Chapter 4

Accelerator Control Systems

Synchrotron radiation sources are the accelerator facilities built for the purpose of producing Synchrotron Radiation to be used in different scientific and industrial applications. Control system of these machines have evolved from small hard-wired systems to complex computer controlled systems with many types of graphical user interfaces and electronic data processing. With distributed layered architecture of control system these facilities have successfully fulfilled the specific operational requirements demanded by different classes of users and different technical requirements imposed by various subsystems of these large facilities. With the development of open source toolkit based Supervisory Control and Data Acquisition (SCADA) systems like Experiment Physics Industrial Control System (EPICS) and TAco Next Generation Objects (TANGO) the collaborative efforts have benefited the existing and upcoming third generation source control systems in terms of reduced development costs and timeline with increased reliability due to the high degree of software reuse. The next generation of synchrotron radiation sources will require much bigger and better control systems. The advances in technology can support the network bandwidth and CPU power required for reasonable update rates and requisite timings. Beyond the scaling problem, next generation systems face additional
challenges due to growing cyber security threats and the likelihood that some degree of remote development and operation will be required.

4.1 Introduction

The particle accelerators started appearing around 1930. The first accelerator used for accelerating protons to energy of 400KeV (Cockcroft & Walton split lithium atom for the first time with this accelerator) was built with few sub systems like H.V. generator, proton source, vacuum pump, lithium target and scintillation screen [15, 21]. It was fully manually controlled during experiments and experimenter had to sit in observation cubicle (experimental area) immediately below the acceleration tube as shown in Picture 4.1 (taken from reference [104]). The whole accelerator was housed in a single room.

With advancements in various technologies much bigger accelerators are now being made with a large number of subsystems spread over large geographical areas. Much more complex instruments and machines are to be run in a synchronized and sequential manner for their operation. Also the number of parameters to be controlled and monitored during the experiments have increased to such an extent that the manual control and observation is beyond the scope of human capabilities. This has led to the development of accelerator control systems in accelerator facilities. In today’s accelerator facilities almost all the operations are exercised remotely and centrally with operators sitting in control room and working from operator console PCs with the help of Graphical User Interfaces (GUI) running on them. Synchrotron Radiation Sources (SRS) are built around the accelerators facilities and comprises of a pre-injector (small accelerator usually Linac or Microtron), beam transport lines, booster (bigger accelerator usually synchrotron) and storage ring. Thus they comprise of many accelerators and hence their control system has evolved out of accelerator control system. The first generation SRS machines were the electron
storage rings built specifically to store continuously circulating electron beam at a fixed energy for periods up to many hours. The control system of some of these early machines were analogue type but with the availability of computers in market around the same time control systems of accelerators started using minicomputers with Central Processing Units (CPU) at the upper layer (operator interface layer) and CAMAC compliant I/O cards in CAMAC crates at lower layer. The second generation of synchrotron radiation sources started around 1980 where the accelerator and storage rings with modified lattice structure were built to attain the increased brightness by minimizing the electron beam
emittance. With the use of microprocessor for most of these facilities, control system architecture still remain two layered with much power full computers at the upper layer and low capacity computers at lower layers. The use of Real time operating systems started appearing during this time at the lower layer controllers where as the upper layer computers mostly used the proprietary OS to the concerned computers. The applications were built using the concept of distributed databases, device description tables, device tables with about 2500 parameters and data archiving rates of once per 2 minutes were developed. The development languages used were mainly C, FORTRAN and Assembly, and the databases used were of text type and relational databases. Some of the Facilities developed around 1985 for the first time used the VME crates at the middle layer and were among the first to adopt the three layer architecture. The software programs at layer one started using the new concepts like event based programming, inter program communication facilities and were based on enhanced graphical plotting abilities (bar graphs, joined line graphs, scatter plots). The operator interfaces were equipped with Alphanumeric terminals, Color TV-raster scan with interactive cursors, track boll, computer controlled knobs with incremental encoders and the facility of multi-parameter control linked with single computer knob used for example for producing bump on closed orbit. The third generation synchrotron radiation sources were the machines specifically built with the motto of providing higher brightness and to accommodate large number of insertion devices. Theses machines are the modern present day synchrotron light sources. They have the most advanced control systems and some of them also provide the facility of top-up injection. In these facilities the computer controlled system normally comprises of two parts. The first part is the hardware that directly interfaces with the sensors and actuators. Since the accelerators are spread over a large area and comprise of many sub-systems, normally this hardware part is spread over one or two layers with many small
computers/controllers connected over field-buses constituting the lower layer and higher computing capacity based computers constituting the upper layer. One or more upper

