Module 9

Conclusion
Lesson 40

Conclusion and Review
Instructional Objectives

This is the concluding lesson of the course. It attempts at providing a brief summary of the lessons discussed. It also attempts to highlight the important features of different lessons.

Assessment and Review of the Course

Before a programme of instruction ends, it is important, not only to review what have been discussed, but also to highlight some of the topics within the area of study that may have been left out. It is also important to discuss, how an interested learner can move ahead from where the present programme ends. It is the main purpose of this lesson to address the above issues.

Industrial Automation is a highly interdisciplinary area, if one intends to go deep enough to the level of a system designer. It is because of this reason, that it is impossible to achieve this depth for any audience with an undergraduate background in any major engineering discipline, not to mention the limitations of the course author. Therefore, the course is restricted to a depth, where the aim is to describe how things work, along with some of their technical features related to system performance. It is not attempted to discuss issues related to design, manufacture and test of such equipment.

Depth of exposition has also been sacrificed with respect to the hierarchy of Industrial Automation Systems. This course is primarily concerned with Level 0 and Level 1 Automation. The discussions on Level 2 Automation, which encompasses Process Monitoring, Supervision and Operational Optimisation, as well as Level 3 Automation which encompasses Process Operations Planning and Management have been very limited.

Within the limitations in scope and depth, the course aims to cover most important topics of Level 0 and Level 1 Automation. It provides a reasonably complete treatment of major types of sensors of important process variables, such as temperature, pressure, flow, which are of importance in continuous processes, as well as mechanical variables such as position, velocity, acceleration, force, etc., which are of importance in discrete manufacturing industries. Similarly, hydraulic and pneumatic actuators, control valves, electric motors and drives, pumps and fans have been described to provide coverage on industrial actuation systems.

One of the most interesting flavors that this course offers to the learner is a flavor of practice. Thus, while a conventional course on Control Systems provides a lot of analytical insight into the working of feedback controlled systems, these generally do not include interesting control structures such as the Smith Predictor which provide significantly superior performance for plants with practical features such as transportation lags. Similarly, they do not discuss practical implementation features to address real-world issues as actuator saturation or auto-manual transfer.

Similarly, conventional courses on Process Control are generally solely concerned with continuous processes. Control problems related to discrete manufacturing are generally discrete in nature, and often involve significant extent of discrete sequence and logic control. Among continuous control functions, they generally require precise control of position, speed, force etc. Moreover, they do not treat issues related to actuation, in depth. Actuation systems however are often so complex and substantive that they deserve an independent treatment at some level of
Without an understanding of actuation, it is difficult to understand the functionality and performance of control systems. In this course actuation systems have been allocated adequate space to enable an appreciation of the working of automated industrial operations. However, the treatment is restricted to hierarchically lower levels of the actuation system, such as drives and hydraulics. Based on these one can appreciate high level industrial machines such as Robots, Automated Guided Vehicles, Cranes, Metal forming and Cutting machines. After basic courses on Control, Process Control and Instrumentation, this course is expected to provide the reader with a more complete and integrated understanding of industrial automation technology.

Another important aspect of the course is the modular structure of the lessons. Broadly speaking, the different modules can be identified as follows:

- Introduction,
- Industrial Instrumentation,
- Process Control,
- Programmable Logic Control Systems,
- CNC Machines and their control,
- Valves and Actuators,
- Electrical Machine Drives,
- Industrial Embedded and Communication Systems.

The modular structure will possibly help the reader to skip some of the modules, if he is familiar with them. Moreover the contents have been written in a way suitable for self-study. Review questions and Points to ponder would help the reader to bring clarity in his understanding and infuse new thoughts and ideas.

**Summary**

The first two lessons (Module-1) provide an introduction to the course. Lesson-1 explains the meaning of the individual terms: industry, automation and control and their interrelations. It also explains the necessity and importance of automation in modern day industries. Various types of processes and different classes of automation are also discussed in this lesson.

Lesson-2 discusses the architecture of an industrial automation process. The functionalities of various levels of automation have been explained in this lesson. Basic sensors, actuators and the primary control loops form level zero and level one of automation, while the higher levels are supervisory and managerial level control. Constant communication and steady flow of information among the various levels is essential for efficient running of the automation process. These issues have been elaborated in Lesson-2.

