao, et al., "Image Acquisition and Analysis for Beam Diagnostics Applications of the Taiwan Photon Source", Proceedings of ICALEPCS2011, Grenoble, France, Oct. 10-14, 2011.

[16] C. Y. Liao, et al., "User Interfaces Development of Imaging Diagnostic Devices for the Taiwan Photon Source", TUPPC123, ICALEPCS 2013, to be published