Figure 4.3: Time between major upgrades in SRS control systems of different facilities.
layer computers logically combine to make the control system for one sub-system. The control systems of various sub-systems together make the overall hardware part of control system for the complete facility. The second part is the software part that comprises of the lower layer subroutines running at the lower layer controllers, the control scripts and Graphical User Interface algorithm running at the operator PC consoles. The control system of these machines has undergone a continuous phase of extension after commissioning to accommodate the signals arising from the large number of experimental station beam lines and insertion devices of increasing complexity as most of these facilities were initially commissioned with few beam lines and later on the users added the new beam lines on demand, for example figure 4.2 shows the increase in the total number of computers in the control system of Spring-8 facility over the time period in the Beamline user area. With the increase in the computing powers of computer and the changing electronic market scenarios the control system of many facilities has seen upgrades at different times,
figure 4.3 shows the time between major upgrades in SRS control systems of different facilities. The SRS control system has passed through many technological changes from 1970 to 2010 and the present trends show the growth around two main technologies first EPICS and the second TANGO figure 4.4 shows the trend in the control system technologies adopted by different sources. Figure 4.5 shows the evolution of different concepts and technologies in SRS control system with time. With the increase in the computing power and lowering of prices of electronic components and computers the present day control system of the new facilities are again moving from three layer architecture to two layer architecture with the fast computers directly provided at lower equipment interface layer.

Figure 4.5: The evolution of different concepts and technologies in SRS control system with time.
4.2 Scope of SRS control system

The control system of today’s SRS facilities is designed to monitor and control model-based and computed data from the accelerator, allied facilities, experimental, safety and operating subsystems to accomplish supervisory control, automation and operational analysis. The scope of the control system extends from the interface of the equipment being controlled through to the designers and operators of the accelerator facility, as well as synchrotron beamline users and staff. The control system addresses the aspects like timing, deterministic data communication, network communication, control room operations, automation and optimization. It comprises of the computers and software required to implement and integrate all subsystems including beam diagnostics, power supplies, low level RF, vacuum, personnel protection, equipment protection, insertion devices like undulator and wigglers, experimental beamlines and conventional facilities. In order to provide this comprehensive monitoring, control and automation, the control systems need to be scalable to support thousands of physical input/output connections and computed variables that can be correlated to analyse events and provide data for all control aspects.

4.3 SRS control system requirements

4.3.1 General conclusions

The actual technical details for control system requirements differ from facility to facility but on examining the various papers on the control system for accelerators some general conclusions can be drawn.

1. The control system in accelerator facility is a support activity. In many cases of installation as well as up-gradation there is always a lack of budget, manpower and the most important, the lack of machine down time and the control engineers are
forced to complete the upgrade process without sacrificing the machine operation
time.

2. As Accelerator machines are in research environment there is a continuous require-
ment for new features/ up-gradation in control system mainly arising from operation
side and at times due to up-gradation or addition of new hardware components to
the facility.

3. For some of the specific requirements such as fast timing system etc., off-the-shelf
solutions are not always available and some development is always needed.