Lessons 3 to 10 discuss the basics of sensing schemes used in industry. Accurate measurement of different process variables is very important for the successful operation of an automated process. These variables are to be measured and according to their deviations from the set points, the input variables are manipulated. These variables are mainly, temperature, pressure, flow, level, speed, displacement, pH etc. Different sensing schemes used for measuring these process parameters have been elaborated in these lessons. A measuring system is characterized by not
only the transducer used but also the measuring circuit used for signal conditioning and processing. The signal received from the transducer an electrical signal of very small strength. This signal has to be amplified, filtered and processed before it is transmitted for further control and data storage. The presence of noise in the measuring signal is inevitable in an industrial environment, but it should be tackled properly so that its effect is minimized. The accuracy and resolution of a measuring system are also limited by the noise level present. All these aspects have been addressed in module –2 (Lessons3-10) of this course.

Lesson 3 discusses about the measurement system specifications. The different terms used for specifying a sensing system have been introduced. The differences between static and dynamic characteristics have also been elaborated. Lesson 4 discusses about different techniques used for temperature measurement and the compensation schemes used. The lesson concentrates on three major types of sensors: RTD, Thermocouple and Thermistor. The other methods of sensing (e.g., radiation pyrometric technique) could not be discussed in this lesson. Lesson 5 discusses different sensing schemes for force and pressure measurement, while methods of displacement and speed measurements have been discussed in Lesson 6. Displacement and speed/velocity sensing is very useful in positioning of tools and other objects. The measuring scheme can be intrusive (where the sensor is directly connected to the moving object; or it may be nonintrusive, where the measurement has to be carried out without any direct contact between the sensor and the moving object. Optical and electromagnetic methods of measurement find wide use under this situation. The principles of operation of such sensors have been discussed in Lesson-6.

Another important area of industrial measurement is flow measurement of flow. In fact most of the controls in process industries are achieved by maneuvering a flow control valve to control the flow rate of a stream. In this way temperature, pressure or level of a tank is controlled. But the fluid may be liquid or gaseous, the measurement requirement may be volumetric or mass flow rate, or we may need to measure the total amount of flow. All these aspects have been discussed in Lesson-7 with particular emphasis towards measurement of liquid flow rate through obstruction type meters. Similarly, the principles of measurement of pH, humidity and level—another three important parameters used in process industries have been elaborated in Lesson-8.

Lesson-9 discusses about the signal conditioning circuits. Whatever the physical parameters measured, it is convenient to convert the signal into form of a small voltage or variation of resistance, inductance or capacitance. Suitable circuits are needed to convert the signals to electrical voltage up to a desired level. Unbalanced d.c. and a.c. bridges are used for resistive, inductive and capacitive sensors. Sensitivity and linearity of the bridge are two major issues for designing the bridges. These aspects, along with different amplifier circuits have been elaborated in this lesson.

Lesson-10 deals with different types of errors in a measurement system those are encountered commonly. The methods for estimating the error of a system made of several blocks in cascade have also been discussed. Another important issue discussed in this lesson is the calibration technique. Every measurement system has to be calibrated in regular frequency against some standard measuring instruments at different points of operation. Different methods of calibration and their adjustment techniques have been elaborated.

Module-3 of this course comprising of seven lessons (Lesson-11 to 17) discusses on process control. Before controlling a plant or process, we must know about the process and its dynamics. Typical features of an industrial process have been discussed in Lesson-11. Presence of time
delay and disturbance in a process unless properly understood would cause deterioration of the performance of closed loop system. The basic reasons behind the presence of these two parameters have been elaborated with simple examples. Examples of SISO (single input single output) and MIMO (multiple input multiple output) systems have also been provided. Another important aspect discussed in this lesson is the linearisation technique. Common processes are nonlinear in nature. But most of the elegant mathematical tools for design and analysis of control systems assume linear system behaviour. In order to achieve a compromise, nonlinear systems are often linearised over an operating point and detailed design and performance studies are carried out. The linearisation technique has also been elaborated in Lesson-11.

The next three lessons (Lesson12-14) are devoted to PID controllers. PID controllers are the most popular among all industrial controllers. The effects of the individual P, I and D elements on the controlled output have been elaborated in Lesson-12. A general guideline has also been provided for selection of P, PI, PD or PID controllers. But the major problem is how to select the proportional gain, integral time and derivative time of a PID controller. They are very much process dependent and improper selection may often lead to instability and deterioration of performance. The tuning is mainly carried out after performing some experiments with the process and the controller. Various tuning rules have been discussed in Lesson-13. There are also several issues (such as smooth transition from manual to auto mode and integration windup) those need to be properly addressed before putting the PID controller in action. These issues along with different schemes for implementing PID control actions have been discussed in Lesson-14.

