T.2 Indus-2 control system

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Any large facility like Indus-2 involves various distributed sub-systems, which must perform the desired functions and deliver required performance. The control system has the key role of facilitating the monitoring, supervision and control of all the important parameters of the machine and its sub-systems. Indus-2 control system has been performing such tasks effectively since first machine commissioning trials began in August 2005. Subsequently, the control system has continuously evolved to meet new challenges and has played a crucial role in machine commissioning. The control system of Indus-2 is so designed that it presents to the machine operation crew, a simple and convenient interface for operating a complex machine. This system is handling nearly 10,000 I/O points with a refresh rate of about one second. It has about 75 Equipment Control Stations (ECS) spread in the field over a large area.

Architecture

The control system is based on master slave architecture enabling functional and physical separation and placement of hardware and software modules across the entire gamut of control system components. Strong and speedy network support is the backbone over which various hardware and software components talk to each other. The system allows the operation of any sub-system from any console in the main control room (Fig T.2.1). It is possible to control the entire machine from a minimum number of operator consoles. The system is designed so as to minimize the cabling over long runs for minimum interference possibility. The control room sees only essential communication cables and minimum instrument cables brought inside to reduce the cabling clutter and maintenance efforts. Operations are achieved with software panels and switches as far as possible. Signals are concentrated, multiplexed and preprocessed in the field. Standard signal levels, connectors, control modes etc. are used across all sub-systems as far as possible. The system is modular, expandable, scalable and easily maintainable.

Fig T.2.1: Common control room for Indus-1 and Indus-2.

Functional division and distribution

The control system is divided into a number of intelligent sub-systems, each of which autonomously controls a specific subsystem such as Magnet Power Supplies, RF, Vacuum, Beam Diagnostics, Timing, Radiation Monitoring, Machine Safety Interlocks, Beam Line Front Ends etc. Identical hardware and software modules are used to perform tasks of similar nature. The control system is distributed over three layers, *viz.* User Interface (UI) layer, Supervisory Control (SC) layer and Equipment Control (EC) layer. These layers are also called Layer-1 (L1), Layer-2 (L2) and Layer-3 (L3) respectively. L1 directly sees the operators while L3 directly connects to the instruments in the field. This distributed and modular architecture makes the system flexible and also helps to improve the overall system response.

A SCADA package (PVSS II) is used at L1. VME controllers based on M68040 processor are used at L2. The communication between L1 and L2 layers is on Ethernet using TCP/IP protocol. At L3 layer, indigenously developed VME controllers using M68000 processor are used. PROFIBUS is used for communication between L2 and L3 layers. At L2 and L3 layers, real time operating system OS-9 is used as a ROM based, small footprint, multitasking operating system with real time features. Fig. T.2.2 depicts the architecture of the control system.

Control Hardware

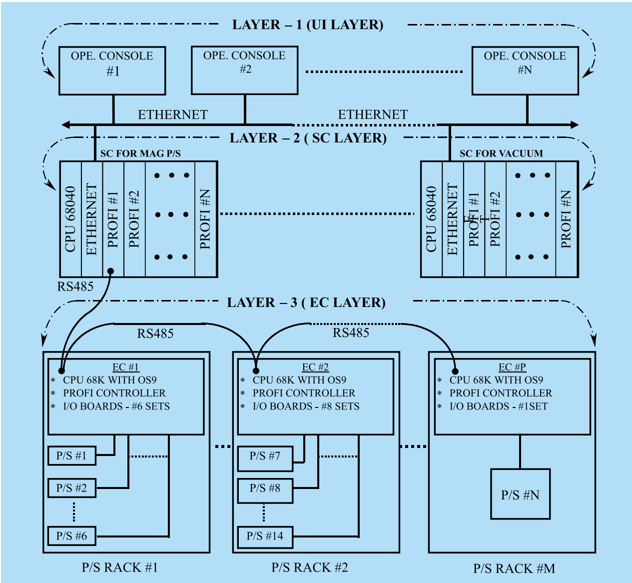

***Fig. T.2.2** Indus-2 control system architecture.*

The modular control system hardware is designed around VME bus. Table T.2.1 gives details of different VME boards, developed in-house and used in the system. In these boards important features are use of SMDs, GALs, CPLDs, high accuracy ADCs, DACs, temperature controlled ovens and ECLinPS family ICs for high frequency operation. Board layouts are done in-house using PROTEL PCB design package. Programming of GALs and CPLDs is done using CUPL and VHDL languages.