4. Control system engineers are often not involved in early phases of machine design.
This seriously affects the over all performance of the control system developed later
as there is not much left in his hands towards standardization of the interfaces with
the machine components already produced or under production. This compels the
control engineers to adopt the complex architecture loosely coupled and with a large
number of different types of electronic boards which are difficult to maintain and
upgrade through out the life span of the facility. One has to understand that it is
only the control system which is connected with all the subsystems and has to take
care of all the general and specific requirements of all the sub-systems collectively
whereas all other systems only have to perform their specific jobs.

5. From figure 4.3 It is clearly seen that only a few of the control systems have served
without up-grade throughout the life span of the facility. The major reasons behind
the upgrades are as below:

   (a) The continuous process of software upgrades in the form of software patches
   reduces the software reliability due to addition of bugs and increase the debug-
ging time.
(b) In present time where the technologies are changing very fast, the lack of staff often poses the maintenance problem.

(c) The fast growing technological changes especially in the field of computers and microprocessor technology in the form of more and more computing power and with additional new features lured the engineers as the implementation of many previously thought functions now become possible.

(d) With the fast growing technology many devices and development tools become obsolete or are on the verge of obsolescent thus the fear of maintaining a obsolete technology / devices without industry support sometimes forces the engineers to chose for upgrade even when the deployed technology / devices suffice their purpose.

(e) Often the maintenance of the old technology becomes more costly affair as compared to the new off-the-shelf available products.

(f) Sometimes the need of participating in the development and becoming a part in the up-to-date technology in accelerator control system by means of collaborations with other facilities, as this is one of the ways to cope with the problem of limited man power, also strongly advocates the system upgrade with reasonably low cost.

6. Although the hardware architecture of almost all facilities can be grouped in two categories (two layered or three layered architecture) but the software architecture of most of them differ from each other.

7. Previously large variation is observed in development tools used by different facilities even when they were developed around the same time. Though with the availability of open source EPICS the trend seems to concentrate towards the common tools.
8. Many facilities have used Real Time Operating System (RTOS) at lower layer i.e. front ends in past and many more are using at present also. But some facilities questioned this and have demonstrated the successful operation of control system without RTOS at any layer. (For example ANKA, DAFNE, ESRF, and LNLS).

9. Different synchrotron radiation sources facilities have chosen their operating electron energy considering various aspects like, demand from the user, maximum potential of research in material sciences, design emittance and brightness, allotted budget etc. Figure 4.6 shows the operating electron energies for different SRS facilities. In the figure it can be seen that the SRS facilities commissioned before 2000 shows a large variation in choosing their operating electron energy spreading from few hundreds of MeV to 8GeV. Whereas for the SRS facilities commissioned after 2000 clearly shows the narrow spread in selecting their operating electron energy with almost all the facilities have chosen the electron energy levels between 2.5GeV to 3 GeV. Thus this indicates that the electron energy range between 2.5GeV to 3Gev is the range that fulfils the current user demand and is mostly be preferred by the new upcoming machines in near future.

10. The evolution of control system shows the continuous developments and inclusion of new ideas based on common facilities developed for society. For example the use of WWW and SMS facility for accelerator control debugging and fault removal from remote places in case the expert has gone to some distinct places. (Figure 4.5)

From above it is evident that the control system must be modular, incrementally upgradeable, scaleable and extendable. Expansion of the control system to accommodate the build-up of the accelerator and Beamlines from early testing, through installation
and commissioning, and during the life of the facility should not impact the performance.

The control system must be available to support all aspects of the project schedule;
from component tests during prototyping to beam characterization and optimization at commissioning.

### 4.3.2 Technical Requirements

Technical requirements differ from machine to machine; some of the technical requirements expected from third generation SRS control system facilities are presented below. [88]

1. Support for about 100,000 direct parameters and about 30,000 derived parameters.

2. Support for about 1 or 2 Hz model-based control (used to correct steering, the orbit, tune, linear chromaticity, optics etc).