Though PID controllers constitute of the main building block of a controller, there are several control actions those are needed for particular types of systems in order to improve the performance. These schemes, such as, Feedforward Control, Cascade Control, Ratio, Predictive control, Split range and Override control have been discussed in Lessons-15-17.

Module-4 (Lessons 18-22) discusses about Programmable Logic Controllers. The control scheme used here is sequential in nature, where one operation follows another. Unlike continuous control schemes discussed in Module-3, these control strategies are open loop, logical in nature and the actuations are on-off type. Programmable Logic Controllers (PLCs) are used to generate the preprogrammed sequence of operations. Lesson-18 provides an introduction to sequence control, giving an example of an industrial use of sequential control. It also provides a lucid background on evolution of PLCs. Typical architecture of a PLC system is also discussed in Lesson-18. This is followed by description of software environment and programming of PLCs in Lesson-19. Given a desired sequence of operation, how to generate a Relay Ladder Logic (RLL) diagram has been explained. Typical switches, timers and counters used for this purpose have also been discussed. Lesson-20 discusses an approach of formal modeling and structured RLL programming. It describes a systematic method for designing the sequential control in a framework of finite state machines and the methodology for developing sequence control programs. Lesson-21 discusses about Sequential Function Chart- a standard method for generating sequential control for complex industrial systems. This is followed by Lesson-22, where the hardware of a PLC has been discussed.

Modern manufacturing and machining process often demands precision positioning of tools. Computer Numerically Controlled (CNC) machines are used for providing translational and rotational motions of the tools in a preprogrammed fashion. Module-5 (Lesson-23 and 24) gives an introduction of operation of CNC machines and their control and drive schemes.
Module-6 deals with different types of actuators used for generating final control actions. Hydraulic and Pneumatic Controllers, Servovalves and actuator systems have been discussed in Lessons 26-30. Lesson-25 describes different types of flow control valves, their construction and characteristics.

Electrical machine drives constitute a major part of the actuation system used for automation of modern industries. Different types of electrical drives have been discussed in Module-7. Lesson 31 describes methods of flow control using industrial fans and pumps. It also shows how considerable energy can be saved using variable speed drives. The construction and principle of operation of step motors have been discussed in Lesson 32.

Lessons 33-35 discuss adjustable speed drives using d.c. motors, BLDC drives and induction motor drives.

Module-8 is devoted towards discussions on industrial embedded and communication systems. A Real Time Embedded System (RTES) is a computational subsystem within an overall system built to discharge a specific industrial task in real time. The typical characteristics of an RTES and its architecture have been elaborated in Lesson 36. Lesson 37 describes typical real time operating systems for such embedded systems. Lesson 38 deals with the communication systems for networking the field devices via Fieldbus. It discusses the protocol, architecture and synchronization issues of a Fieldbus system.

Finally in Lesson-39 of the concluding module (Module-9) discusses hierarchy in a production control and management system. Different levels of automation, responsibility of each level and communication among each levels have been discussed. The functionality of a distributed control system has been elaborated. Lastly, the typical example of a large rolling mill automation system has been taken and the functions of lower levels of automation have been explained.

Discussions on Process Control in such a course on Industrial Automation and Control must strike a balance between theory and practice. Keeping this in view, the exposition in the area of Control, which is very rich in theory, has focused towards practical features of popular control schemes, such PID controllers, feedforward and cascade control. Note that the latter two are extensions over the standard unity feedback control configuration that an undergraduate student is exposed to, in her first course on control. However, one should mention here that some of the more advanced control strategies, such as Model Predictive Control, have not been included. The interested reader can locate (without a great deal of effort, using the internet) sufficient references and material on these topics.

Among some of the technology areas significant to industrial automation that have been left out or treated only briefly, are:

- Process Monitoring, Fault Detection and Diagnosis
- Scheduling and Performance Analysis
- Sensor Fusion, Signal Estimation and Virtual Sensing
- Industrial Robotics and Material Handling Systems
- Manufacturing Quality Assessment and Control
• Industrial Communication and Data Management and Computing Systems
• Embedded Systems.

Concluding Remarks

The authors have tried to uncover the different aspects of the subject “Industrial Automation and Control”. However catering the need of such an interdisciplinary subject is not easy. The pace and depth of presentation was also not even. But the basic motivation of the course was to give the reader an exposure to the actual working of an industrial automation system. It is intended that if the reader is acquainted with the workings of an industry or if he visits and works in an industry he would be able to appreciate the function of the various building blocks of an automation system and develop a comprehensive knowledge about its complexities and challenges.

Lastly feedback on the content of the course and suggestions on further improvement of the contents would be highly appreciated by the authors. The readers may send their comments by email to the following addresses:

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