Table T.2.1.
Different VME boards developed at RRCAT

S. No.	VME BOARDS	Q. IN USE
1	M 68000 based CPU board	78
2	DAC for Magnet Power Supplies (16-bit)	150
3	ADC Magnet Power Supplies (16-bit, 4-channel)	146
4	Profi Master Controller Card	9
5	Profi Slave Controller Card	78
6	ADC Magnet Power Supplies (24-bit, 4-channel)	28
7	DAC Magnet Power Supplies (18-bit)	28
8	Relay-out card (32-channels)	88
9	Digital-input card (32-channels)	140
10	Digital-out card (32-channles)	1
11	Integrating ADC card (12-bit, 16/32-channels)	7
12	Isolated ADC card (16-bit, 4-independent channels)	57
13	Isolated ADC card (12-bit, 16/32-channles)	65
14	Isolated DAC card (16-bit, 8- independent channels)	5
15	Programmable Clock Generator card	1
16	Fine Delay Generator card (2-channels)	5
17	Coarse Delay Generator card (4-channels)	2
18	Co-incidence Generator card (4-channels)	2
19	Current-to-Voltage Converter	90
20	Voltage-to-Current Converter	1
21	VME-interrupt Generator card	1

Control of magnet power supplies

Indus-2 has about 315 magnets Dipoles (DPs), Quadrupoles (QPs), Sextupoles (SPs) and Steering Magnets (SMs) that are used to guide the beam trajectory, control its focusing and defocusing and correct the chromaticity during various modes of operation while the electron beam circulates inside the vacuum chamber (the ring). There are about 200 power supplies to energize these magnets to generate the required magnetic fields. The magnet power supplies are located around the ring in the equipment gallery and in the power supply hall. All these power supplies are remotely controlled from the central control room. The control system for this particular subsystem performs monitoring of various analog and status signals of power supplies and allows required control actions. It also provides stable and accurately controlled reference voltages to power supplies for setting currents into magnets. The accuracies and stabilities provided by the control system (Best case - better than 50 PPM) make it different from a conventional process/ industrial control system. In addition, the control system provides the special function of synchronous ramping of all magnet currents for increasing the electron beam energy without affecting the machine optics. Cycling of all the magnet power supplies is also supported to minimize the remnant field effects over beam. The control system performs all such and other similar tasks with the required flexibility.

Energy Ramping

Beam in Indus-2 SRS has to be ramped from the injection energy (550 MeV) to 2.5 GeV. Ramping the beam energy requires ramping of magnetic fields in the DPs, QPs, SPs and SMs and ramping of cavity gap voltages for RF cavities in a very flexible manner. During ramping, the beam optics may shift and severely affect the stored beam. Therefore, the ramping has to be programmed in such a way that the stored beam is least affected. The increments in the field value of various magnets have to be synchronized for this purpose. This requires increasing the currents of power supplies synchronously, allowing the user to select the rate of current increase and selectively stop in-between for seeing and then adjusting the machine parameters.

The ramping scheme is supported by appropriate hardware and software. At hardware level, the DAC boards at the layer-3 are equipped with Look Up Tables (LUT).

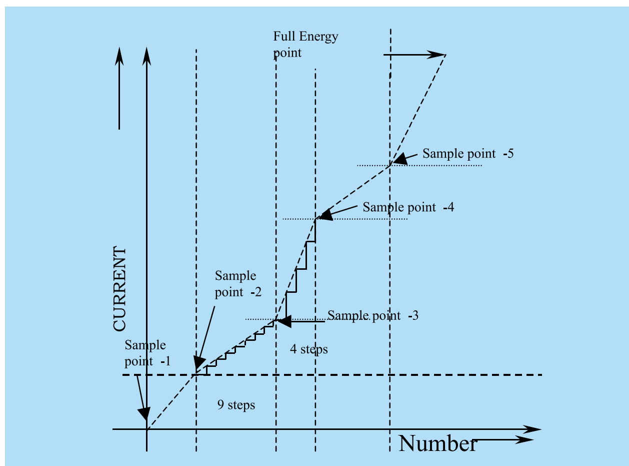

Fig. T.2.3 Typical ramping curve.