3. Synchronous power supply and RF ramping, where the power supplies may be spread over a large geographical area. Some rings are having circumference in Km (for
example APS with circumference of 1104m)

4. Event based timing system with jitter less than 100ps and resolution down to 20 ns. Synchronization signals are to be supplied to different subsystems such as RF and P/S located at different geographical areas.

5. 500 MHz RF control Amplitude, phase, synchronization, etc,

6. 5 KHz fast orbit feedback (for coherent bunch instabilities) and about 50 to 100 Hz global and local orbit feedback.

7. About 20 to 200 millisecond equipment protection system.

8. About 5 Hz updates to operators of up to 1,000 chosen parameters.

9. Coherent turn-by-turn orbit data for up to $2^{10} = 1,024$ consecutive turns (for FFT).

10. Archive up to 6,000 parameters at a rate of 0.5 Hz continually.

11. Latch the last 10 seconds of data from all parameters in the storage ring when a fault is detected in the Machine Protection System (MPS), for postmortem analysis.

12. Archive up to 1,024 consecutive turn by turn data for 1,000 parameters at a rate of 10 Hz.

13. Provide pulse-to-pulse beam steering in the injectors (Linac or small accelerators) at 1 Hz.

14. For improved overall reliability the use of proven technology such as uninterruptible power supply (UPS), programmable logic controllers (PLC), battery backup, and redundant power supplies for Equipment crates are required for control of some of the critical sub systems such as the cryogenic, machine safety and personal safety
systems. Further to this to reduce the machine down time, control system modifications that add new functionality are performed during scheduled down times and after operational testing on equipment test stands before installation.

15. To address different class of users the system must manage the *Access Control* requirements to guarantee security of its computers and network systems. At the same time the overall system should be well integrated irrespective of the source of data origin, for example, it should be possible to display data from the control system from the associated relational database and from an accelerator model on one full-screen synoptic.

16. The overall software framework should be designed with well defined interfaces to support the modular upgrade/replacement of code to enable future upgrades in an economical way.

17. For supporting the hassle-free reconfigurability of the systems all the system design and configuration data of accelerator components and signal lists such as: magnetic lengths, min/max currents, calibration coefficients for currents vs. gradients, diagnostics channels, and configuration parameters should be managed version wise.

18. For future maintenance and upgrades, the control system hardware should have a layered structure. The functionality implemented at layers should be tried to be self consistent and built with standard interfaces so that the modification in one layer does not affect the other layers.

19. The networking hardware should be selected such that it is easily scalable, supports redundant configuration and include provision for network evolution. Where ever possible the network traffic should be isolated between different network layers using switches. Network security is to be implemented through physical security that
limits access to the control network from outside using gateways and firewalls.

20. The presentation layer comprising of operator’s consoles, database manager, simulation computer, alarm generation/recording, data logging, displays and a gateway to the local-area network should be built with the features that distinctly addressed the individual requirements of different user classes such as accelerator operators, accelerator physicists, Technical group, Beamline Staff & Experimenters, Control System Engineers and Facility Managers.

(a) Accelerator operators should be provided with a complete and consistent interface. The data presentation should be logical and rational to support easy equipment behaviour identification. Further to this the operation of the accelerators requires real-time control and monitoring of the equipment, archiving, alarm handling, sequencing, backup and restore for routine operation. For operators the alarm and error messages should be supported by information regarding recommended courses of action. The control system should allow the automation of plant operating tasks. It should provide applications that encourage and facilitate the keeping and passing of operation logs, particularly from shift to shift.

(b) For accelerator physicists the control system should provide methods to integrate different accelerator models with the system. Functionality is required to allow easy acquisition of data produced as part of an experimental run, and to provide the ability to switch between different accelerator models. Data retrieved from the control system must be acquired with sufficient time accuracy to enable accurate correlation.

(c) For technical groups all the diagnostic information necessary to assist in commissioning and debugging of equipment should be provided through easy inter-
face. An easy interface to databases of equipment properties, manufacturers, documentation, cabling data and fault histories is required, as well as access to information clearly identifying the geographical location of equipment and a system of fault prediction facilities to allow for scheduled maintenance of components likely to fail.

(d) For beamline staff and experimenters the machine data needed during experiment should be provided. This is particularly necessary in the case of synchronizing scanning of a sample with changing of a parameter on an insertion device in the storage ring e.g. the gap of an undulator. Experimenters require clear information on light source status, performance, and timing signals, and may require remote access (i.e., from off site) to experiments and beam-lines.

(e) Control system engineers require current and archived data on the status and behaviour of the entire control system. Information required includes CPU loading, network loading, application monitoring (for frozen/crashed applications), connectivity status and reports of any control system faults.

21. The control system must include a relational database as a central repository for all configuration information. This should include all static information about accelerator components such as coefficients to calculate field magnetic strength from current. Consideration should be given to extending the database to include all technical information to enable subsequent support and maintenance. At the application level, there should be a unified and seamless interface to both the static and dynamic data.
4.4 Accelerator Subsystems

4.4.1 RF

The booster and storage ring RF system mainly comprises of RF source, RF pre amplifiers, RF power amplifiers and the RF cavities along with the RF transport mechanism. These along with the normal operational control also requires the control loops for cooling water fine temperature control, frequency control, amplitude control and phase control. Some times the RF of booster also requires ramping and hence needs special programmable waveform synthesizers and RF generators to be interfaced with the control system often on GPIB or on LAN. Normally all the components are installed in the near vicinity of the RF cavities and hence usually single equipment controller suffice the need.

4.4.2 Vacuum

Vacuum system mainly consists of sputter ion pumps, vacuum gauges and valves, fast closing shutters and residual gas analyzer. Digital I/O and serial lines are the electrical interfaces used for most of vacuum devices. For high voltage power supplies powering more than one pump, special interfaces are used to read individual pump currents, based on voltage to frequency converters so as to insulate Equipment controllers from high voltage devices. This is the most wide spread (geographically) system and mainly comprises of more than one equipment controllers.

4.4.3 Injector (Linac / Microtron)

The injectors are small accelerators which accelerates the electrons to energies up to few tens of MeV for example at RRCAT we are having Microtron as injector to booster which provides electrons at 20MeV energy. Mostly machines use either Linac or Microtron
for this purpose. The control requirements of these are similar to the other accelerator control requirements but since these are the small machines the number of parameters is low and all devices are placed near the accelerator and hence usually one or two Equipment controller is sufficient for this.

4.4.4 Diagnostics

Accelerator diagnostics is the crucial system for proper functioning of the facility and mostly requires the state of the art technology to address its stringent requirements. These include the fast digitizers and frame grabbers to grab the images of fluorescent screens and synchrotron radiation profile monitors installed throughout the ring and transport lines. Current measurement devices like DCCT (DC Current Transformers) and FCT (Fast Current Transformers). For monitoring and controlling top-up injection, high-precision DC current measurements are carried out by digital multimeters interfaced over GPIB. Beam Position Monitors (BPM) provides the information about the beam position on-line and requires the fast and precise electronics. Since this data is used for implementing the fast and slow orbit control system the equipment controllers for this subsystems usually are provided with boards with feedback loop implemented using the FPGA and sometimes with the dedicated communication links to other equipment controllers of the subsystems for fast data transfer between them. This layer also many times uses the principle of over sampling to improve accuracy of analog parameters by averaging.

4.4.5 Magnet Power Supplies

This subsystem comprises of many different power supplied both AC type and DC type. Because of the high inductance of the dipoles the tracking of the reference signal by the
PS can only be guaranteed to within a given maximum accuracy. On the other hand, quadrupole current have to precisely track the bending magnet current because tracking errors translate into undesirable betatron tune changes. Further more, eddy currents proportional to the bending field time derivative generate sextupolar fields that may have to be compensated by powering the sextupoles with waveforms tracking the said derivative.