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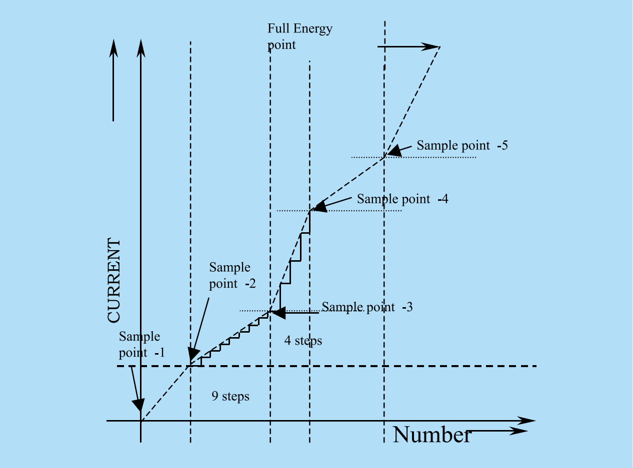

Fig. T.2.3 *Typical ramping curve.*

has slip free synchronization. PROFIBUS provides broadcast and multicast communication. These features and versatility of PROFIBUS was suitable for our application. The PROFI controller boards using micro-controllers were developed in house. Both master and slave modules for PROFIBUS-DP have been implemented. The physical communication link is powered with isolated on board supply that eliminates any galvanic ground loops between the subsystems. Data communications over a 500 meter RS 485 link was tested for 750 K baud and maximum 244 bytes of data in a data packet. All the layer-2 to layer 3 communication is based on PROFIBUS. In all, around 80 PROFI controllers are put on to work. There are total 8 PROFIBUS links inter-connecting about 80 stations in total in multidrop mode. The typical link for magnet power supplies has about 30 stations on one link. The station response time is less than 125 micro sec for the present implementation. A typical CRO response time of PROFI is shown in Fig. T.2.5.

Isolation

While designing the system, a thought was given to the problems of interference due to ground loops, various noise sources and cross talks between different sub-systems. This is reflected in form of galvanic isolation provided at the control system interface for all front-end electronics. Each analog I/O board has galvanic isolation from VME bus. All the communication links, clock-carrying links, triggers to various power supplies are powered with isolated floating sources. This has minimized the cross coupling among various sub-systems due to common galvanic paths through control system interfaces. A typical floating voltage that was seen across the isolation barrier on the PROFI-bus link is shown in Fig. T.2.6. The communication packets can be seen riding over the 10 Vp-p, 50 Hz noise.

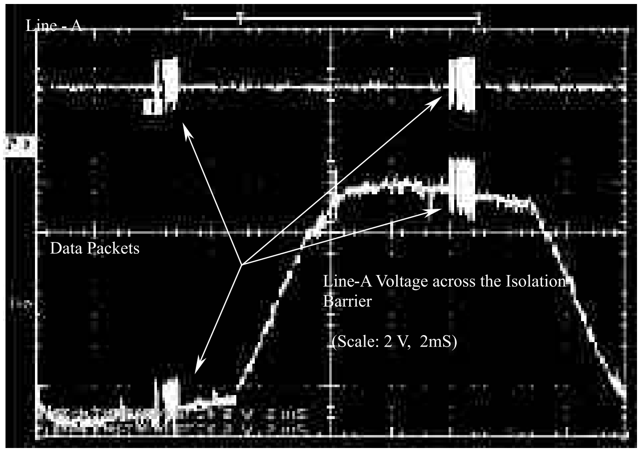

Fig. T.2.6 *Isolation barrier of the PROFI link.*

Real Time Operating System

The Real Time Operating System (RTOS) OS9 has been used in the control system layers 2 and 3. OS-9 provides a host of features like real-time performance, multi tasking core, modular program structure, scaleable deployment, ROMmability, kernel customizations, re-entrant and re-locatable modules, unified, device independent I/O system, dynamically modifiable I/O system, various inter process communication methods, networking support (TCP, IP, UDP) etc., most of which are essential for the required system performance and upkeep.

The OS-9 BSP (Board Support Pack) has been ported on Motorola 68040 based CPU boards. The IP-addressing and the network support programs that are customized for each CPU board are also put along with the OS-Image. These boards are used at L-2. The OS image was customized and successfully ported on in-house developed boards based on Motorola 68000 CPU. The device initializations and accesses have been modified according to the devices used on these boards. These boards are used at L-3. Device drivers for OS-9 were written for about 20 types of boards using the assembly language of Motorola 68000. Assembly language was chosen to achieve fast and deterministic operation of driver routines.

The application layer programs for PROFIBUS protocol were developed in OS-9 for PROFI-master mode of operation at all the stations of L-2 and PROFI-slave mode of operation at all the stations of L-3. This enables the exchange of status and commands between L-2 and L-3. Communication programs based on TCP/IP sockets were developed for all the stations of L-2 to enable the communication with L-1.