To meet all the above requirements, the control system should allow the generation of independent, programmable, synchronized waveforms of arbitrary shape (sinusoidal, linear ramp, compensated ramp, etc) for each power supply. Even in references of DC power supplies (i.e. the power supplies meant for supplying current to DC magnets) provision is to be provided for arbitrary wave forms as they have to undergo the cycling process in order to attain the desired level of field uniformities and accuracy. To achieve this digital sample buffers and D/A converters, whose buffer content can be changed in between cycles to allow cycle-to-cycle tuning are used. The required precision determined by the maximum allowed tracking error is generally met by 16 bits at a conversion frequency of 10 KHz for both reference and read-back. New facilities are also investigating the implementation of feed-forward or feedback systems based on magnetic field or tune measurements.

4.4.6 Interlock System

This system must fault-protect equipment and people and prevent damage by mishandling to either. Some facilities divide this into two systems as Machine safety system and personal safety system, where as some facilities have a common machine interlock system. This system requires high reliability and in most of the machines is built using high reliability technology. This includes the use of an uninterruptible power supply, programmable logic controllers, battery backup, and redundant power supplies for VME
crates used for these subsystems. Subsystems to be interlocked are:

- Power supplies and magnets
- Injection and extraction HV power supplies
- Vacuum
- Injectors (Linac / Microtron)
- Insertion Devices (i.e. inhibit injection if certain devices are closed).
- Beam lines and experimentation stations.

This system generally collects signals from other subsystems and often sends commands to other subsystems. It is usually built using industrial PLC and also many times uses the industrial SCADA for their control. Often the signals used are digital signals and the response time of 20 to 200 ms serves the purpose. Since the signals are to be collected from almost all parts of the machine, the signals are distributed and normally use more than one equipment controllers.

### 4.4.7 Timing System

The Timing System in accelerators is responsible for synchronising beam and RF and all control and data acquisition tasks. It generates the master trigger patterns that governs all the operation mode events in the machine. It generates all the synchronization pulses needed to control the beam injection into the ring for initial fill and top-up. The timing system many times also communicate data that are required for operation and correlation, as well as data communicated to the subsystems that change with the mode of the machine. Like time stamp/pulse ID, machine mode, and global machine status. It mainly comprised of electronic delay generator cards where the delays can be generated in synchronism to the master pulse. these synchronisation pulses are required for control
of the beam transfer from the electron source to the storage ring and are also provided to diagnostic equipment and beamline equipment for synchronisation.

**Fast Timing**

Some of the accelerator synchronisation tasks such as those related with the injection and extraction process that requires the triggering of particle source and firing the transfer line components, such as injection and extraction pulsed magnets, beam diagnostic components (such as beam position monitors and current transformers) at the correct times are termed as fast timing tasks. These tasks require synchronisation with fine time resolution, to RF frequency, clock precision, and low jitter. Table 4.1 shows the main specifications of the hardware available from KEK and Stanford Research for fast timing system.

<table>
<thead>
<tr>
<th></th>
<th>KEK TD4V</th>
<th>Stanford Research DG535</th>
</tr>
</thead>
<tbody>
<tr>
<td>Form</td>
<td>VME 6U</td>
<td>Bench/Rack mounting</td>
</tr>
<tr>
<td>Delay</td>
<td>16 Bit/RF clock</td>
<td>0 to 1000s -5ps steps</td>
</tr>
<tr>
<td>EPICS Support</td>
<td>Yes</td>
<td>Yes, via GPIB</td>
</tr>
<tr>
<td>Channels</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Jitter</td>
<td>4.5ps at 508MHz</td>
<td>&lt;60 ps</td>
</tr>
</tbody>
</table>

**Event System Signals**

There are some other accelerators components synchronisation tasks that are at course level where the requirement on timing resolution is more relaxed. This includes triggering the magnets for an acceleration ramp, triggering operational sequences such as the filling of the storage ring, BPM acquisition, feedback timing, insertion device control, and
supplying the distributed control system with time synchronization pulse to control and correlation of data. These tasks are termed Events. Event signals are produced with a precision set by the storage ring revolution period and with predictable jitter. Table 4.2 gives the specification of one of the most advanced event based timing system developed at APS and enhanced by SLS and, more recently, DIAMOND.

4.4.8 Beamline Front-end and Experimental System

This sub system is the attachment between machine and the experimentation stations. On one hand the beam line users need to control insertion devices which are in the machine controls network, need information about beam position, as well as numerous other signals from the accelerator control system where as on the other hand beamline information, along with intensity and beam position from the beamlines, is needed in the accelerator control system to provide continuous control of the beam. Thus a bidirectional data flow is needed. Often it is seen that the facility is built with few beamlines (about 4 to 7) at first and then at later stages the number increases to fully occupy the beamline slots for which machine is designed. Also this addition of new beam lines is done when the machine is in normal operation with the beamline front-ends (specific zone designed for coupling of beam lines with the accelerator facility). Many times, the beamline developing agencies

Table 4.2: specification of timing event system at DIAMOND.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Events</td>
<td>8-bit code -255 events</td>
</tr>
<tr>
<td>Resolution</td>
<td>8ns</td>
</tr>
<tr>
<td>Event Tx Trigger</td>
<td>Hardware inputs, software, Event Ram Clock</td>
</tr>
<tr>
<td>Event Rx output</td>
<td>Hardware outputs, software (EPICS record process)</td>
</tr>
<tr>
<td>Transmission medium</td>
<td>Gigabit Ethernet</td>
</tr>
</tbody>
</table>
are also different as organisations some time sell the beam lines to other units. And most important, the beam lines are designed to perform different types of experiments and thus all beam lines have different operational requirements.

Thus the machine control system and its interfaces are needed to be built in such a way that the continuous development and commissioning of beamlines do not affect the normal operation of the machine. Normally the beam line control systems are separated from the machine control system with the help of gateway PC and dedicated networks. Also since this layer is mostly built by different agencies, the software for these show the blend of different technologies.

4.5 Future trends in SRS control system

Control systems for future large machine will continue to use the increase in CPU speed, memory size and network bandwidths offered by future electronic market. Future sys-
tems will employ a substantially larger number of devices, and with the movement towards front end processors becoming embedded in each device, the number of processors communicating on the network stands to grow by two orders of magnitude [48]. Though the upcoming machines show less increase towards energy front (see figure 4.6 for the new facilities i.e. facilities coming after 2000 are having energies between 2.5GeV to 3GeV) but some machines in future may also operate at high energies for example the upcoming fourth generation ultimate high-energy X-ray source PETRA-III to be operated at particle energy of 6GeV)[24]. As the circumference or size of machine depends on the electron energy the most of the future machines are expected to be of intermediate size and few like PETRA-III will be physically quite large, thus causing the control system to span tens of kilometers. From figure 4.7 one can see that the new machines may limit to the electron energy of 2.5 to 3GeV but they will certainly have to be operated at higher beam currents 300mA to 500mA, thus presenting control engineers with the challenge of beam instabilities arising out of nonlinear effects observed at high currents. Also, the use of undulators for getting the same photon energy as obtained by large high energy storage rings from a lower energy electron beam but with higher harmonic of the undulator emission and/or by using a shorter undulator period poses the tight requirement on beam emittance [24] and beam orbit stability [33], thus requiring a faster orbit feedback control mechanisms. Additionally, timing requirements will be tighter and the amount of data to be archived will increase. As the future systems will use larger number of devices higher reliability requirements will be imposed on the control system in order to ensure the uninterrupted operation of the machine. Thus the future control systems may consider the use of redundant components with automatic changeover as a way to increase reliability. But due to budget limitation every component can not be made redundant; therefore, engineers will need to evaluate the characteristics of each element in order to use redundancy to
maximum advantage. Another method to improve system availability is to reduce the repair time and since, the repair time consists of the time taken to diagnose the problem and the time to replace the faulty component, the future trend is towards minimising the diagnostic time. Thus by incorporating intelligence at machine component level to provide integrated diagnostics features that can detect problems at early stages and support the control system can be of great advantage. So that the control system can constantly verify, in a uniform fashion, that all devices are functioning correctly, or, in the event of an error, enabling quick identification for repair.