An RTOS is being used for the first time in RRCAT for a project of such magnitude as control system of Indus-2. As the field of accelerator development is always evolving and new requirements keep coming, various features of OS-9 like modularity, scalability and rommability help in easy modifications and up gradation. The performance of the system running on OS-9 has been satisfactory.

Software at user interface layer

Indus-2 control system uses PVSS II SCADA as the main component at L1. It has an object oriented *data-point* (DP) concept and thus common objects can be identified and developed as reusable components. It provides interface to standard protocols and can even be extended to custom protocols. Use of commercial SCADA package provides faster and better development and ease of expansion in the future. Data trending, alarms, configurations, and data archival are easily implemented in PVSS. LabVIEW applications, custom C++ applications and Java applications can also be used to handle the data coming from the front-end instruments. All these applications (clients) take data from the server applications supporting different protocols. Thus with this client-server architecture multiple applications can simultaneously acquire the data. This modular and client server architecture uncouples the GUI from the field related I/Os. PVSS uses Application Programming Interface (API) manager to interface to the L2 layer server applications on Ethernet over TCP/IP socket. User commands and settings are given through the PVSS User Interface Manager (UIM) to the API manager, which in turn are passed onto the L2 layer without wait. Each sub-system of Indus-2 has a supervisory controller at L2 layer and corresponding API manager at L1. API managers have been used to provide features like auto-connection to the L2 layer server and also provide maintenance and testing related information on the GUI.

The instruments and equipments interfaced to the L1 layer of control system are Supervisory Controllers (SC), Digital Storage Oscilloscope (DSO), Digital Multi-Meter (DMM), Function Generators (FG), Residual Gas Analyzer (RGA), Spectrum Analyzer (SA), Custom Controllers etc. Normally they have different communication standards like GPIB, OLE for Process Control (OPC), TCP/IP, custom socket communication, custom 485 communications, MODBUS etc. All these standards are supported and any new or custom protocol can also be easily added in the software architecture. Use of industry standard protocols like OPC and MODBUS provides seamless interface of commercial instruments. Fig. T.2.7 depicts the software architecture of Indus-2 control system. OPC servers for various DSOs are developed which allow monitoring and control of these DSOs with various software packages e.g. PVSS, LabVIEW and custom OPC clients. Publish and subscribe model of OPC is very useful for getting signals

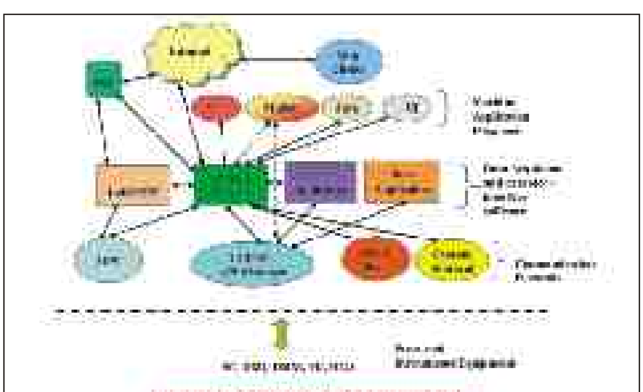

Fig. T.2.7 Software architecture for control system.

whenever they change. A package called reed RGA was developed in LabVIEW to interface with 16 RGA units in the ring. It facilitates monitoring of vacuum quality, which becomes important as beam current is stepped up.

Web Based Machine Monitoring and Information Management

It was realized and decided early during the development phase to provide machine status and operation history over campus intranet. This is extremely convenient and useful for the system experts, beam line users, machine operators and general users associated with Indus accelerator complex to be able to get machine and sub-system related information remotely on their personal computers using web browsers. Using JVM enabled web browser all the following applications can be used from any where over entire campus network. The same facilities can also be extended to be accessible over Internet. A screen shot of web application is shown in Fig. T.2.8.

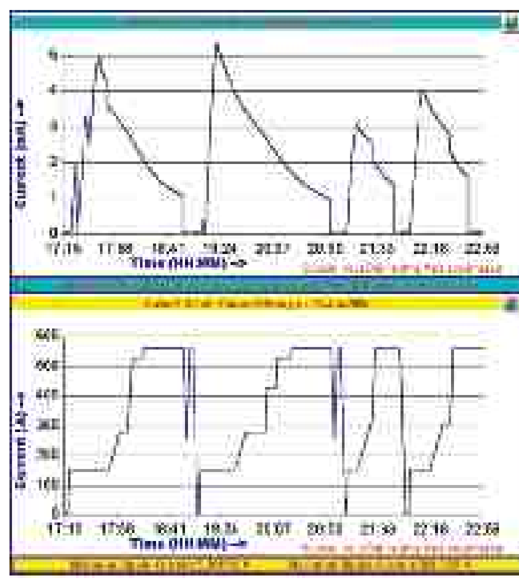

Fig. T.2.8 Web based machine information.