To address the issue of maintainability, future control system software will trend towards increased use of modular architecture as this facilitates changing components in one software layer without impacting the rest of the control system. With the increase in the size of generated data in future machine, the interface designers will have to consider carefully what data is needed by each type of user. As it is not enough to present such large volumes of data and expect humans to make efficient interpretations and responses, the control system would provide a high degree of automation, with interfaces becoming more for information than for control. To provide the needed level of automated setup, control will rely on having accurate machine model available to all applications and having software adapt to empirical data. All this requires the addition of intelligence at upper level of control system to automatically adjust according to the machine and user requirements.

4.6 Summary and conclusion

In early days the SRS facilities grew around large accelerator laboratories mainly built for particle physics experiments and allowed the synchrotron radiation users to use the SR produced in booster or storage rings in parasitic mode. Later on, inspired by the in-
creasing demand of SR users, the dedicated SRS facilities started appearing. The control system, for these SRS facilities have mainly evolved out of accelerator control systems built for large accelerators facilities with modifications to adopt the extra signals coming from the SR beam lines and the insertion devices integrated in the bending magnets and the straight sections of storage rings. From the beginning, the SRS control systems have faced the challenge of surviving and fulfilling the SRS control demands in the continuously upgrading, expanding and evolving SRS environment. Older control systems have undergone upgrades, incorporating advances in technology to meet ever increasing requirements for speed, accuracy and automation. Architecturally, control systems have evolved from two-layer architectures popular in early days to the three layer structures followed by again to two layer structures favoured today by successfully adopted technology advances to add functionality and enhance performance.

The line based CRTs used as control system user interfaces of old facilities have been uniformly replaced with animated graphical displays featuring multiple windows and often multiple physical screens per console. Today’s control rooms are populated with dozens of monitors, some even prominently featuring wall sized displays. Numerous graphics software packages are used to create a wide variety of graphical user interfaces including synoptic displays and graphs with advanced alarms systems providing the facility to filter out of context alarms and collapse related alarms into trees. Early SRS control systems were almost exclusively custom creations. With the exception of commercial computers, virtually every piece, both hardware and software, of early systems was created by laboratory scientists and engineers. Today the controls community is increasingly inclined towards the use of commercial and shared components in an effort to reduce development costs and improve reliability. EPICS and TANGO are the two emerging free tool kit based control system development frame works adopted by many facilities to reduce de-
velopment costs and time line, and increase reliability with high degree of software reuse. Reusing software components eventually results in code that has been tested far more extensively than is possible with individual custom developments.

Although the requirement of operation of future SRS machines with higher beam currents and very low beam emittance will throw new challenges to control engineers for beam stabilities, the current pace of development of commercial technology will likely meet the basic requirements for the building blocks of future control systems. It will be more challenging to provide a reliable, maintainable, secure and operable control system due to the international nature of future machines and the likelihood of distributed development, standards need to be developed first and enforced throughout the project. The requirements for the control system need to consider all stages of the project, including maintenance and the inevitable upgrades, rather than just making the control system work for the initial machine configuration and commissioning. Incorporating commercial solutions and the best features of existing systems along with the use of vigilant engineering practices, future SRS control systems will successfully operate the facilities.