1. Fault Information Management System: For tracking the faults occurring in sub-systems involved in operation of Indus-1, Transfer Line-3 and Indus-2 a Web Based 'Fault Information Management System' package has been developed and hosted on Indus control system web server.
2. Indus On-line: This web application has been developed and hosted on Indus control system web server to provide all the live, historical and statistical data related to Indus-1, Transfer Line-3 and Indus-2 to users and system experts.

3. Storage Ring Status Information System: This web application is developed to display online machine status and any important message entered by machine operation in-charge.
4. Electronic Log Book: Electronic log book application called 'E-log' allows logging of pre-defined machine snapshots (set of machine parameters) on the press of a software button, as well as automatic logging of machine snapshot in the event of an abnormal machine behavior, like sudden fall of stored current, trip events etc. Operator can also initiate machine snapshot logging added with his comments whenever the machine is performing well or otherwise. It allows adding of operator specific inputs, shift information, description of machine behavior etc. Presently, it stores the textual information and displays the logged parameter information in tabular format. This is aimed at electronically maintaining a machine operations logbook, which should further help in finding performance problems and debugging easily.

Central Alarm Handling System

Alarm handling system for Indus-2 keeps watch on all machine parameters, viz. analog values and status information and raises alarms whenever abnormal conditions are detected. Severity levels can also be defined on analog value alarms. Logging of all the steps and events with date and time stamp helps in correlating the information that is crucial in case of system malfunctioning and helps in speedy recovery.

The Control Network

The Control System of Indus-1 & Indus-2 is composed of 25 operator console computers, which are connected through 100 MBPS Local Area Network (AccNet). Apart from these machines, 6 server machines are also connected on the same network for specific purposes. Out of these six server machines, the first two machines are used as Domain Controllers (Primary and Back up), next two machines are used as DBMS Servers (Main and Standby) and last two machines are used as PVSS Servers (Main and Standby). One of the machines of the network, on which web server is installed, is connected to the CAT campus network (CATNet) also to provide the information to users not connected with control room network (AccNet).

Automation of Indus-2 low conductivity water (LCW) plant

The automation of this plant was completed long before the main controls and it is under full remote operation. It has been done completely in house using VME controllers for the front-end, LabVIEW software for the GUI, and PROFIBUS as the Field-bus. The system handles approximately 1300 signals with 800 plant status **inputs,** 350 analog inputs and 150 control outputs. Based on client server architecture, the system allows monitoring of the critical plant parameters from LCW control room, main control room and from any PC on control LAN with proper authentication. It provides feedback control for controlling inlet & outlet temperatures, flow rates, conductivity, quantity and pressure of the circulating cooling water. In GUI different windows are provided for monitoring different areas. Control package is made modular and configurable for incorporating future developments.

Machine safety interlock system

Many components of the machine may require protections when machine is operated at higher currents and energies. MSIS ensures safe and trouble free operation of the machine and protects it under potentially unsafe conditions. Fail-safe system design and reliable operation are the main considerations. To achieve higher reliability and availability, the system is planned to have various redundancy features.

The system will trip appropriate sub-systems and/or dump the beam to provide protection against over heating of magnet coils and vacuum chamber photon absorbers due to loss of cooling, damage of sector valves due to beam injection in closed valve condition, over heating of DCCT core, unintentional openings of beam shutters in beam line front ends, trapping of persons in potentially high radiation conditions etc. In order to achieve these, it monitors all thermal switches of the magnets in the ring, all flow switches of the photon absorbers, status of sector valves and status of beam shutters of all front ends. It also ensures that all the doors are locked, all scram switches are in healthy condition and radiation levels are safe in the ring and experimental hall. On detecting any potentially hazardous state of the machine, it would kill the beam by tripping off RF or some of the power supplies.

Conclusion

The control system is in continuous operation since August 2005 and since then, it has played a crucial role in various aspects of the commissioning experiments. It has worked continuously to allow injection trials, building up of the stored current and ramping up the energy. In the following phases of commissioning, the system will again be subjected to some more critical tests and continue to evolve functionally. The news article in this issue highlights the role of control system in machine commissioning, future challenges and evolution.